Lecture Notes in Civil Engineering

James Olabode Bamidele Rotimi
Wajiha Mohsin Shahzad
Monty Sutrisna
Ravindu Kahandawa *Editors*

# Advances in Engineering Management, Innovation, and Sustainability

## Proceedings of the 13th International Conference on Engineering, Project, and Production Management, 2023, Volume 1

Springer

# Lecture Notes in Civil Engineering

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# Preface

This book is a collection of papers that were presented at the highly regarded 13th International Conference on Engineering, Project, and Production Management (EPPM) that took place in Auckland, New Zealand, from 29 November to 1 December 2023. The conference was a joint effort between the EPPM Association and the School of Built Environment at Massey University, New Zealand. This book series features a diverse range of quality-assured theoretical discussions, data analysis, industry practices, and case studies presented by leading global researchers and practitioners. While the conference centred around the theme of "Creating capacity and capability: re-energising supply chain for sustainable management of projects and productions in engineering", this volume specifically highlights papers related to engineering management, innovation, and sustainability. These comprehensive, multidisciplinary, and advanced papers are perfect for researchers and practitioners from various industries seeking the most up-to-date information on the fields of engineering, project, and production management. The volume promises to be an invaluable resource for those seeking to stay abreast of industry trends and innovations.

Albany, New Zealand

James Olabode Bamidele Rotimi
Wajiha Mohsin Shahzad
Monty Sutrisna
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# About the Editors

**Prof. James Olabode Bamidele Rotimi** is Professor of Construction Economics and Management at the School of Built Environment, Massey University, New Zealand. He is also Visiting Professor in the School of Construction Economics and Management, University of the Witwatersrand, Johannesburg, South Africa. James has qualifications in building construction management, civil engineering, commerce, and education. He is Fellow of the Chartered Institute of Building UK and holds professional membership of the Royal Institution of Chartered Surveyors, UK, New Zealand Institute of Building, Facilities Management Association of New Zealand, and the Nigerian Institute of Building (NIOB). His research has focused on improving performance within the construction industry, integrating its supply chain, and optimizing the achievement of construction and project deliverables. He has over 30 years of tertiary teaching and research experience in academic institutions in Nigeria, UK, South Africa, and New Zealand. He also has various building construction industry experiences, including a senior associate role in a quantity surveying consultancy in Nigeria. James publishes extensively within peer-reviewed journals, conference proceedings and in edited books. He is Founding Editor of the *International Journal of Construction Supply Chain Management* IJCSCM, established in 2011.

**Dr. Wajiha Mohsin Shahzad** is a highly experienced academic with over 15 years of academic and construction industry experience. Currently, Senior Lecturer in Construction Management and Postgraduate Lead at the School of Built Environment, Massey University in New Zealand, her expertise includes construction management, productivity, and modern methods of construction, with a specific focus on offsite construction. She leads a research group on 'Future Material Technologies in Built Environment'. Her research has been recognised for its impact and novel contributions to the field of offsite construction. She has published various quality-assured journal papers, conference papers, book chapters, and industry reports. Her work has played a significant role in shaping policies surrounding the advancement of the construction industry in New Zealand.

**Prof. Monty Sutrisna** is Professor of Construction and Project Management and Head of the School of Built Environment at Massey University, New Zealand. He is President of the Australasian Universities Building Education Association (AUBEA) and current member of the Board of the International Council for Research and Innovation in Building and Construction (CIB). His research expertise includes construction and engineering management, construction productivity, construction procurement and contracts, construction IT and other advanced technologies applied in construction, including offsite construction, decision making modelling/support, knowledge based systems and artificial intelligence. Prior to joining Massey University, he was Head of Construction Management Department at Curtin University in Western Australia and Director of PG Research Training and Outreach as well as the Programme Director for Construction Management Programme at the University of Salford, UK.

**Dr. Ravindu Kahandawa** is Lecturer in Quantity Surveying at the School of Built Environment at Massey University with 8 years of experience in the construction industry and academia. Ravindu graduated with a B.Sc. (Hons) in quantity surveying from the University of Moratuwa, Sri Lanka, and completed PhD at Massey University, New Zealand in the area of "Cost Estimation Model for Earthquake Damage Repair Work". Ravindu is also the lead researcher in a NZD 200,000, BRANZ (Building Research Association of New Zealand)-funded project titled: "Construction cost blowouts—can a standardized opensource cost estimation process help?", and a key researcher in another BRANZ-funded project on Zeron Carbon. Ravindu's research areas include construction waste, circular economy, and construction company insolvencies.

# Theme: Management

# Managing Construction Supply Chains: Application of the Agile Ways of Working

**Pearl Li Ng, Farshid Rahmani, and Tayyab Maqsood**

## 1 Introduction

The construction industry plays a vital role in economic growth, infrastructure development, and societal progress. It encompasses the planning, design, construction, and maintenance of buildings, infrastructure, and various types of projects. Rapid urbanisation is driving the demand for construction, particularly in emerging economies. By 2050, it is estimated that around 68% of the global population will live in urban areas, increasing the need for infrastructure and buildings [39]. The supply chain is a critical component within the construction industry, facilitating the timely provision of materials, equipment, and services essential for project execution. This industry is increasingly embracing innovative technologies and practices to enhance efficiency, sustainability, and safety [26]. Furthermore, the supply chain industry plays a key role in sourcing sustainable materials, managing waste, and ensuring adherence to environmental standards and regulations. Effective supply chain management in construction ensures optimal availability of materials and resources at the right time and place, resulting in streamlined project schedules and minimised cost overruns [11, 37].

The construction supply chain is not immune to the challenges posed by change and uncertainties. Consequently, there is a pressing need for the industry to embrace innovative management approaches to effectively navigate these complexities [15]. Change and uncertainties are pervasive across industries, and as a response, many sectors have increasingly turned to the agile ways of working in recent years. Originally stemming from software development, the agile ways of working has proven its applicability beyond its origins and has found relevance in diverse industries,

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including construction [12]. Adopting an agile approach in construction supply chain management could enable companies to respond swiftly and adaptively to change and uncertainties. Agile methodologies emphasise collaboration, flexibility, and iterative problem-solving [12].

This study aims to investigate the application of the agile ways of working in the supply chain management of the construction industry. It builds upon a comprehensive literature review examining common issues faced in both the construction industry and software development industry, particularly in relation to change, uncertainties, and risks. This study aims to establish the role of agile ways of working, in effectively managing supply chain challenges within the construction sector. To address the research aim, the following research question is defined: "*How can the concept of agile ways of working be leveraged to effectively manage supply chain issues and improve adaptability, productivity, and collaboration in construction projects?*". By bridging the gap between the construction industry and agile practices, this research aims to contribute to the knowledge base and provide valuable recommendations for industry professionals seeking to optimise their supply chain management approaches in the face of change, uncertainties, and risks.

## 2 Methodology

This study employs a comprehensive research approach that combines extensive literature reviews and semi-structured interviews with industry professionals. The purpose of this approach is to identify and highlight the key agile ways of working that can be effectively applied in the context of the construction supply chain.

Systematic literature review was performed to address the research question by thoroughly reviewing, evaluating, and analysing four key thematic areas: (1) agile mindset, values, and principles; (2) change, uncertainties, and risks in the construction industry; (3) agile ways of working in supply chain management; and (4) success factors and barriers for the implementation of agile ways of working in the construction industry.

The selection of a systematic literature review methodology is justified as it offers a comprehensive overview of previous studies within the chosen research domain. It allows the authors to identify relevant characteristics or relationships between key concepts derived from existing studies. Systematic reviews are recognised as a specific methodology that systematically locates existing studies, rigorously analyses and synthesises data, and provides clear conclusions about the existing knowledge and research gaps [49]. It is the foundation of any research projects [17]. In this study, the authors adhere to the principles proposed by Briner and Denyer [9] to ensure the rigour and transparency of the review process. These principles include (1) conducting the review systematically by following a well-defined process, (2) employing a transparent method that can be easily understood and replicated; (3) ensuring the review is replicable and updatable, allowing for future revisions and updates; and (4) summarising and analysing the key topics relevant to this research, providing a comprehensive understanding of the subject matter.

To collect the relevant literatures for this review, a comprehensive search was conducted across various commonly used resources. Specifically, the authors adopted the following procedures: (1) choose the database source; (2) choose keywords and search criteria based on the thematic areas defined; (3) apply backward and forward search as required; and (4) evaluate the appropriateness of the literature subset [13]. The search was performed within the fields of article titles, abstracts, and keywords to ensure a comprehensive coverage of relevant studies. Keywords used include "agile in construction", "agile ways of working", and "agile supply chain". The initial search yielded a significant number of papers in the area of agile ways of working, with thousands of papers found that were relevant to the first two thematic areas. 198 papers were identified for the application of agile approaches in construction, and 41 papers were identified to be relevant to understand the application of agile approaches in construction supply chain management. Given the fast-emerging nature of this field, careful consideration was given to search filters and paper selection to ensure the inclusion of the most relevant and recent studies. The search process continued until theoretical saturation was achieved, ensuring that a sufficient number of studies were included to provide a comprehensive and representative overview of the research landscape. Recognising the presence of industry "buzzwords", the authors of this study also acknowledge the need to consider synonymous terms during the literature search process. When determining the inclusion criteria, the authors prioritised peer-reviewed articles, studies published in reputable journals and conferences, empirical research featuring data and analysis, books from notable publishers or authors, and relevant case studies. Conversely, the authors established exclusion criteria to filter out specific study types. These exclusions encompassed non-peer-reviewed articles, conference abstracts, studies in languages other than English, complete simulation and mathematical modelling papers, and articles with limited relevance to the research topic. Additionally, the authors considered the geographical scope of their search, aiming to explore agile practices in construction from a global perspective while also focusing on specific regions or countries as per their research objectives. Figure 1 illustrates the review process, and Table 1 summarises the data sources used.

Semi-structured interviews were also conducted with industry professionals who possess extensive knowledge and work experience in construction management and agile management. The participants selected for the interviews had been actively working in the industry for more than 10 years, bringing valuable insights and expertise to the research. A total of five participants were interviewed, ensuring a diverse range of perspectives and experiences (Table 2).

The semi-structured nature of the interviews allowed for flexibility in exploring various aspects of construction supply chain management and the application of agile principles. The authors conducted the semi-structured interviews, each lasting approximately 45–60 min, to collect the data. Exploratory follow-up questions and non-directive probing techniques were utilised to ensure that the participants freely expressed their own perspectives and were not influenced by the authors' viewpoints

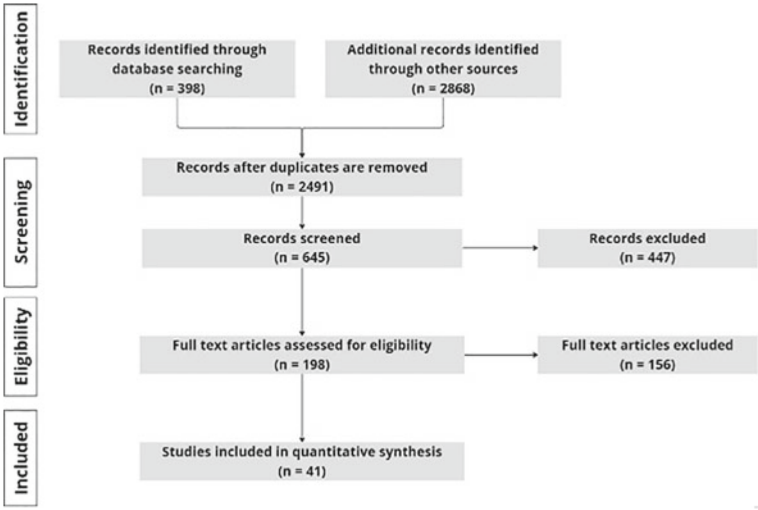


**Fig. 1** Flow diagram describing process of articles being reviewed and selected

**Table 1** Authors and year of publication

| Author | Year | Author | Year |
|---|---|---|---|
| Ajmal, Khan, Gunasekaran, & Helo | 2022 | Larson & Gray | 2010 |
| Attar & Abdul-Kareem | 2020 | Lau & Kong | 2006 |
| Beck et al. | 2001 | Longo, Nicoletti, & Padovano | 2017 |
| Belhadi, Mani, Kamble, Khan, & Verma | 2021 | Love, Irani, & Edwards | 2004 |
| Braunscheidel & Suresh | 2009 | Lu, Olofsson, Jensen, & Simonsson | 2011 |
| Broft, Badi, & Pryke | 2016 | Mrugalska & Ahmed | 2021 |
| Ciric et al. | 2018 | P. Xu | 2009 |
| Cox & Ireland | 2002 | Rajagopal & Bernard | 1993 |
| D. Lee & Lee | 2021 | S. Xu, Zhang, Feng, & Yang | 2020 |
| Elmughrabi, Sassi, Dao, & Chabaane | 2020 | Srivastava, Bhardwaj, & Saraswat | 2017 |
| Fiksel | 2003 | Stray, Moe, & Sjoberg | 2018 |
| Foehrenbach & Heldstab | 2017 | Thunberg | 2016 |
| Gibbert, Hoegl, & Välikangas | 2007 | Tserng, Yin, & Li | 2005 |
| Goldman, Nagel, and Preiss | 1995 | ul Hassan, Ahmad, & Zuhaira | 2018 |
| H. L. Lee | 2002 | Van Hoek | 2001 |
| Holbeche | 2015 | Van Hoek, Harrison, & Christopher | 2001 |
| Hu | 2022 | Virolainen | 1998 |
| Ibem & Laryea | 2014 | Vrijhoef & Koskela | 2000 |
| Jiang, Klein, Tsai, & Li | 2018 | Yeo & Ning | 2002 |
| Kleindorfer & Saad | 2005 | Zayat & Senvar | 2020 |
| Krishnaiyer & Chen | 2017 | | |

**Table 2** Information of participants

| Participant | Professional background |
|---|---|
| 1 | A system engineer and an agile coach with a demonstrated history of working in the oil and energy industry with strong expertise and experience on how to embed digital tools and new ways of working to optimise the delivery of industrial scale, multibillion capital projects |
| 2 | A consultant focuses on technical and program advisory services, heavily involved in project management bodies and working groups with publications and thought leaderships delivered |
| 3 | A multidisciplinary consultant who is experienced in adopting agile delivery in managing heavy industry and capital-intensive projects, and has successfully adopted agile in different phases of a capital projects, demonstrating tangible cost and time savings |
| 4 | A system engineer in capital projects turned software project manager and has played various roles at different levels and different organisations |
| 5 | A registered mechanical engineer with more than 10 years of experience in delivering projects in the commercial building sector and in establishing continuous improvement practices |

[27]. The insights gathered from these interviews provided valuable first-hand information and real-world examples, contributing to a comprehensive understanding of the topic. These interviews provide an opportunity to delve deeper into practical experiences, challenges, and successes in implementing agile in real-world scenarios.

By combining the findings from the literature reviews and insights gained from the interviews, this study aims to provide a holistic and practical understanding of the how the agile ways of working can enhance the efficiency and effectiveness of the construction supply chain. Ultimately, the goal of this study is to contribute practical knowledge that can inform construction professionals in optimising their supply chain management processes and improving project outcomes.

## 3 Literature Review

The section covers the overview of supply chain management in the construction industry, the agile ways of working in the software industry, and the common occurrence of issues the construction supply chain and the software industries.

### *3.1 Supply Chain Management in the Construction Industry*

The construction industry operates within complex supply chains characterised by decentralised and fragmented structures, as well as temporary and project-oriented nature. These supply chains involve intricate networks with diverse relationships, resources, products/services, logistics, information, and financial flows [16].

Planning and executing construction projects require extensive communication efforts due to the involvement of multiple participants from various organisations. Each construction project presents unique requirements and constraints, further adding to the challenges of supply chain management. Within this context, the logistics and supply chains in construction face the complexity of temporary organisations formed for project execution. These temporary supply chains involve a multitude of trades, including consultants, suppliers, and subcontractors [14]. Material, equipment, and labour flows are the primary components of a construction supply chain, each demanding meticulous coordination and synchronisation to ensure seamless project execution [16, 43]. Effectively managing these complex and dynamic supply chains is crucial for the successful delivery of construction projects.

Numerous research studies have emphasised the capacity of supply chain management (SCM) to address the significant hurdles posed by fragmentation, adversarial relationships, and a lack of customer orientation in the execution of construction projects [10]. SCM encompasses various important aspects, and one of them is the planning process, which involves continuous involvement and integration of all supply chain members. This collaborative planning approach is referred to as supply chain planning (SCP). Within SCP, procurement planning takes place to identify the necessary materials, components, and services required to fulfil the demand. Supply plans are developed, including material delivery schedules that indicate the expected arrival of ordered materials. Distribution planning is performed to determine the most efficient logistics routes, warehousing locations, and transportation methods to deliver the products to customers. The objective of SCP is to ensure effective coordination and integration of crucial business activities, ranging from raw material procurement to the distribution of final products to customers. In the context of construction, procurement activities are typically planned and executed before on-site production begins [43]. For project managers overseeing construction projects, strategic, tactical, and operational supply chain planning are essential tasks to effectively manage the project's supply chain activities [52].

By performing these planning activities, project managers can optimise resource allocation, streamline processes, and enhance overall project performance [43]. Poor supply chain planning often leads to material shortages, which can subsequently disrupt the project schedule [44]. Conversely, overcompensating by producing or supplying materials earlier than necessary can result in substantial inventory costs. It is crucial to implement effective planning and inventory management strategies to mitigate these challenges and maintain project timelines and cost efficiency [44]. The inability to plan well is often due to multiple factors, include the lack of connections between production and material delivery schedules, limited involvement of suppliers and subcontractors in planning, and a focus on meeting client requirements rather than improving the supply chain [43].

Once the planning phase is completed, the execution phase begins. This includes procurement execution, where materials and services are procured from suppliers based on the procurement plan. The production execution phase involves carrying out manufacturing or construction processes according to the production plan to ensure the timely availability of finished goods. Finally, logistics and distribution come into play as products are transported from manufacturing facilities to distribution centres and then delivered to customers [24, 40, 47].

Various supply chain disruptions can occur throughout a construction project. Supplier issues, such as delays, quality problems, or disruptions in the supply of materials or services, can significantly impact operations. Production delays may arise due to equipment breakdowns, labour shortages, or unexpected events that disrupt the production schedule. Transportation problems, including delays, capacity constraints, or disruptions in the transportation network, can also disrupt the smooth flow of goods. Inventory shortages may occur due to unexpected demand fluctuations, production delays, or supplier issues. Additionally, demand variability, regulatory changes, and geopolitical factors such as political instability or trade disputes can introduce further disruptions [28, 51].

To address these disruptions, supply chain management teams need to swiftly assess the situation and identify alternative solutions. By effectively managing disruptions and incorporating agile ways of working into supply chain management, companies can enhance their ability to respond to challenges.

### *3.2 The Agile Ways of Working*

The agile ways of working originated in the realm of software development in the 1990s, as a response to the traditional waterfall methodology that often resulted in rigid processes and delayed project deliveries [12]. The need for a more flexible and collaborative approach to software development led to the emergence of the Agile Manifesto in 2001, which outlined the core values and principles of the agile movement [4]. To achieve success in agile management, having the right mindset is important.

The agile mindset is the cornerstone of agile ways of working, and while the Agile Manifesto was introduced in 2001, the concept of agility has been explored even before that. An agile mindset refers to a set of attitudes and beliefs that individuals and organisations adopt to embrace agility in their work and decision-making processes. It is a way of thinking that emphasises adaptability, collaboration, and continuous learning and improvement. In a study by Goldman et al. [21], four fundamental dimensions of agility were identified: (1) enriching the customer, (2) cooperating for enhanced competitiveness; (3) organising to master change and uncertainty, and leveraging the impact of people and information. The agile mindset challenges the notion of stability and requires a shift in thinking towards adaptability, collaboration, and continuous improvement. It encourages individuals and teams to embrace change, value feedback, and foster a culture of learning. Open communication, trust, and empowerment are emphasised, enabling teams to respond effectively to challenges and capitalise on opportunities [22, 46].

Agile values guide the behaviours and decisions of individuals and teams. The Agile Manifesto outlines four core values: individuals and interactions over processes and tools, working solutions over comprehensive documentation, customer collaboration over contract negotiation, and responding to change over following a plan [4]. The Agile Manifesto is complemented by twelve principles that provide practical guidelines for project management. These principles advocate for early and continuous delivery, embracing change, delivering value to customers, fostering collaboration, empowering teams, and promoting sustainable development [5].

Agile practices encompass a wide range of methodologies and techniques that are utilised to implement agile principles effectively. These practices include well-known frameworks such as Scrum, Kanban, Lean, and Extreme Programming (XP) [30]. Scrum, for instance, introduces time-bound iterations called sprints and incorporates cross-functional teams, daily stand-ups, backlog management, and sprint reviews [41]. The Scrum practices and workflow are as illustrated in Fig. 2. Kanban focuses on visualising and managing work through a kanban board, facilitating a continuous flow of tasks [53]. As discussed earlier, agile methodologies promote iterative and incremental development. A sprint, which typically lasts one to three weeks, serves as the fundamental unit of work with a fixed timebox [41]. The product backlog consists of user requirements, features, or functionalities that provide value to end-users or customers [30]. Agile teams may also utilise story mapping, a visual representation technique that aims to bridge the gap between usability scenarios and requirements [19]. To facilitate short, iterative development cycles, the work items in the product backlog are distributed among multiple sprint backlogs. During sprint planning, the team gathers to prioritise the work items and discuss the methods to accomplish the sprint. It is important to note that once a sprint begins, the sprint backlog should remain unchanged. Throughout the sprint, the team collaborates daily, holding meetings where each member shares their progress and addresses any concerns. At the end of each sprint, the team conducts retrospectives to reflect on the sprint's outcomes and identify potential opportunities for improvements [42].

### *3.3 Common Issues in Construction Supply Chain and the Software Industry*

Construction supply chain and software development, despite belonging to different industries, share common issues in the areas of change, uncertainties, and risks. Both construction projects and software development projects often experience scope changes due to evolving requirements. Stakeholders may have new insights, clients may request modifications, or market conditions may require adjustments. These changes can introduce uncertainties and impact the supply chain, necessitating adjustments in material procurement, resource allocation, and scheduling. Uncertainties

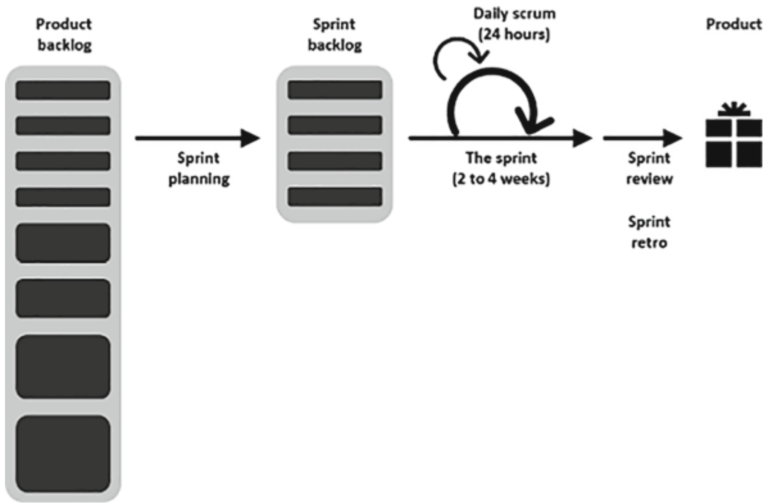


**Fig. 2** Scrum practices and workflow

in project requirements are also prevalent in both construction and software development. Clients may have evolving needs, unclear expectations, or difficulties articulating their requirements [1]. Similarly, in software development, changing user needs or evolving business processes can lead to uncertainties and scope creep [45]. These uncertainties affect the supply chain by requiring flexibility in sourcing materials, adjusting resource allocation, and adapting project plans. Both construction and software development industries face uncertainties related to market conditions and technological advancements. Economic fluctuations, regulatory changes, or shifts in customer demands can introduce uncertainties and impact project timelines and resource availability in the supply chain. In software development, evolving technologies, emerging platforms, or changes in software frameworks can introduce uncertainties.

Construction supply chain and software development projects rely on external suppliers for various components, materials, or software modules. Supplier reliability is crucial to ensure on-time delivery, quality, and adherence to project specifications [14, 25]. However, uncertainties such as supplier delays, quality issues, or supplier bankruptcies can introduce risks and impact project timelines and deliverables. Robust supplier evaluation, risk assessment, and contingency planning are essential to mitigate these risks. Both domains also require specific resources, such as skilled labour, equipment, and materials. Resource constraints can arise from factors such as shortages of skilled workers, limited availability of specific equipment, or material shortages due to market conditions [20, 31]. These constraints affect project schedules, supply chain operations, and may require alternative sourcing strategies or adjustments in project plans to mitigate their impact.

Both domains require proactive risk management to address uncertainties and mitigate potential risks. Identifying, assessing, and managing risks are crucial to ensure project success. Risks related to supply chain disruptions, material availability, scope changes, or market uncertainties need to be actively monitored and addressed through robust risk management strategies. Effective communication and collaboration are vital in both construction supply chain and software development projects [43, 50]. Lack of clear communication, misalignment among stakeholders, or insufficient collaboration among project teams can lead to misunderstandings, delays, and errors. Close coordination, frequent information sharing, and effective communication channels help mitigate these risks.

# 4 Results and Discussion

The agile ways of working takes an integrated and holistic approach to cultural agility and technical agility. This phenomenon can be described using the “agile onion” model, where the mindset, which is invisible from the outside, is the core and has the highest impact. The processes and tools, on the other hand, are visible from the outside but will fall apart if the right mindset is not adopted. Digital tools and technology act as a key enabler for the implementation of the agile ways of working (Fig. 3).

## *4.1 Agile Mindset*

Having an agile mindset, especially when it comes to adapting to change and responsiveness, plays a crucial role in construction supply chain management. An agile

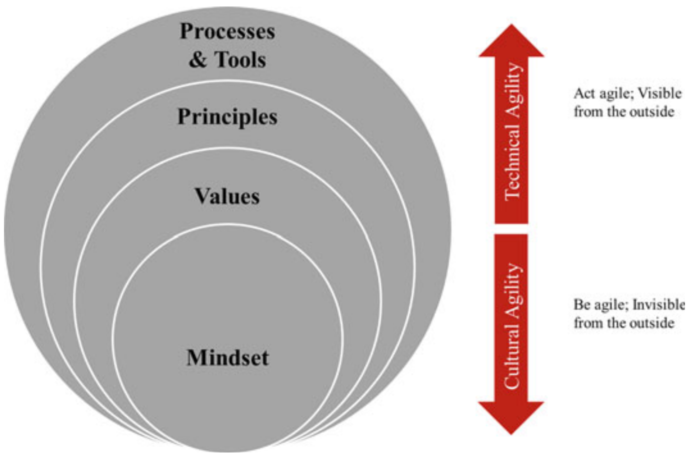


**Fig. 3** Adapted agile onion [7]

mindset encourages individuals and teams to view change as an opportunity rather than a hindrance. It promotes a culture where employees are open to exploring new ideas, adapting to evolving circumstances, and embracing innovative solutions [2].

The agile mindset is important to construction supply chain, not just during the planning phase, more importantly when there is a disruption, as shared by Participants 3 and 4. In the construction supply chain planning process, this involves considering various scenarios and time horizon (short-, mid-, and long-term), anticipating potential disruptions, and building flexibility into the plans [18]. With an agile mindset, construction organisations can be quick to identify alternative sources for materials or components when disruptions occur in the supply chain [33]. Another aspect of embracing change in the construction supply chain is agile procurement. Construction organisations need to re-evaluate their procurement strategies and processes to ensure they are agile and responsive to disruptions. This may involve establishing relationships with multiple suppliers, implementing just-in-time delivery approaches, or adopting dynamic procurement methods that can quickly adapt to changing market conditions [46] Participant 4 also elaborated that the collaborative relationships are essential when embracing change during supply chain disruption. By building strong with suppliers, subcontractors, and other stakeholders, organisations can work together with their suppliers to proactively address disruptions, share information, and collectively find innovative solutions.

Participant 5 explained that his team were doing a weekly resource profiling and re-allocation during the COVID-19 pandemic. The team's openness to change had helped them to navigate the complexity related to site access during that period. Construction organisations should view disruptions as opportunities for improvement. They can identify areas for optimisation, strengthen their risk management strategies, and develop contingency plans to better prepare for future disruptions. By continuously learning from disruptions and implementing improvements, construction organisations enhance their supply chain resilience.

Effective communication and transparency play a crucial role in embracing change during supply chain disruption. Construction organisations should openly share information about disruptions, potential impacts, and mitigation strategies within their organisation and across the supply chain [8]. All participants agreed that good communication and the mindset of embracing are important in navigating uncertainties, identifying opportunities, and implementing strategies that minimise the impact of disruptions.

## *4.2 Agile Values*

During a construction supply chain planning and disruption, embracing the four core values of agile can significantly contribute to effective management and mitigation of the challenges. First, prioritising individuals and interactions over processes and tools fosters collaboration and communication among stakeholders involved in the supply chain. For example, project teams can actively engage in problem-solving discussions, exploring alternative suppliers, and adjusting material sourcing strategies to minimise the disruption's impact [28].

Second, emphasising working solutions over comprehensive documentation is crucial. Rather than getting caught up in extensive paperwork, project teams should focus on finding practical solutions that address the immediate effects of the disruption. Real-time information sharing through digital platforms enables teams to collaborate effectively, share updates, and make timely adjustments to plans in response to the disruption. One example is on how the PPE industry used digital platform as a means of communication during the supply chain disruption amid the COVID-19 pandemic [23].

Third, placing customer collaboration over contract negotiation is essential. By involving customers in decision-making processes related to changes in project scope or resource allocation, construction organisations can ensure that customer expectations are met while effectively managing the disruption and identifying innovative solutions. Participant 5 shared how they engaged the customers and other stakeholders to co-create the design of a building so that all parties are on the same page during resource allocation. The team also discovered an innovative delivery approach to deliver the project.

Finally, prioritising responding to change over following a plan is critical in a disrupted supply chain. Participants 2 and 3 shared that construction organisations should be proactive in adapting plans to the new circumstances. They can revise construction schedules, adjust procurement strategies, and conduct risk assessments to identify and address potential risks associated with the disruption. By applying these core values and implementing relevant examples, construction organisations can navigate supply chain disruptions with resilience and maintain project progress despite the challenges.

### *4.3 Agile Principles*

Agile principles can be effectively applied in construction supply chain management, particularly during supply chain disruption. Construction organisations can embrace the agile principle of iterative and incremental development, breaking down their supply chain activities into smaller iterations or phases. This allows them to continuously assess the impact of disruptions, make necessary adjustments, and gradually improve their supply chain processes. Participant 2 shared that his team broken down their plans to smaller pieces during a disruption. As a result, the tasks are more achievable, and the team managed to overcome the disruption in a calm and collected manner. In addition, cross-functional collaboration is emphasised in agile principles. Construction organisations can bring together representatives from different areas such as procurement, logistics, project management, and suppliers to collaborate and address challenges collectively [35]. This collaborative approach helps in finding innovative solutions, sharing knowledge, and ensuring smooth communication throughout the supply chain.

Agile principles advocate for continuous improvement and a learning-oriented culture. Construction supply chain management can apply this principle by encouraging regular feedback loops and reflection on supply chain processes and practices [48]. By analysing the impact of disruptions, identifying areas for improvement, and implementing changes based on lessons learned, organisations can enhance their supply chain resilience and responsiveness. Flexibility and adaptive planning are key components of agile principles. Visual management and transparency are also important in agile principles. Construction organisations can utilise visual management tools such as kanban boards or dashboards to provide real-time visibility into the status of materials, inventory, and project milestones [29]. This transparency enables stakeholders to identify bottlenecks, anticipate potential issues, and make data-driven decisions to mitigate the impact of disruption.

By applying these agile principles, construction supply chain management can effectively manage challenges, maintain project continuity, and optimise their supply chain operations for improved performance and customer satisfaction.

### *4.4 Agile Tools and Processes*

Agile tools and processes, such as daily stand-ups, sprint planning, retrospectives, and progress visualisations, e.g. Kanban boards, can greatly benefit the construction supply chain by improving communication, collaboration, and efficiency. In the context of the construction supply chain, daily stand-ups can help different teams involved in the supply chain, such as procurement, logistics, and construction teams, to coordinate their efforts, identify potential bottlenecks, and proactively address issues. Participants 1 and 2 shared how agile teams were specifically created during a disruption and how the teams utilise these tools and processes to manage the disruptions.

Backlog management plays a crucial role in construction supply chain by providing a comprehensive view of tasks, requirements, and priorities. The backlog serves as a centralised repository of tasks, enabling efficient resource allocation and facilitating better coordination among team members. Retrospectives provide an opportunity for the supply chain teams to reflect on their performance, identify areas for improvement, and make necessary adjustments.

In the context of construction supply chain management, the human aspect plays a critical role in the success of projects. User stories, a fundamental component of agile methodologies, help capture and prioritise stakeholder needs in the construction supply chain. By considering the end-users' perspectives and preferences, supply chain teams can develop systems that are intuitive, easy to use, and tailored to the specific needs of the construction industry [34].

### 4.5 Implementation of the Agile Ways of Working

Successfully implementing agile ways of working in the construction supply chain requires careful planning, effective communication, and a collaborative approach. It is essential to assess the readiness of the organisation and identify champions who can drive the implementation process. Employees should be equipped with the necessary knowledge and skills related to agile principles, methodologies, and tools, as shared by all participants. This will enable them to effectively implement agile practices in their daily work. Participants 1 and 3 mentioned that having an agile coach is crucial for the successful implementation of agile ways of working in a construction supply chain project. To begin the implementation process, Participant 1 advised to start with pilot projects. These projects should be small scale and selected based on their potential for quick wins and demonstrating the benefits of agile methodologies. This allows teams to learn, experiment, and adapt in a controlled environment before scaling up to larger projects. Establishing agile frameworks and processes is essential for structuring the implementation of agile ways of working, as elaborated by Participant 1.

### 4.6 Enablers of the Agile Ways of Working

Various technologies play a significant role in enhancing agility in the construction industry. These technologies enable real-time collaboration, data-driven decision-making, rapid adaptation to changes, and improved project coordination.

- Building Information Modelling (BIM): With BIM, stakeholders can identify potential clashes, optimise designs, and make informed decisions, thereby minimising rework and improving project coordination. By leveraging BIM's capabilities, construction teams can adapt quickly to changes, respond to unforeseen challenges, and maintain a high level of agility throughout the project lifecycle [36].
- Artificial Intelligence (AI): The application of AI enhances agility by enabling the prediction of project outcomes, risk analysis, and proactive decision-making [6]. By harnessing the power of AI, construction professionals can identify potential issues, mitigate risks, and optimise construction processes, ultimately improving project efficiency and adaptability.
- Modular Construction: This method enhances agility by reducing accelerating project delivery, facilitating rapid adaptation to changing requirements, and enabling greater flexibility in responding to supply chain disruptions. Construction teams can easily adjust modular components to meet evolving project needs, ensuring efficient construction even in dynamic environments [32].
- Augmented Reality (AR) and Virtual Reality (VR): AR and VR can be used for visualising designs, simulating construction processes, and providing virtual walkthroughs. These technologies enhance agility by enabling stakeholders to

visualise and understand complex design concepts, detect design flaws, and make informed decisions in real-time [38].

- Digital Twins: This technology enables real-time monitoring, analysis, and simulation of project performance. Digital Twins enhance agility by providing accurate and up-to-date information about the construction project, facilitating predictive maintenance, and enabling efficient decision-making. The ability to simulate different scenarios and test solutions virtually enables construction professionals to make data-driven decisions and improve project outcomes, ultimately enhancing agility in the construction supply chain [32].

## 5 Limitations and Future Work

Due to limited time and scope of work, this research paper is developed solely based on previous literatures and limited interviews with professionals. In spite of the valuable insights gained from the semi-structured interviews conducted with industry professionals, it is important to acknowledge the limitation of the study's small sample size. The interviews involved a limited number of participants, which may restrict the application of the findings to a wider population of construction industry professionals. While efforts were made to select interviewees from diverse backgrounds and roles within the industry, a larger and more diverse sample could have provided a more comprehensive understanding of the research topic. Another possible direction is to quantify the effectiveness of the agile ways of working in the supply chain management, followed by a benchmarking exercise with other industries. As this is an emerging field, it is also essential to consider the skills required for the agile ways of working to be applied successfully.

## 6 Conclusion

In this study, the authors examined the application of agile practices in the construction supply chain, focusing on the mindset, values, and principles that underpin agile approaches. Through a combination of literature review and interviews with professionals in the construction industry, the authors have gained valuable insights into the relevance and benefits of agile practices in this context.

The findings confirm that an agile mindset, characterised by adaptability, collaboration, and customer-centricity, is crucial for managing the complexities and uncertainties of the construction supply chain. The emphasis on working deliverables, customer collaboration, and embracing change over rigid plans aligns with the agile values advocated in the Agile Manifesto. The identified agile principles are consistent with the principles of lean construction and supply chain agility. These principles provide a roadmap for enhancing project outcomes, responsiveness, and efficiency within the construction supply chain. The comparison of the findings with existing literature reveals a strong alignment, validating the applicability and benefits of agile practices in the construction industry. This study contributes to the existing body of knowledge by providing empirical evidence and practical insights into the implementation of agile practices specifically within the construction supply chain.

In conclusion, this study highlights the relevance and applicability of agile practices in the construction supply chain. The implications of this research are significant for construction practitioners, project managers, and other stakeholders involved in the construction supply chain. By embracing an agile mindset, values, and principles, construction professionals can navigate the challenges and complexities of the industry, ultimately leading to enhanced project success and customer satisfaction. Further research should continue to explore and refine the implementation of agile practices in various construction contexts to advance the field and drive continuous improvement.

## 7 Ethics Statement

Informed consents are obtained during the interview with industry experts and direct identifiers, e.g. participant's name, company name, and project name are removed at the transcription phase to ensure anonymity.

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## References

1. Ajmal MM, Khan M, Gunasekaran A, Helo PT (2022) Managing project scope creep in construction industry. Eng Constr Archit Manag 29(7):2786–2809
2. Attar M, Abdul-Kareem A (2020) The role of agile leadership in organisational agility. In Agile business leadership methods for Industry 4.0. Emerald Publishing Limited
3. Australian Government (2022) Infrastructure investment program. Retrieved from https://investment.infrastructure.gov.au/
4. Beck K, Beedle M, van Bennekum A, Cockburn A, Cunningham W, Fowler M, Grenning J, Highsmith J, Hunt A, Jeffries R, Kern J, Thomas D (2001a). Manifesto for agile software development. Retrieved from https://agilemanifesto.org/
5. Beck K, Beedle M, van Bennekum A, Cockburn A, Cunningham W, Fowler M, Grenning J, Highsmith J, Hunt A, Jeffries R, Kern J, Thomas D (2001b). Principles behind the Agile Manifesto. Retrieved from https://agilemanifesto.org/principles.html
6. Belhadi A, Mani V, Kamble SS, Khan SAR, Verma S (2021) Artificial intelligence-driven innovation for enhancing supply chain resilience and performance under the effect of supply chain dynamism: an empirical investigation. Ann Oper Res 1–26
7. Bornert D (2021) Working agile: getting the right mindset. Retrieved from https://mediaan.com/mediaan-blog/agile-mindset

8. Braunscheidel MJ, Suresh NC (2009) The organizational antecedents of a firm's supply chain agility for risk mitigation and response. J Oper Manag 27(2):119–140
9. Briner RB, Denyer D (2012) Systematic review and evidence synthesis as a practice and scholarship tool. In: Handbook of evidence-based management: companies, classrooms and research, pp 112–129
10. Broft RD, Badi S, Pryke S (2016) Towards supply chain maturity in construction. Built Environ Project Asset Manage 6(2)
11. Childerhouse P, Hong-Minh SM, Naim MM (2000) House building supply chain strategies: selecting the right strategy to meet customer requirements. Paper presented at the 8th IGLC conference, Brighton, UK
12. Ciric D, Lalic B, Gracanin D, Palcic I, Zivlak N (2018) Agile project management in new product development and innovation processes: challenges and benefits beyond software domain. Paper presented at the 2018 IEEE international symposium on innovation and entrepreneurship (TEMS-ISIE)
13. Cocchia A (2014) Smart and digital city: a systematic literature review. In: Dameri RP, Rosenthal-Sabroux C (eds) Smart city: how to create public and economic value with high technology in urban space. Springer, Cham, pp 13–43
14. Cox A, Ireland P (2002) Managing construction supply chains: the common sense approach. Eng Constr Archit Manag 9(5/6):409–418
15. Dallasega P, Rauch E, Linder C (2018) Industry 4.0 as an enabler of proximity for construction supply chains: a systematic literature review. Comput Ind 99:205–225
16. Elmughrabi W, Sassi OB, Dao T-M, Chabaane A (2020) Collaborative supply chain planning and scheduling of construction projects. IFAC-PapersOnLine 53(2):10761–10766
17. Esa MR, Halog A, Rigamonti L (2017) Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. J Mater Cycles Waste Manage 19(3):1144–1154
18. Fiksel J (2003) Designing resilient, sustainable systems. Environ Sci Technol 37(23):5330–5339
19. Foehrenbach S, Heldstab C (2017) User story mapping: the hands-on course. In: Paper presented at the proceedings of the 2017 CHI conference extended abstracts on human factors in computing systems
20. Gibbert M, Hoegl M, Välikangas L (2007) In praise of resource constraints. MIT Sloan Manag Rev 48(3):15
21. Goldman SL, Nagel RN, Preiss K (1995) Agile competitors and virtual organizations. Manuf Rev 8(1):59–67
22. Holbeche L (2015) The Agile Organization: how to build an innovative, sustainable and resilient business. Kogan Page Publishers
23. Hu L (2022) The PPE industry in Italy during COVID-19: supply chain disruption and the adoption of digital and social media in B2B firms. J Bus Ind Market
24. Ibem EO, Laryea S (2014) Survey of digital technologies in procurement of construction projects. Autom Constr 46:11–21
25. Jiang JJ, Klein G, Tsai JC-A, Li Y (2018) Managing multiple-supplier project teams in new software development. Int J Project Manage 36(7):925–939
26. Joseph S, Trueman P, Watson B, Nangia I, Tilahun L, Sahulhameed R (2019) Australia's infrastructure innovation imperative. Retrieved from https://www.mckinsey.com/featured-insights/asia-pacific/australias-infrastructure-innovation-imperative?cid=other-soc-lkn-mcp-mcp-oth-1911
27. King N (2004) Using interviews in qualitative research. Sage
28. Kleindorfer PR, Saad GH (2005) Managing disruption risks in supply chains. Prod Oper Manag 14(1):53–68
29. Krishnaiyer K, Chen FF (2017) A cloud-based Kanban decision support system for resource scheduling & management. Procedia Manuf 11:1489–1494
30. Larson EW, Gray CF (2010) Project management: the managerial process: McGraw-Hill Irwin

31. Lau E, Kong J (2006) Identification of constraints in construction projects to improve performance. In: Paper presented at the proceedings of the joint conference on construction, culture, innovation and management, Dubai, November
32. Lee D, Lee S (2021) Digital twin for supply chain coordination in modular construction. Appl Sci 11(13):5909
33. Lee HL (2002) Aligning supply chain strategies with product uncertainties. Calif Manage Rev 44(3):105–119
34. Longo F, Nicoletti L, Padovano A (2017) Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. Comput Ind Eng 113:144–159
35. Love PE, Irani Z, Edwards DJ (2004) A seamless supply chain management model for construction. Supply Chain Manage: Int J
36. Lu W, Olofsson T, Jensen P, Simonsson P (2011) BIM-based lean-agile supply chain for industrialized housing. In: Paper presented at the international conference on construction applications of virtual reality, 03 Nov 2011–04 Nov 2011
37. Lundesjö G (2015). Supply chain management and logistics in construction: delivering tomorrow's built environment. Kogan Page Publishers
38. Mrugalska B, Ahmed J (2021) Organizational agility in industry 4.0: a systematic literature review. Sustainability 13(15):8272
39. Profiroiu CM, Bodislav DA, Burlacu S, Rădulescu CV (2020) Challenges of sustainable urban development in the context of population growth. Eur J Sustain Dev 9(3):51–51
40. Rajagopal S, Bernard KN (1993) Strategic procurement and competitive advantage. Int J Purch Mater Manag 29(3):12–20
41. Srivastava A, Bhardwaj S, Saraswat S (2017) SCRUM model for agile methodology. In: Paper presented at the 2017 international conference on computing, communication and automation (ICCCA)
42. Stray V, Moe NB, Sjoberg DI (2018) Daily stand-up meetings: start breaking the rules. IEEE Softw 37(3):70–77
43. Thunberg M (2016) Developing a framework for supply chain planning in construction, vol 1782. Linköping University Electronic Press
44. Tserng HP, Yin SY, Li S (2006) Developing a resource supply chain planning system for construction projects. J Constr Eng Manag 132(4):393–407
45. ul Hassan I, Ahmad N, Zuhaira B (2018) Calculating completeness of software project scope definition. Inf Softw Technol 94:208–233
46. Van Hoek RI, Harrison A, Christopher M (2001) Measuring agile capabilities in the supply chain. Int J Oper Prod Manage
47. Virolainen V-M (1998) A survey of procurement strategy development in industrial companies. Int J Prod Econ 56:677–688
48. Vrijhoef R, Koskela L (2000) The four roles of supply chain management in construction. Eur J Purchasing Supply Manage 6(3–4):169–178
49. Webster J, Watson RT (2002) Analyzing the past to prepare for the future: writing a literature review. MIS Quart xiii–xxiii
50. Xu P (2009) Coordination in large agile projects. Rev Bus Inf Syst 13(4):29. https://doi.org/10.19030/rbis.v13i4.4310
51. Xu S, Zhang X, Feng L, Yang W (2020) Disruption risks in supply chain management: a literature review based on bibliometric analysis. Int J Prod Res 58(11):3508–3526
52. Yeo K, Ning J (2002) Integrating supply chain and critical chain concepts in engineer-procure-construct (EPC) projects. Int J Project Manage 20(4):253–262
53. Zayat W, Senvar O (2020) Framework study for agile software development via scrum and Kanban. Int J Innov Technol Manage 17(04):2030002

# Revisiting Construction Delays in GCC: Oman Versus UAE

**Nasra S. S. Al Sharji, Taleb M. Al Rousan, Abdullahi A. Umar, and Atef Badr**

## 1 Introduction

Globally, the issue of construction projects delays has become ubiquitous across the different types of construction projects. Studies after studies have continued to seek to identify the most common causes of construction projects delays with varying results across different countries, sectors, and regions. It has been reported that over 8% of global GDP is spent on construction projects annually and 99% of those projects are often delayed [13]. Another study of over 3,022 projects around the world found that only 2.8% were completed on-time and on-budget,and if promised benefits were to be taken into consideration, the percentage dropped to only 0.2% [12]. A review of construction reports from the Simon report of 1944 to Egan's report of 1998 shows that the issue of construction delays has been intractable for a long time now [29]. Construction delays have been defined as the time that exceeds the contractual agreed completion date [7]. The Society for Construction Law (SCL) protocol broke delays into two, viz. employer delay to completion and contractor delay to completion [36]. Some of the globally iconic projects today are known to have faced huge delays during construction. These include the Sydney Opera House, the Thames Barrier project, Berlin Brandenburg Airport, and the Scottish Parliament Building. There have been some projects that were completed on time such as the Guggenheim Museum, the Madrid Metro extension, and the Hong Kong Cross Harbour Tunnel, but these seem to be the exceptions. Because of the disturbing nature of delays,

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researchers have put efforts into coming up with the most critical delay causes in order to finally determine an effective global solution. However, results after results have shown that the issue of construction delays tend to be country-specific [28] is impacted by culture [33] and they change over time [4]. In their study of delays in the UAE construction industry, Mpofu et al. [28] found that delays are country-specific, time related and should be viewed within the social, economic, and cultural settings of a country. Ren et al. [33] also found that culture was a major factor that contributed to delay in construction projects in the UAE. Two important studies have sought to summarize the global [35] and universal causes [48] of construction projects delays but both efforts yielded different results, confirming the impact of *country-specific* nuances and *time* on the most critical causes of project delays. It is noteworthy to clarify one important fact about both previous studies above—they both relied on content analysis of previously published works. Therefore, it is pertinent to undertake studies such as this one to unearth these latent differences between seemingly similar countries in order to reduce the liability of foreignness for foreign contractors and consultants in the region. Liability of foreignness describes the additional costs that multinational enterprises have to face relative to their indigenous competitors when operating in foreign markets [8]. This liability of foreignness has been shown to exist in international business, and coping mechanisms have also been suggested [46, 47]. The purpose of this study is to test if differences exist in terms of causes of construction delays between two countries with similar history, geography, governance systems, religion, and culture. Section two looks at previous studies of delays in both countries, section three describes the methods used, section four presents the results, while section five concludes.

## 2 Construction Delays in the GCC

The Gulf Cooperation Council (GCC) Countries is an umbrella name for the six oil rich Gulf countries consisting of the Kingdom of Bahrain, the Kingdom of Saudi Arabia, the Sultanate of Oman, Kuwait, Qatar, and the United Arab Emirates (UAE). The members of this group share similar cultural practices, history, religion, and system of government-monarchy. These group of countries have a pipeline of mega construction projects both ongoing and planned to run into billions of dollars. The UAE and the Sultanate of Oman are two countries within the bloc with the closest relationship both historically and geographically. For example, the Sultanate of Oman has an enclave (Madha) which can only be reached through the UAE, while the UAE also has a counter Enclave (Nahwa) within the same Madha Enclave. Both countries have citizens who have extended family members as citizens of the other. Both share similar cultures, food, and festivals even though their development trajectories seem to differ considerably. Both countries have considerable oil wealth and have both put this wealth into providing their citizens good infrastructure to spur economic development and economic growth. The contribution of infrastructure to a country's GDP exceeds the capital cost of the infrastructure [10]. However, the efficiency of the construction industry has implications for the sustained growth and long-term development of any country [1]. Therefore, it is pertinent for governments and policy makers to be interested in the barriers to efficiency in the construction industry of GCC. There have been numerous studies in both countries on the causes of construction delays with a view to finding lasting solutions to the issue.

In Oman, Al Nuaimi and Al Mohsin [4], while assessing the pre-Tropical Cyclone Gonu and post-Tropical Cyclone Gonu causes, found that the most important causes of delays changed over time. For example, the top five causes of delays pre-Gonu were weather, variations and claims, financial issues, new government rules, and unforeseen ground conditions. While post-Gonu, the top five causes of delays were poor planning and scheduling, poor contractor experience, shortage of materials, failure of work programme, and change in initial designs. Interestingly, the only common variable between the pre- and post-results at the level of the top five causes was variations/change in initial design. In a 2017 follow-up study of delays in Oman, selection of lowest bid, contractor financial difficulties, delay in decision making by client, poor planning and scheduling, and variations/change in initial design were found to be the top five causes [30]. In a 2020 study, variations/change in designs, poor site management and supervision, poor planning and scheduling, inadequate design details, and poor contractor qualifications were found to be the top five causes of delays in that order [42]. Another study conducted in 2022 also found that, variations/change in designs, poor contract management, poor planning and scheduling, client financial difficulties and poor site management and supervision in that order [5]. Another 2022 study in Oman found that variations/change in designs, client slow decision making, labour shortages, client financial difficulties, and subcontractor issues were the most common causes of delays [20]. It was observed that the two 2022 publications only had two common causes-variations/change orders and client financial difficulties. Interestingly across the five Omani studies, only one factor (variations/change orders) was recurring across all five studies. Two other factors (poor planning and scheduling and client financial difficulties) were recurring across four of the five studies examined. This indicates that these three factors were likely the most critical causes of delays across construction projects in Oman.

In the UAE on the other hand, a 2006 study found that delay in approval of drawings, poor planning and scheduling, client slow decision making, shortage of manpower, and poor site management and supervision were the top five causes [11]. A 2010 follow-up study found that variations/change orders, lack of capability of client representative, client slow decision making, poor client experience in construction and poor site management and supervision were the top five delay factors [27]. Another study in 2017 found that, unrealistic project durations imposed by client, incomplete designs at tender, variations/change orders, poor planning and scheduling, delays in government permit were the top five causes [28]. A follow-up study in 2018 also found, variations/change in designs, unrealistic project durations, delay in government permits, poor planning and scheduling, and client scope change were the top five causes of delays [21]. Finally, in a 2021 study of the subject matter, variations/change in designs, client slow decision making, contractor financial difficulties, poor site management and supervision, and poor planning and scheduling were found to be the top five causes of delays [3]. In the UAE assessments, it is noteworthy to point out that two factors (*poor planning and scheduling* and *variations/change orders*) were recurring across four of the five studies examined. Poor site management and supervision, delay in government permits, and client slow decision making also recurred in three out of the five studies examined.

Overall, there were only two factors that were common between the two countries, namely variations/change orders and poor planning and scheduling. Summarizing all the most important factors across both countries indicates that variations/change orders, poor planning and scheduling, poor site management and supervision, delay in government permits, client slow decision making, and client financial difficulties are the six most important causes of delays as shown by an assessment of past studies. A look at the two 2017 studies in Oman and UAE [30] and [28] shows that only two factors were common between the two, viz. poor planning and scheduling and variations/change orders. The summarized number of variables causing delays and their citing literature are given in Table 1.

With regard to solutions to construction delays, researchers have proposed a wide variety of solutions from upskilling the workforce to the adoption of technology-based solutions. For example, Oyegoke and Al Kiyumi [30], in their study found that the most significant solutions to delays include the use of experienced contractors and consultants, effective planning and scheduling by the main contractor, and effective site management and supervision [1]. On the other hand, argues for better communication, effective management, better use of information systems and technology, enforcement of contract clauses, and improved financial arrangements. Others have argued for the implementation of Building Information Modelling (BIM) as a tool that can assist in improving the performance of construction projects in the GCC [39]. Humans are the heart and soul of projects [22], hence for any solution to be effective the training of all cadres of construction professionals will have to be at the forefront. Training in the use of technology for professionals while training in efficient use of new power tools should be the focus for all specialist trades including safety training. Furthermore, the House of Commons has also suggested giving completion time in a 'range' between two dates rather than a specific calendar date, given the inherent uncertainties associated with construction work [17].

## 3 Method

A literature review of existing delay studies across the GCC was undertaken, and the major causes of delays were compiled as given in Table 1. There has been no consensus on the actual number of delay causes across all the highly cited literature on construction delays. Among the literature examined, there exists a huge variability between the number of causes across the different literatures. For example, Sambasivan and Soon [34] cited 2,152 times had 28 delay causes, Faridi and El-Sayegh [11] cited 870 times had 44 delay causes, Sweis et al. [37] cited 786 times had 40 delay causes, and Abd El-Razek et al. [2] cited 732 times with 32 delay

**Table 1** Delay factors and their citing literature

| S/No | Delay causes | Citing literature |
|---|---|---|
| 1 | Variation and changes in design | Al Gheth and Sayuti [3], Al Subhi et al. [5] |
| 2 | Poor site management and supervision | Al Gheth and Sayuti [3], Al Subhi et al. [5] |
| 3 | Client's slowness in making decision | Al Gheth and Sayuti [3], Al Subhi et al. [5] |
| 4 | Low labour productivity | Al Subhi et al. [5], Umar et al. [42] |
| 5 | Delay in material delivery | Al Subhi et al. [5], Umar et al. [42] |
| 6 | Heat and bad weather conditions | Al Nuaimi and Al Mohsin [4], Emam et al. [9], Umar et al. [42] |
| 7 | Inadequate experience in consultant | Al Subhi et al. [5], Umar et al. [42] |
| 8 | Unclear and inadequate details in drawing | Al Subhi et al. [5], Umar et al. [42] |
| 9 | Poor qualification of the contractors | Al Subhi et al. [5], Umar et al. [42] |
| 10 | Poor planning and scheduling | Al Gheth and Sayuti [3], Umar et al. [42] |
| 11 | Delay in payment to contractors | Al Subhi et al. [5], Umar et al. [42] |
| 12 | Economic environment | Al Subhi et al. [5], Umar et al. [42] |
| 13 | Poor Communications between the parties | Al Subhi et al. [5], Umar et al. [42] |
| 14 | Delay in client approval | Al Subhi et al. [5], Umar et al. [42] |
| 15 | Unqualified work force | Al Subhi et al. [5], Umar et al. [42] |
| 16 | Delays of statutory approvals | Al Subhi et al. [5], Umar et al. [42] |
| 17 | Unrealistic contract duration | Mpofu et al. [28], Johnson and Babu [21], Ren et al. [33] |
| 18 | Delays in producing design documents | Al Subhi et al. [5], Umar et al. [42] |
| 19 | Shortage of labour | Faridi and El-Sayegh [11], Al Subhi et al. [5] |
| 20 | Design errors | Al Subhi et al. [5], Umar et al. [42] |
| 21 | Poor Communication designers and contractor | Al Subhi et al. [5], Umar et al. [42] |
| 22 | Material procurement | Al Subhi et al. [5], Umar et al. [42] |
| 23 | Delays of inspection and testing of work | Al Subhi et al. [5], Umar et al. [42] |
| 24 | Subcontractor issues | Ren et al. [33], Al Subhi et al. [5], Umar et al. [42] |
| 25 | Unrealistic designs and drawings | Al Subhi et al. [5], Umar et al. [42] |
| 26 | Client financial difficulties | Al Subhi et al. [5], Umar et al. [42] |
| 27 | Type of project bidding and award | Oyegoke and Al Kiyumi [30], Al Subhi et al. [5] |
| 28 | Differing Site condition (ground problems) | Al Subhi et al. [5], Umar et al. [42] |
| 29 | Contractor financial problems | Al Gheth and Sayuti [3], Al Subhi et al. [5] |

(continued)

**Table 1** (continued)

| S/No | Delay causes | Citing literature |
|---|---|---|
| 30 | Shortage of material suppliers | Al Subhi et al. [5], Umar et al. [42] |
| 31 | Lack of required equipment | Al Subhi et al. [5], Umar et al. [42] |
| 32 | Inappropriate government policies | Al Subhi et al. [5], Umar et al. [42] |
| 33 | Mistakes during construction | Al Subhi et al. [5], Umar et al. [42] |
| 34 | Quality and specifications of materials | Al Subhi et al. [5], Umar et al. [42] |
| 35 | Working hour restrictions | Al Subhi et al. [5], Umar et al. [42] |
| 36 | Change in material cost | Al Subhi et al. [5], Umar et al. [42] |
| 37 | Wrongly shipped orders | Al Subhi et al. [5], Umar et al. [42] |
| 38 | Labour accidents | Al Subhi et al. [5], Umar et al. [42] |

causes. Even studies from the two countries under study Oyegoke and Al Kiyumi [30] and Mpofu et al. [28], both published in the same year, have different number of causes, 44 and 88, respectively. A close scrutiny of those studies with over 30 causes revealed that some causes were broken down to differentiate between consultant delays/client delays and subcontractor/nominated subcontractors. On our part, such issues were merged because the consultant is viewed as a representative of the client, and nominated subcontractors remain subcontractors. Therefore, in this study, a more condensed version containing 38 causes of delays which has been validated through two earlier studies was adopted [5, 38]. Furthermore, a combination of random, convenience, and purposive sampling techniques was employed in the distribution of the questionnaires [31, 40, 41]. The Oman data were collected at two continuing professional development (CPD) events organized by the Royal Institution of Chartered Surveyors (RICS) and Oman Society of Engineers (OSE), respectively. The organizing committees of both events were approached and requested to assist in distributing the questionnaires to their members. The UAE data on the other hand were collected using convenience sampling approach to reach construction professionals and ex-students working in construction-related fields. IBM SPSS version 29 was used to perform inferential statistical procedures including reliability analysis, normality tests, nonparametric statistics (*Mann–Whitney U tests and Kruskal–Wallis H tests*) and factor analysis. The Monte Carlo PCA for parallel analysis software was used to confirm the ideal number of factors after the factor analysis [45].

## 4 Results and Discussions

A total of 312 responses were received from the respondents in both countries, 145 responses from the UAE and 167 responses from the Sultanate of Oman, although 300 questionnaires were sent out in each case. The responses represent a 52% response rate overall, and they also represent 48% and 56% response rates for the UAE and Oman, respectively. Sambasivan and Soon [34] relied on 150 responses while Oyegoke and Kiyumi [30] relied on 53 responses, hence the number of responses for this study I inadequate. As given in Table 2, 71% of the respondents have over 5 years of industry experience while about 273 respondents representing 87.5% of total possess a B.Sc. degree and above. Furthermore, there were 126 Engineers, 46 Architects, 43 Contractors, 43 Clients, and 54 respondents belonging to '*Other*' construction-related professions.

In terms of respondents' sector, 215 were from the private sector, while 97 were from the public sector. From the foregoing respondents' profiles, it can be seen that the respondents were qualified to provide credible opinions on the subject matter. The data were further tested for reliability and the result returned a *Cronbach Alpha* of 0.919 which falls under the 'excellent' classification of George and Mallery [14]. According to Ghasemi and Zahediasl [15], an assessment of Normality should be undertaken when intending to use parametric statistical tests. Both *lilliefors tests* of Normality (Kolmogorov–Smirnov = 0.021, Shapiro–Wilk = 0.001) returned a significant result indicating that the data violates normality assumptions; hence, *nonparametric statistics* were employed.

The *Mann–Whitney U test* was used to assess if there were statistically significant differences between the respondents based on respondents' country and sector affiliation. The results revealed that there were statistically significant differences between the respondents based on respondents' country (ρ-*value = 0.001, z-78.16, df-1*) as given in Table 3.

However, there was no statistically significant difference between the respondents on the basis of sectoral affiliation (ρ-*value = 0.609, z-0.262, df-1*).

Kruskal–Wallis H tests were used to test if differences exist between the respondents on the basis of professional affiliation, years of industry experience, and academic qualifications. The results revealed that there were statistically significant differences (*ρ-value = 0.001, z-27.13, df-4*) between the respondents on the basis of their *professions* with Architects responsible for the difference. Upon further analysis it was found that 42 of the 46 Architects were from the UAE sample, hence

**Table 2** Crosstab of respondents' profession and years of experience

| | Respondents' years of experience | | | | | |
|---|---|---|---|---|---|---|
| Respondents background | 1–5 Years | 5–10 Years | 10–15 Years | 15–20 Years | Over 20 Years | Total |
| Architects | 25 | 13 | 3 | 5 | 0 | **46** |
| Clients | 4 | 2 | 20 | 17 | 0 | **43** |
| Contractors | 9 | 6 | 17 | 5 | 6 | **43** |
| Engineers | 46 | 15 | 13 | 30 | 22 | **126** |
| Others | 7 | 9 | 10 | 4 | 24 | **54** |
| **Total** | **91** | **45** | **63** | **61** | **52** | **312** |

The typographical emphasis was used to highlight to the reader total, values and remarks that were accepted

**Table 3** Results of nonparametric statistical tests

| S/No. | Categorical variables | Nonparametric tests | Test statistics | *df* | Asymp. Sig. values |
|---|---|---|---|---|---|
| 1 | Respondent country | *Mann–Whitney U test* | 78.840 | 1 | ***0.001*** |
| 2 | Respondent sector (public v Private) | *Mann–Whitney U test* | 0.262 | 1 | ***0.609*** |
| 3 | Respondent profession | *Kruskal–Wallis H test* | 27.130 | 4 | ***0.001*** |
| 4 | Respondents' years of experience | *Kruskal–Wallis H test* | 18.290 | 4 | ***0.001*** |
| 5 | Respondent academic qualification | *Kruskal–Wallis H test* | 4.412 | 4 | ***0.353*** |

The typographical emphasis was used to highlight to the reader total, values and remarks that were accepted

only reflects the difference already revealed between the two countries. When the test was conducted based on *years of experience* of respondents, it also revealed statistically significant differences (ρ-*value* = *0.001, z-18.29, df-4*) with 5–10 years category responsible for the differences. Upon further review through *crosstab*, it was found that 36 out of the 45 respondents in that category belonged to the UAE sample further reinforcing the country differences earlier revealed (*ρ-value* = *0.001, z-78.16, df-1*). However, when the Kruskal–Wallis test was performed using respondents' academic qualification as the categorical variable, the result indicated that there was no statistically significant difference (*ρ-value* = *0.353, z-4.412, df-4*) between the groups.

**Exploratory Factor Analysis (EFA)**

The data was subjected to Exploratory Factor Analysis (EFA) in order to reduce the variables into a smaller number of manageable factors. Factor analysis is a data reduction technique which takes a large number of variables and clusters them into a smaller number using the latent correlation among the variables [32]. Several authors have put forward certain conditions that must be met by data meant for factor analysis. The results of Kaiser–Meyer–Olkin test not being less than 0.6, Bartlett's tests of sphericity being significant along with the number of subjects not being less than 150 [32], are some of the preconditions for factor analysis. For N-312, the KMO was 0.752, while BTS was significant (0.001) indicating that the data were fit for EFA. The communalities values all exceed 0.5 for all variables in the analysis. The EFA extracted nine factors, and these factors were further analysed using the *Monte Carlo PCA for parallel analysis* to confirm the ideal number of factors. Table 4 shows the results of the EFA for N-312, and it can be seen that although nine factors were extracted but the *Monte Carlo PCA for parallel analysis* only confirmed seven factors, while two factors were rejected. The *Monte Carlo PCA for parallel analysis* is an independent software used to confirm the ideal number of factors from SPSS factor analysis results [45], although the version of SPSS used for this analysis (IBM SPSS V29) has the software integrated into it. The software works by generating random eigen values which are then compared with those generated by SPSS factor analysis. Any factor whose SPSS eigen values are higher than those generated by the *Monte Carlo PCA for parallel analysis* are accepted, while those lower are rejected [32].

From the foregoing, it can be seen that **weather conditions** were determined as the most critical cause of construction delays in the GCC. Although an earlier country-specific study in Oman found from factor analysis that weather was the third factor extracted out of four factors in total [5]. The authors argued that contractors in the region are aware of the impact of the summer months and have already developed methods for reducing the impacts of weather issues. Temperatures during the summer months are known to range between 45 and 50 °C. As a result, the governments across GCC countries prohibit work outside between the hours of 12noon and 3 pm when the temperatures are at their maximum. In Oman, article 16/3-3 of ministerial resolution No. 286/2008 as amended by ministerial resolution No. 322/2011 mandates work stoppage from 12.30 to 3.30 pm, while Ministerial Decree No. 401/2015 is the guiding law in the UAE. There are heavy fines attached to each of the decrees as deterrents to prevent contractors forcing workers to work in the hot afternoon heat. The break in routine construction work impacts delivery over the course of the four months of summer in the region as workers struggle to gain back work momentum or work rhythm after each break. Earlier studies of construction delay causes in the GCC have also identified weather as a significant contributor to construction delays

**Table 4** Factor analysis for all respondents (N-312)

| S/No | Factors | SPSS eigen values | Monte Carlo eigen values | Remark |
|---|---|---|---|---|
| 1 | Weather conditions | 9.768 | 1.730 | **Accept** |
| 2 | Delays in payment to contractors | 3.213 | 1.645 | **Accept** |
| 3 | Shortage of materials | 2.968 | 1.574 | **Accept** |
| 4 | Economic environment | 2.805 | 1.514 | **Accept** |
| 5 | Poor site management and supervision | 1.841 | 1.466 | **Accept** |
| 6 | Poor communication between parties | 1.711 | 1.422 | **Accept** |
| 7 | Subcontractor issues | 1.408 | 1.381 | **Accept** |
| 8 | Inappropriate government policies | 1.285 | 1.341 | **Reject** |
| 9 | Unrealistic contract duration | 1.146 | 1.299 | **Reject** |
| ***Percentage of variance explained by the factors: 68%*** | | | | |

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**Table 5** Factor analysis for Oman respondents (N-167)

| S/No. | Factors | SPSS eigen values | Monte Carlo eigen values | Remark |
|---|---|---|---|---|
| 1 | Poor communications between parties | 7.081 | **2.064** | **Accept** |
| 2 | Poor site management and supervisions | 4.545 | **1.919** | **Accept** |
| 3 | Design errors | 4.351 | **1.810** | **Accept** |
| 4 | Materials procurement | 3.681 | **1.716** | **Accept** |
| 5 | Client financial difficulties | 2.229 | **1.651** | **Accept** |
| 6 | Change in materials costs | 2.130 | 1.582 | **Accept** |
| 7 | Inappropriate government policies | 1.686 | 1.455 | **Accept** |
| 8 | Labour accidents | 1.602 | 1.397 | **Accept** |
| 9 | Working hours restrictions | 1.408 | 1.345 | **Accept** |
| 10 | Delay in client approval | 1.110 | 1.295 | **Reject** |
| 11 | Weather conditions | 1.078 | 1.247 | **Reject** |
| ***Percentage of variance explained by the factors: 81%*** | | | | |

The typographical emphasis was used to highlight to the reader total, values and remarks that were accepted

in the region [9, 25]. But an older study by [37] found that weather was one of the least causes of construction delays in the region. This finding may be the result of the growing impact of climate change in the region. A recent study employing simulation has predicted that the average temperature in the GCC would rise to 42 °C in five of the six capital cities in the region, while daily temperatures are projected to exceed 55 °C during the same period within the region [6].

Delays in payment to contractors were the second most important factor causing delays across the two countries under study. This cause extends well beyond these two countries to other members of the GCC as evident by the report on the collapse of Carillion in 2018, where the House of Commons found that delays in payments for Carillion's GCC projects were a major factor in its bankruptcy [16, 26]. In the USA, the 2020 National Construction Payment Report (NCPR) found that over 80% of the 540 contractors surveyed indicated that they spent a substantial part of their time chasing down payment for completed work [24]. Across many studies of delays in the region, delay in payments to contractors has always featured as a major factor and has consistently been ranked in the top ten causes [9, 30], while in the UAE, it ranked 66th place out of 88 delay causes. **Shortage of construction materials** was the third most significant factor causing delays in both countries under investigation. Consistent with an earlier study of the region, this factor was also ranked in third place [9]. Country-specific studies in Oman also found this factor as a major cause of construction delays [42], while this was not found to be an issue in the UAE where it ranked 71 out of 88 delay causes [28]. The economic environment was found to be the fourth most important cause of delays from the EFA results. In one of the recent studies, it was ranked in 16th place [25].

In fifth place is *poor site management and supervision*, this factor is ranked in fourth place by the two previous cross-region studies of delays [9, 25]. This indicates the continued relevance of this factor in causing delays to construction projects in the region. However, this finding also indicates a failure on the part of contractors in the region to undertake and benefit from post-project lessons learned. Across almost all country-specific studies, this factor finds itself ranked among the **top ten** causes of construction delays in the region. It was also ranked in fifth place in an Oman-specific study [5]. Even in the USA, 70% of the contractors surveyed in a recent study indicated that poor site management was a major contributor to delays and cost overruns on construction projects [24]. *Poor communication between the contracting parties* was found to be the sixth factor. This poor communication was also ranked in 10th place by the two previous cross-region studies of the subject matter. In terms of country-specific studies, it was ranked in 8th place by Al Subhi et al. [5] in Oman, while Faridi and El-Sayegh [11] ranked it in 16th place in the UAE. Even in developed countries such as the USA, poor communication between the stakeholders has also featured among the top ten causes of construction delays [38]. The fact that it found itself in the top ten across so many studies indicates the need for training of construction stakeholders on the importance of effective communication strategies in the construction industry. However, this factor was ranked outside the top ten in the two global studies of the subject matter, 15th place in [48] and 20th place in [35]. Delay events resulting from *subcontractor issues* closed out the accepted number of factors in 7th place. The importance of this factor stems from the fact that it was also ranked in 7th place by Emam et al. [9], a major cross-region study of delays in the GCC. This ranking may not be unconnected to the ongoing affirmative action in the region requiring jobs to be awarded to local contractors under the Omanization and Emiritization policies in both countries. Many of the subcontractors do not possess the requisite experience, a weakness in affirmative action policies.

### Country-Specific EFA

Country-specific *Exploratory Factor Analysis* (EFA) was performed for both countries. Interestingly, the IBM SPSS extracted eleven factors for each country despite varying number of respondents (Oman-167, UAE-145). However, upon the confirmatory test using *Monte Carlo PCA for parallel analysis* the number of accepted factors dropped to Nine for Oman and five for the UAE. The result for the Sultanate of Oman revealed that the most critical factor was *poor communications between contract parties*, while the least was *working hours restrictions* resulting from the hot summer temperatures. *Delays in client approval* and *weather conditions* were rejected by the *Monte Carlo PCA for parallel analysis* confirmation.

Design errors by the designer is ranked in third place for Oman. This factor was not reflected in the overall EFA (N-312) nor in the UAE result. However, it is instructive to note that it is a very common factor in the top ten in other studies, for example Mahdi and Soliman ranked it in 8th place while in the USA, *design errors* is ranked in third place [38]. Materials procurement and client financial difficulties, the two common factors between Oman and UAE were ranked as fourth and fifth factors in the Oman sample. However, weather conditions which ranked in first place in the overall sample (N-312) did not make it into the accepted factors by the Monte Carlo PCA. Hence, the least factor causing delays according to the EFA for Oman is *working hours restrictions* which is coincidentally linked to the *weather conditions*. This is an affirmation of the impact of weather conditions on safe and timely delivery of construction projects in the GCC.

As stated above, although SPSS also extracted 11 factors for the UAE, *Monte Carlo PCA for parallel analysis* only confirmed five factors which include *client financial difficulties, subcontractor issues, low labour productivity, materials procurement* and *inadequate consultant experience* as given in Table 6. Interestingly, there were only two common factors between the EFA results of both countries (*client financial difficulties* and *materials procurement*) further affirming the significance of their differences. This result further affirms the earlier findings of [28] that the most critical delay factors tend to be country-specific.

**Table 6** Factor analysis for UAE respondents (N-145)

| S/No | Factors | SPSS eigen values | Monte Carlo eigen values | Remark |
|---|---|---|---|---|
| 1 | Client financial difficulties | **10.788** | **2.064** | **Accept** |
| 2 | Subcontractor issues | **3.469** | **1.919** | **Accept** |
| 3 | Low labour productivity | **2.499** | **1.810** | **Accept** |
| 4 | Materials procurement | **2.222** | **1.716** | **Accept** |
| 5 | Inadequate consultant experience | **1.759** | **1.651** | **Accept** |
| 6 | Labour accidents | 1.534 | 1.582 | **Reject** |
| 7 | Poor planning and scheduling | 1.376 | 1.519 | **Reject** |
| 8 | Unrealistic contract duration | 1.240 | 1.455 | **Reject** |
| 9 | Design errors | 1.184 | 1.397 | **Reject** |
| 10 | Economic environment | 1.078 | 1.345 | **Reject** |
| 11 | Poor communication between designers and contractors | 1.005 | 1.295 | **Reject** |
| ***Percentage of variance explained by the factors: 74%*** | | | | |

The typographical emphasis was used to highlight to the reader total, values and remarks that were accepted

## 5 Conclusions

Construction projects delays have become pervasive across the global construction industry. It is an area where even the developed countries have been unable to excel over developing countries as both groups struggle with delay problems on major construction projects. However, differences do exist with regard to the most important causes of delays across different countries and regions. This study sets out to identify and determine if differences existed between two culturally similar countries, Oman, and UAE with regard to causes of construction delays. The results indicate that, despite their similarities in terms of governance, religion, culture, history, geography, and even filial relationship, significant differences exist between both countries. While nine factors were found to causes construction delays in Oman, only five factors were found for the UAE. Interestingly, only two causes were similar between both countries. The results are of practical importance to construction professionals, especially consultants and contractors, to help them manage the *liability of foreignness* when moving between countries in the Middle East, especially the GCC for work purposes. Contractors should review and standardize their materials procurement process to make it more efficient by focusing on their supply chain management processes. The client should ensure they have made adequate financial arrangements with financial institutions before contractors are mobilized to site. These two areas—materials procurement and client financial difficulties—were the only common variable between the two countries under study, hence should be the focus of future process re-engineering within the construction industries in both countries.

**Limitation of the Study**

The findings of this study relied on 312 responses from two countries within a region comprising six countries. Therefore, the results and findings should be viewed within the context of these two countries and not the entire region.

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## References

1. Abd Aziz N, Mohd Rahim FA, Aziz NM (2022) Delay mitigation strategies and the implication on the construction industry: a systematic literature review. Plann Malaysia: J Malaysian Inst Plan 20(5):223–234
2. Abd El-Razek ME, Bassioni H, Mobarak A (2008) Causes of delay in building construction projects in Egypt. J Constr Eng Manage 134(11):831–841
3. Al Gheth A, Sayuti MI (2021) An investigation of causes of delay affecting the United Arab Emirates construction industry. In: Mohamed Nazri F (ed) Proceedings of AICCE'19 lecture notes in civil engineering, vol 53. Springer, Penang, pp 403–413. https://doi.org/10.1007/978-3-030-32816-0_26
4. Al Nuaimi AS, Al Mohsin MA (2013) Causes of delay in completion of construction projects in Oman. In: International conference on innovations in engineering and technology (ICIET'2013), 25–26 Dec, Bangkok
5. Al Subhi OM et al (2022) Revisiting the causes of construction delays in Oman: a post-pandemic study. Association of Engineering, Project, and Production Management (EPPM), Athens
6. Almazroui M (2020) Summer maximum temperature over the gulf cooperation council states in the twenty-first century: multimodel simulations overview. Arab J Geosci 13(477). https://doi.org/10.1007/s12517-020-05537-x
7. Assaf SA, Al-Hejji S (2006) Causes of delay in large construction projects. Int J Project Manage 24:349–357
8. Denk N, Kaufmann L, Roesch J-F (2012) Liabilities of foreignness revisited: A review of contemporary studies and recommendations for future research. J Int Manag 18(4):322–334
9. Emam H, Abdelaal M, Farrell P (2014) Causes of delay in GCC construction projects: a critical review. CIB-MENA, Abu Dhabi, pp 607–621. https://doi.org/10.13140/2.1.1211.8086
10. Esfahani HS, Ramírez MT (2003) Institutions, infrastructure, and economic growth. J Dev Econ 70(2):443–477
11. Faridi AS, El-Sayegh SM (2006) Significant factors causing delay in the UAE construction industry. Constr Manag Econ 24(11):1167–1176
12. Flyvbjerg B (2019) Why Megaprojects systemically fail—And what can be done about it?. Available at https://www.sbs.ox.ac.uk/oxford-answers/why-megaprojects-systemically-fail-and-what-can-be-done-about-it. Accessed 19 Jan 2022
13. Flyvberg B (2020) How to fix a failed megaproject in 90 days. Available at https://www.sbs.ox.ac.uk/oxford-answers/how-fix-failed-megaproject-90-days. Accessed 08 Sept 2022
14. George D, Mallery P (2003) SPSS for Windows step by step: a simple guide and reference. 11.0 update, 4th edn. Allyn & Bacon, Boston
15. Ghasemi A, Zahediasl S (2012) Normality test for statistical analysis: a guide for non-statisticians. Int J Endocrinol Metabol 10(2):486–489
16. HoC (2018) Carillion. House of Commons Business, Energy and Industrial Strategy and Work and Pensions Committees, London
17. HoC, (2019) The government's management of major projects: an interim report. House of Commons Public Administration and Constitutional Affairs Committee, London
18. Hofstede G (1980) Culture's consequences: international differences in work-related values, 1st edn. Sage, Beverly Hills, CA
19. Hofstede G et al (2010) Comparing regional cultures within a country: lessons from Brazil. J Cross Cult Psychol 41:336–352
20. Javed S, Hussain MI, Al Aamri AM, Akhtar J (2022) Investigation on factors causing construction delay and their effects on the development of Oman's construction industry. EUREKA: Phys Eng 6:33–44. https://doi.org/10.21303/246
21. Johnson RM, Babu RII (2018) Time and cost overruns in the UAE construction industry: a critical analysis. Int J Constr Manage 20(5):402–411: https://doi.org/10.1080/15623599.2018.1484864

22. KPMG (2019) Global Construction Survey 2019: future-ready index. KPMG, US
23. Latif QB, Al Saadi AMD, Abdul Rahman I (2019) Identification of delay factor in oman construction industry. Int J Sustain Constr Eng Technol 10(1):34–45. https://doi.org/10.30880/ijscet.2019.10.01.004
24. Levelset (2020) 2020 National construction payment report. Levelset & Fieldwire, Texas
25. Mahdi I, Soliman E (2018) Significant and top ranked delay factors in Arabic Gulf countries. Int J Constr Manag 21(2):167–180
26. Mor F, Conway L, Thurley D, Booth L (2018) The collapse of carillion: breifing paper no 8206. House of Commons Library, London
27. Motaleb O, Kishk M (2010) An investigation into causes and effects of construction delays in UAE. Association of Researchers in Construction Management (ARCOM), Leeds
28. Mpofu B, Ochieng EG, Moobela C, Pretorius A (2017) Profiling causative factors leading to construction project delays in the United Arab Emirates. Eng Constr Archit Manag 24(2):346–376
29. Murray M, Langford D (2003) Construction reports 1944–98. Wiley-Blackwell, s.l.
30. Oyegoke AS, Al Kiyumi N (2017) The causes, impacts and mitigations of delay in megaprojects in the Sultanate of Oman. J Financ Manag Prop Constr 22(3):286–302. https://doi.org/10.1108/JFMPC-11-2016-0052
31. Palinkas LA et al (2015) Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. Admin Policy Mental Health Mental Health Services Res 42(5):533–544
32. Pallant J (2020) SPSS survival manual: a step by step guide to data analysis using IBM SPSS. 7th ed. Open University Press, London
33. Ren Z, Atout M, Jones J (2008) Root causes of construction project delays in Dubai.ARCOM, Cardiff, pp 1–3
34. Sambasivan M, Soon YW (2007) Causes and effects of delays in Malaysian construction industry. Int J Project Manage 25(5):517–526
35. Sanni-Anibire MO, Zin RM, Olatunji SO (2020) Causes of delay in the global construction industry: a meta analytical review. Int J Constr Manag. https://doi.org/10.1080/15623599.2020.1716132
36. SCL Protocol (2017). Society of construction law delay and disruption protocol, 2nd edn. Society of Construction Law (SCL), UK
37. Sweis G, Sweis R, Hammad A, Shboul A (2008) Delays in construction projects: the case of Jordan. Int J Project Manage 26(6):665–674
38. Tafazzoli M, Shrestha PP (2017) Investigating causes of delay in U.S. construction projects. Associated Schools of Construction (ASC), Seattle
39. Umar T (2022) Challenges of BIM implementation in GCC construction industry. Eng Constr Archit Manag 29(3):1139–1168
40. Umar AA, Zawawi NAWA, Abdul-Aziz A-R (2019) Exploratory factor analysis of skills requirement for PPP contract governance. Built Environ Project Asset Manage (BEPAM) 9(2):277–290
41. Umar AA, Zawawi NAW-A, Abdul-Aziz A-R (2023) Does regional characteristics influence PPP contract governance skills requirements? Eng Constr Architect Manage (ECAM) J. ahead-of-print. https://doi.org/10.1108/ECAM-08-2022-0729
42. Umar A, Al Rizeiqi RK, Badr A (2020) Major causes assessment of construction delays. J Eng Project Prod Manage 47(1):128–134
43. Walsh A, Walker P (2021) The significance of cultural risks for western consultants executing gulf cooperation council megaprojects. Int J Soc Bus Sci 14(8):649–658
44. Walsh A, Walker P, Ellis M (2021) The underestimation of cultural risk in the execution of megaprojects. Int J Civil Environ Eng 5(1):33–40
45. Watkins M (2000) Monte Carlo PCA for parallel analysis (computer software). Education and Psychology Associates, State College Pensylvania

46. Zaheer S (1995) Overcoming the liability of foreignness. Acad Manag J 38(2):341–363
47. Zaheer S, Mosakowski E (1997) The dynamics of the liability of foreignness: a global study of survival in financial services. Strateg Manag J 18(6):439–463
48. Zidane YJ-T, Andersen B (2018) The top 10 universal delay factors in construction projects. Int J Manag Proj Bus 11(3):650–672

# Team Dynamics and Its Effect on the Design Process Within the Construction Industry

**Ronald Manyathi and Rolien Terblanche**

## 1 Introduction

The traditional method of construction is a three-phase linear process which consist of design–bid–build. This project delivery method is widely used in KwaZulu-Natal for public construction building projects. At design phase, the project owner procures construction professionals to form a design team to work in an interdisciplinary project organization. Collectively, these team members become responsible for producing a complete design that is fully defined and scoped to enable contractors to bid for the project and complete the construction of works.

According to Buffinton et al. [2], teams are designed to function in a similar manner, yet some teams function better than others and at least one team usually suffers with significant team dynamic problems. Team dynamics encompass the interaction and process within groups that allow the group to function and complete tasks [5, 22]. According to Schulz et al. [22], the characteristics of team dynamics are multifaceted and include decision-making, problem solving and conflict resolution process, communication strategies and comfort in expressing opinions; leadership and influence, trust between team members, commitment and participation.

The construction industry is no exception to dealing with team dynamics due to the nature of the field being project-based, involving different companies that form multidisciplinary project organization for the purpose of constructing facilities according to agreed contractual obligations and specifications [29]. The success of these project organizations relies on each team member working effectively within a team [20], however conflict of confrontational relationships, disputes on tasks and conflicting team objectives among team members arise and make it difficult to achieve project objectives [12]. Research has identified design information, design processes and

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design management practices as the main attributes to disputes in the construction industry (Love et al. 2010).

In the context of the construction building industry, design management can be defined as a managerial practice with a specific objective of improving design procedure and develop high quality buildings using effective processes [25]. The introduction of design management resulted from the construction industry having challenges related to specialized disciplines, complexity of construction project delivery, high level of collaboration, cooperation, coordination within design and engineering processes [19]. Construction building professional teams like any other teams are exposed to team dynamics. The performance of design management processes should be investigated when disrupted by the team dynamics of construction building professionals while working on construction building projects.

The aim of this study is to investigate the effect of the team dynamics at play, while interdisciplinary design teams work on the design management task during the design phase of construction building projects. This was achieved by identifying the key design team members accountable for the design management process, establishing the problem areas hindering design management, evaluating the level of team dynamics encountered by interdisciplinary design teams and testing the interrelation between team dynamics and design management.

### *1.1 Literature Review*

The topic of team dynamics has been broadly researched and explored in various contexts. Buffinton et al. [2] indicated that problems solving styles and interpersonal dynamics of teams are critical factors for effective functioning of teams. This study aimed to understand problem solving strategies among project team members. Although the study was conducted on university students from the engineering and management schools, Buffinton et al. [2] shared the same view with Lehmann-Willenbrock et al. [12] after investigating team dynamics at the workplace among industrial workers in Germany.

Conflict was evident among team members although the studies differed with respect to the cause of conflict. Buffinton et al. [2] concluded that conflict was associated with cognitive styles within teams. Lehmann-Willenbrock et al. [12] argued that team members' individual status related to starting and ending disagreements. Lehmann-Willenbrock et al. [12] mentioned leaderless team interactions at the industrial workplace as a limitation, yet according to Buffinton et al. [2] even if project teams are established without leaders, leaders emerge through a democratic process or by default. In the context of construction building professionals, there is a need to take into consideration remuneration and contractual obligations that may influence the leadership and involvement of a professional service provider.

Che Ibrahim et al. [6] identified seven indicators for multi-disciplinary project teams to be successful. The indicators are team leadership, trust and respect, single team focus on project objectives and key result areas, collective understanding, commitment from project alliance board, creation of single and co-located alliance team and free flow communication. This study contextualized team dynamics into the construction industry with client, contractor and consultant as participants. However, the research was based in New Zealand, and the design alliance is not a procurement strategy that is used in South Africa.

Majority of the literature studied placed trust as a dominant indicator of team dynamics to measure the level of team work performance. Lindskold [16] indicated that people experience lower levels of conflict when interacting with people they trust. Uusitalo et al. [27] researched interpersonal trust and information flow from the lean design management (LDM) concept to solve design management problems in construction projects. LDM consists of a social domain that creates trust among project team members and a technical domain which improves project information flow.

According to Uusitalo et al. [27], USA, Finland and Brazil actively use the lean construction method; hence, the study was conducted in these countries. South Africa is not known for utilizing the above-mentioned method; therefore, applying the LDM concept would be out of context. However, the building information modelling (BIM) approach is favourable over LDM for research based in South Africa as previous studies have indicated that the use of both BIM and LDM increases the level of interaction among design team members [1].

Uusitalo et al. [27] indicated that construction professionals require trust among each other which will in return produce team chemistry, allow for communication, openness, transparency and create a sense of shared goals. However, this study did not include leadership as part of the social aspect required for teams to succeed. Furthermore, Uusitalo et al. [27] identified that trust alone is not a prerequisite for solving design quality problems. However, according to Rezvani et al. [20] trust is positively associated with team performance.

Walker et al. [28] could not associate positive team dynamics with performance in a study of health students as much as students studied in collaboration and in teams, assessments required individual performance. In the same study, Walker et al. [28] identified interpersonal team relations and task functions as the two categories of team dynamics that allow teams to function. Cresswell-Yeager (2020) also applied the two categories in the study of small group communication among students exploring the interpersonal relationships among the students collaborating in task-orientated small groups.

Cresswell-Yeager [8] identified communication, leadership, diversity, conflict, ethical decision-making and problem solving as key indicators of successful collaboration in task-orientated small groups. Although the origins of the two categories used in the studies from Walker et al. [28] and Cresswell-Yeager [8] cannot be factually proven, they gained popularity from Tuckman [24] applying the two categories of team dynamics in the forming, storming, norming and performing theory. Tuckman [24] identified them as two realms of group development: interpersonal relationships and task activities. Using the Tuckman theory model Tuckman [24], Cresswell-Yeager [8] found small groups are able to communicate, delegate and find solutions.

The literature review can identify the historical pattern of research in topic of team dynamics in the construction industry. Recent studies have investigated trust in solving design management problems followed by trust as a prerequisite of solving design quality [26, 27]. It can be concluded that to achieve high quality design, solving the design management process is key to solving design quality problems.

Jin et al. [13] indicated that countries like China have a growing demand for BIM professionals. The demand in the South African context should be investigated as it impacts the ability to perform design management. Furthermore, BIM as a design management tool in South African projects should be studied as BIM has been found to affect the traditional role of architects in project designs due to multi-disciplinary involvement [13].

Researchers have indicated team meetings are a fundamental design management technique for resolving design technical issues. Most interactions in construction meetings are task-focused according to [10]. However, Otter and Emmitt [18] suggested that agreed outcomes from personal dialogue among team members may also be presented in formal design meetings for other stakeholders to discuss. There is an opportunity to use meetings to address and resolve social issues that have a negative impact to the design management task.

Taking to consideration the well-publicized level of corruption among state-owned enterprises in South Africa, trust alone cannot be relied on to enhance team performance hence research that seeks to understand team dynamics in the form of interpersonal relationships and task orientations can contribute to the body of knowledge. The topic of team dynamics requires a task to be performed in order to understand the interpersonal relationship among the parties involved; hence, team dynamics can be researched in conjunction with design management at design phase. The construction professionals that forms part of the design and management is predominantly the architect that designs [9], the quantity surveyor that manages the cost of the design [23] and the project manager that manages the time [17].

## *1.2 Theoretical Review*

Team dynamics have been historically explored using the Tuckman [24] theory of forming, storming, norming and performing small group development sequence model which depicts the four stages required to reach effective group functioning [3]. According to Cresswell-Yeager (2020), the forming stage team members are civil towards each other. The storming stage introduces conflict and resistance to the team formation [3]. The norming stage is about developing cohesion and the team functioning as an entity [24]. The final stage of performing, team members focus on collaboration to achieve task goals (2020). This theory is relevant in assessing the performance of design team members' performance during the implementation of the design management task. The small group development model is shown in Fig. 1.


**Fig. 1** Tuckman [24] model of small group development

# 2 Method

## *2.1 Research Philosophy and Approach*

This study is based on the interpretivism philosophy from the school of epistemology. Interpretivist paradigm seeks to understand humans in their roles as social actors [21]. The subjects for this study are construction professionals working in design teams that are required to individually contribute towards the design management process. The social context of these subjects was entered with the objective of gaining insight of the phenomenon by obtaining individual perspectives from multiple participants which revealed the social pattern required for this study.

Inductive reasoning is based on an observation of a sample which leads to conclusions on the larger population drawn from the sample [14]. This study is based on the inductive approach which intends to systematically analyse qualitative data gathered from interviews conducted on the construction building professionals about the social phenomenon. The data analysis is subjective with the objective of searching for patterns that reflect on the data. Theory serves as a lens for an inquiry during the research study [7]. This study used the Tuckman theory model of forming, storming, norming and performing Tuckman [24] to compare patterns from the data collected.

## *2.2 Methodology*

Qualitative research explores and seeks to understand individual meaning to social problems [7]. This study used the qualitative research methodology, using semi-structured interviews as a tool to gather data from individual construction professionals experiencing the same phenomenon. There are various ways of conducting one-on-one interviews with the participants. They can be conducted by having the researcher and the participants in the same room, virtually or via email [7]. For the purpose of this study, the interviews were be conducted in the same room with the participants and virtually. Graue [11], Leedy and Ormrod [14] and Tibben (2015) indicated that triangulation is the use of interdependent data sources to corroborate research findings. This study corroborated research findings using literature review, Tuckman [24] theory and semi-structured interviews and is illustrated in Fig. 2.

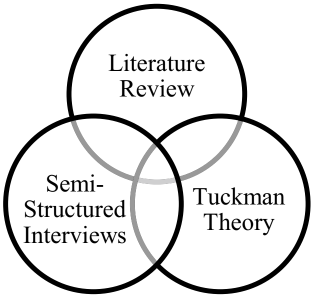


**Fig. 2** Triangulation. *Source* Researcher's own development

## 2.3 Research Methods

There are two types of semi-structured interviews, viz. exploratory and explanatory type, both used to gather data from open-ended questions that require order and logic, thereafter analysed qualitatively [21]. This study utilized semi-structured interviews to gain individual perspectives from construction building professionals.

## 2.4 Population and Sampling

This study targeted the population that encompasses architects, project managers and quantity surveyors working for small, medium to large consulting firms. A qualitative sampling method of purposive sampling (non-probability) was used. A total of 15 construction building professionals based in KwaZulu-Natal, South Africa, participated.

## 2.5 Development of the Research Instrument

Qualitative research data was collected by verbal data which was in a form of scheduled semi-structured interviews. Construction building professionals working in design teams have had different experiences from various construction building projects which this research seeks to discover.

## 2.6 Data Collection Protocol

Fifteen one-on-one semi-structured interviews were conducted to collect individual experiences from construction building professionals across KwaZulu-Natal, South

Africa. The state-owned enterprises COEGA Development Corporation, the Department of Public Works and the Independent Development Trust as implementing agents were approached for a database of construction building professionals. An invitation to professionally registered architects, project managers and quantity surveyors sourced from the databases was sent out via email. The invitation requested for participation from construction building professionals that have experienced team dynamics in the design phase of the construction building projects and would like to share the experience in a one-on-one interview session with the researcher.

## 3 Results

Thematic analysis was used for this study using a six-step process of familiarizing, generating initial codes, search for themes, reviewing themes, defining and naming themes and finally producing the report (Braun and Clark 2006). Audio interview question responses were transcribed into a word document, broken down into smaller segments and grouped for coding. NVivo computer software was used to analyse the data collected.

The study findings were as follows.

### *3.1 Design Management*

- High Level of Collaboration: Multi-disciplinary organizations distributed projects within the organization for project teams to collaborate. Joint ventures were another form of collaboration between same discipline organizations assembled to increase capacity to deliver large construction building projects. Collaboration was found to be problematic when joint venture arrangements were not mutual and were imposed for black broad-based economic empowerment. Project organizations collaborated better when all disciplines were involved from the inception project stage.
- High Level of Cooperation: Multi-disciplinary organizations had the benefit of organization culture, policy and procedures that allowed for cooperation. Project organizations relied on high professionalism and contractual obligations to cooperate with one another.
- High Level of Coordination: Coordination of design documentation using 2D drawings was found to be time-consuming and contributed to a lengthy design process. Same discipline joint ventures required design team members to work in one office to enable efficient coordination among themselves prior to coordinating with other disciplines. Design teams experienced coordination problems when design team members were using different software programmes.

### 3.2 Interpersonal Relationships

- Trust: Design team members valued trust, those that did not take trust into consideration chose respect and professionalism, respectively. Trust was found to be something that is developed over a period of time working together on different construction building projects. Participants emphasized that trust can be gained and lost, when design team members repeatedly fails to resolve design issues relating to their discipline, a reduction of trust levels is consequently experienced. The study found that professional registration builds confidence when design team members are working together for the first time.
- Leadership: This study found leadership during the design process to be between the architect and the project manager, however the project manager was the preferred leader. When design teams do not have a project manager or the project manager demonstrates incompetence to lead, the architect would acquire the leadership role. The leader is given authority to give the project direction by setting up processes and standards that the team is required to follow.
- Communication: Emails and meetings were the main communication channels used by design teams. Emails were the primary communication method for they kept record of correspondence. Phone calls were the secondary communication method utilized to follow up on emailed correspondence. Informal chats and WhatsApp were used to gather ideas which were subsequently presented in formal design meetings.
- Commitment to Project Goals: According to the study, commitment was demonstrated by design teams retaining the same individuals throughout the design phase. The study found that not all design team members were committed, team members would resign and fail to complete the design process.

### 3.3 Task Orientation

- BIM: Design teams that used BIM were able to produce design documentation effectively within desirable timeframes. However, participants that had access to BIM did not apply it to all construction building projects as setting up BIM required a lot of time and should be used selectively depending on the project complexity. Large organizations had the benefit of having dedicated BIM mangers to assist in model coordination and provide training to professionals. Experienced professionals preferred the traditional approach to managing the design process. Cost factors associated with BIM, purchasing software and training contributed to the no-use of BIM.
- Meetings: Participants indicated that design team members can get more out of getting people around the table face to face and sharing information rather than using BIM. Weekly meetings were commonly used to resolve design issues and coordinate design documentation. Team members present in the meetings were

expected to be competent enough to resolve discipline related matters during the meeting sittings.

### 3.4 Working Style

- Integrated Design Under the Strong Direction of the Architect: Design teams that preferred to work under the strong direction of the architect required value engineering of initial designs for the final design to be within the client's budget. This working style was primarily adopted by architects with vast experience in projects of similar nature.
- Cooperative Design Based on Team Work: Cooperative working style based on team work was preferred on refurbishments, addition and alteration construction building projects. Findings suggest that architects relied more on other disciplines to support the architectural information in projects of this nature.

### 3.5 Variations

- Errors and Omissions: Variations during the design process were common especially on refurbishments, addition and alteration construction building projects. These projects are infamous to have a high probability of variations due to unforeseen elements that cannot be predetermined. The cause of design changes stem from design teams not performing a detailed analysis on a design that incorporates design documentation from all disciplines. Furthermore, a substandard business case and a lack of detailing and coordination between the design team create scope creeps.
- Design Information and Documentation Delays: Design information delays are caused by a shortage or a change of resources within the design team. Political pressure contributed to the provision of inadequate timeframes to manage the design process. Furthermore, state organizations lacked internal coordination resulting in gradual design approval processes contributing to the design information and documentation delays.

Tables, figures and appendix must be embedded in the corresponding order in the manuscript. An example of table content is given in Table 1. The width of the table line is 1/2p. The width of the table is the same as that of the single column or double column arrangements. Wilder table should be accommodated in a single column arrangement. Please try not to use the bold format in the column unless the authors would like to highlight something important.

### 3.6 Conflict

- Personality Clashes: Personality clashes existed in design teams in a form of egos. Design team members experience attitude that created unease for team members. Project management was identified discipline for having a historical background of intimidating fellow design team members.
- Late Submissions: The allocation of short timeframes or failing to project accurate timeframes required to complete deliverables resulted in late submissions. Furthermore, design team members deliberately withheld information when remuneration for work done was not adhered to.
- Unhappiness with on Another: Racial, language barriers and personal problems brought into the design process overtime created unhappiness. Disorganized organizations would introduced new individuals during the design process which triggered unhappiness. Also, unhappiness was experienced when architects would marginalize design inputs from design team members and when quantity surveyors proposes economical solutions that complement the project budget.

### 3.7 Development Sequence

- Forming: Design teams established boundaries during the first meeting which included a joint project plan which entailed processes and procedures, communication strategy, teamwork strategy, allocation of resources, meeting schedule and setting timelines against deliverables.
- Storming: The boundaries formed also changed during the course of the design process; hence, a live project plan was altered at any point in time depending on circumstances.
- Norming: A long design process duration contributed to design team forgetting about the boundaries set at project inception. Design teams were required to continuously remind and encourage each other to adhere to the set boundaries. Transparency, high professionalism, adhering to the respective discipline's code of conduct and having the end goal of completing the design phase allowed design team members to treat each other as colleagues.
- Performing: Participants revealed that design teams performed well when team members have a previously worked together on similar projects with the same client over a number of years. Design teams remunerated according to the government gazette fee scale were inspired to work well with each other throughout the design process.

### 3.8 Performance

- Time: Government design process timelines are not adhered to because they are not profit driven like private sector timelines. Design approval processes and red tape from government departments influenced the time delays. Value engineering completed design documentation prolonged the design process beyond the scheduled timeframe.
- Cost: The duration of the design phase had an impact on the client's original budget. Escalation was found to be a factor since additional time spent on the design process increased the construction building project cost.
- Quality: The quality of design documentation is highly influenced by time. Information supplied for the bidding phase became compromised when the design documentation was not given adequate time to be completed.

## 4 Discussion

### 4.1 Team Dynamics: Social Domain

Hackman (2002) found that personalities or behaviours of individual team members were not essential for teams to thrive. However, this study has indicated that team dynamics among design team members are highly instrumental in the performance of the design management task implemented at the design phase of a design–bid–build project. The dominant team dynamics indicators established were trust, leadership, communication and commitment to project goals. Results suggest that professionalism facilitated trust thus design team members should approach one another in a respectful and professional manner throughout the design process. Furthermore, professionalism also plays a significant role when design team members advance into conflict resolution after personality clashes are encountered.

The study found design teams to function better when they are led by project managers as oppose to architects who remain leadership contenders. Therefore, team members should be agreeable to being led and given guidance by a project manager during the design process. Accordingly, the leader has the obligation to keep the design team motivated and committed to delivering high quality design documentation on time and on budget. During the design phase the leadership role of a project manager should direct the design team to adopting a working style of developing a design that is based on a collaborative effort of teamwork.

### 4.2 Team Dynamics: Technical Domain

Rojas et al. (2019) found that the use of BIM allows quicker and more accurate project cost estimates. This design management tool supports the participation of a quantity surveyor at the early stages of the design. A quantity surveyor is skilled in maintaining the client's original budget by monitoring and value engineering all stages of the design. The study found open communication is a prerequisite to keeping all design team members cognizant of the projects design status. While there are several communication channels available for the design team to use, phone calls, WhatsApp and informal chats are among the popular ones nonetheless emails and meets remain the formal communication platforms for design teams to agree and disagree on matters involving design documentation.

Organizations and the older generation of construction professionals involved in design teams need to adapt to the changing world. Resisting the available technology is contributing to the failure of construction building projects. Project managers should introduce BIM technology to design teams as this tool is capable of managing the design process better if applied correctly. BIM features encourage collaboration, cooperation and coordination of design information which eliminate design information delays. BIM should be explored to reduce time on the design process, monitor the project cost during the design stages and ensure quality information is supplied to produce high quality design documentation for construction.

## 5 Conclusion

The study was able to identify the architect, project manager and quantity surveyor as the key design team member accountable for the design management process. These three disciplines play the principal roles when design teams collaborate in designing, planning and costing of a construction building project. The study suggests that both interpersonal relationships and task orientations are problematic during the implementation of design management. The study found team dynamics to be at a high level during a volatile design management process; hence, design teams experienced a development sequence. The study found a link between the two variables of team dynamics and design management. The social and technical attributes coexist in design teams.

The aim of this research was to establish the effect of team dynamics on design management performance. This research has shown that team dynamics have a significant effect on design management performance. Positive team dynamics increase the level of collaboration, cooperation and coordination. Furthermore, it eases the team management. These factors are prerequisites that enable design teams to perform design management. In the contrary, negative team dynamics can decrease the ability for design teams to perform design management.

Although participants stated that team dynamics did not prevent the continuity of the design management process, negative team dynamics made the design management a challenging task that became labour intensive and time-consuming. Findings suggest that positive team dynamics enhance design management performance by keeping trust levels high, electing appropriate leadership that correlates with the working style and having a communication strategy that will allow for conflict resolutions when design team experience the development sequence.

The study was limited to one research instrument of semi-structured interviews with a population only in South Africa. The participants were predominantly male due to the willingness to participate and the nature of the construction industry. Future research should investigate the effect of team dynamics on design management performance among South African design teams working on public construction building project. Researchers should further investigate the team dynamics on South African design teams using BIM as a design management tool.

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## References

1. Baiden BK, Price ADF, Dainty ARJ (2006) The extent of team integration within construction projects. Int J Project Manage 24(1):13–23
2. Buffinton KW, Jablokow KW, Martin KA (2002) Project team dynamics and cognitive style: EMJ. Eng Manag J 14(3):25–33
3. Bonebright DA (2010) 40 years of storming: a historical review of Tuckman's model of small group development. Hum Resour Dev Int 13(1):111–120
4. Braun V, Clarke V (2006) Using thematic analysis in psychology. Qual Res Psychol 3:77–101
5. Chapman KJ, Meuter M, Toy D, Wright L (2006) Can't we pick our own groups? The influence of group selection method on group dynamics and outcomes. J Manag Educ 30(4):557–569
6. Che Ibrahim CKI, Costello SB, Wilkinson S (2018) Making sense of team integration practice through the "lived experience" of alliance project teams. Eng Constr Archit Manag 25(5):598–622
7. Creswell JW, Creswell JD (2018) Research design: qualitative, quantitative, and mixed methods approaches, 5th edn. SAGE Publications, Thousand Oaks, California
8. Cresswell-Yeager T (2021) Forming, storming, norming, and performing: Using a semester-long problem-based learning project to apply small-group communication principles. Commun Teach 35(2):155–165
9. Eldeeb AS (2022) The Relationship between Competences of Architectural Education and Architect Role for Professional Practice in Egypt, ERJ. Eng Res J 45(2):225–234

10. Gorse CA, Emmitt S (2007) Communication behaviour during management and design team meetings: a comparison of group interaction. Constr Manag Econ 25(11):1197–1213
11. Graue C (2015) Qualitative data analysis. Int J Sales Retail Mark 4(9):5–14
12. Jelodar MB, Yiu TW, Wilkinson S (2015) Distinguishing conflict source from type in association with relationship quality in construction projects. Const Eng Manage (in review)
13. Jin R, Yang T, Piroozfar P, Kang B, Wanatowski D, Hancock CM, Tang L (2018) Project-based pedagogy in interdisciplinary building design adopting BIM. Eng Constr Archit Manag 25(10):1376–1397
14. Leedy PD, Ormrod JE (2015) Practical research: planning and design, 11th edn. Pearson Education, Harlow
15. Lehmann-Willenbrock N, Chiu MM, Lei Z, Kauffeld S (2017) Understanding positivity within dynamic team interactions: a statistical discourse analysis. Group Org Manag 42(1):39–78
16. Lindskold S (1978) Trust development, the GRIT proposal and the effects of conciliatory acts on conflict and cooperation. Psychol Bull 85:772–793
17. Munthali NC (2022) Project management strategies for success: *The case of Zambia*. Doctoral dissertation, Walden University
18. Otter AD, Emmitt S (2008) Design team communication and design task complexity: the preference for dialogues. Architect Eng Des Manage 4(2):121–129
19. Pikas E, Koskela L, Seppänen O (2020) Improving building design processes and design management practices: a case study. Sustainability (Basel, Switzerland) 12(3):911
20. Rezvani A, Barrett R, Khosravi P (2019) Investigating the relationships among team emotional intelligence, trust, conflict and team performance. Team Perform Manage: Int J 25(1/2):120–137
21. Saunders M, Lewis P, Thornhill A (2012) Research methods for business students, 6th edn. FT/Prentice Hall, Harlow
22. Schulz AJ, Israel BA, Lantz P (2003) Instrument for evaluating dimensions of group dynamics within community-based participatory research partnerships. Eval Program Plann 26(3):249–262
23. Terblanche R, Root D, Vosloo R (2021) Actants influencing the successful compilation of economic feasibility studies: the developer's perspective. In: Proceedings of international structural engineering and construction, vol 8, issue 1. ISSN 2644-108X
24. Tuckman BW (1965) Developmental sequence in small groups. Psychol Bull 63(6):384
25. Tzortzopoulos P, Cooper R (2007) Design management from a contractor's perspective: the need for clarity. Architect Eng Des Manage 3(1):17–28
26. Uusitalo P, Lappalainen E, Seppänen O, Pikas E, Peltokorpi A, Menzhinskii N, Piitulainen M (2021) To trust or not to trust: is trust a prerequisite for solving design quality problems? Constr Manag Econ 39(4):279–297
27. Uusitalo P, Seppänen O, Peltokorpi A, Olivieri H (2019) Solving design management problems using lean design management: the role of trust. Eng Constr Archit Manag 26(7):1387–1405
28. Walker ER, Lang DL, Caruso BA, Salas-Hernández L (2020) Role of team dynamics in the learning process: a mixed-methods evaluation of a modified team based learning approach in a behavioral research methods course. Adv Health Sci Educ 25(2):383–399
29. Zhang P, Ng FF (2012) Analysis of knowledge sharing behaviour in construction teams in Hong Kong. Constr Manag Econ 30(7):557–574

# Building Organizational Resilience Capacities and Capabilities in Construction Firms

**Zamageda Zungu and Samuel Laryea**

## 1 Introduction

The construction industry holds a prominent position on a global scale, as it accounts for an average annual contribution of just over a tenth of the gross domestic product of nations globally [57]. Its significant contribution extends beyond economic output, impacting various socioeconomic indicators in diverse countries [4, 8, 13, 18]. Nevertheless, this strong interdependence between the construction industry and the economy renders it highly susceptible to economic fluctuations, making it vulnerable to disturbances [41]. Thus, in the light of recent escalations in the frequency of major disruptive events, including natural disasters, terrorism, economic recessions, mass migration, cyber threats, and epidemics, which have exerted a detrimental influence on the global economy [63, 67], it comes as no surprise that the construction industry stands as one of the sectors profoundly affected by such occurrences. Over the past decade, growing market volatility and the rise in environmental disasters have prompted numerous organizations to reorient their strategic objectives [26]. This shift, from a traditional emphasis on profit-seeking to a concerted pursuit of resilience, has captured the attention of both scholars and practitioners in the field of management.

In order to thrive in unpredictable environments and cultivate long-term success, construction organizations must possess the ability to effectively navigate various manifestations of the unexpected. It is imperative for firms to cultivate a capability and capacity for organizational resilience, enabling them to respond appropriately to unforeseen circumstances and anticipate risks that may pose potential threats to the organization's survival [36]. Consequently, the topic of organizational resilience

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in the contexts of firms has emerged as a focal point of research and practice in this domain.

In recent years, there has been a substantial growth in the body of research dedicated to the exploration of resilience within the realms of business and management [28, 38]. However, despite the growth of scholarly works focusing on resilience in management and business disciplines, there still exists a lack of clarity regarding the specific actions undertaken by resilient organizations and the practical means by which organizational resilience can be attained [9, 19, 21]. Furthermore, there is a notable scarcity in the literature concerning the organizational capabilities and capacities that foster organizational resilience, particularly within the context of construction firms [14, 27]. This study contributes to this knowledge gap by answering the following research question: "*What are the capacities and capabilities required by construction firms to attain organizational resilience when disruptive events occur?*" As part of this research endeavour, a systematic literature review encompassing articles published from 2014 to 2023 is undertaken. This review focused on the examination of firm-level resilience capacities and capabilities, and we conducted a rigorous analysis of 20 selected publications.

This study aims to identify the capabilities and capacities required by construction firms to attain resilience against disruptive events. Although the capability perspective of resilience is not novel, this literature review offers additional value by identifying the capacities and capabilities of organizational resilience that are unique to the construction industry. By articulating the various organizational capabilities and capacities that construction firms require to attain resilience, this study makes a noteworthy and original contribution to the ongoing discourse on resilience within the management literature. This aligns with [47], who highlighted the importance of developing specific capabilities as the basis for improved performance.

The structure of the remainder of this paper is organized as follows. Firstly, an overview of literature on organizational resilience capabilities is presented. Secondly, the research methodology is outlined, which entails a description of our criteria for selecting relevant literature and the protocol employed for data analysis. Subsequently, the primary findings are presented and analyzed. Finally, a conclusion is offered and suggestions for future research directions, aiming to further enhance the comprehension of firm capacities and capabilities.

## 2 Overview of Organizational Resilience Capabilities

Currently, there is limited research on resilience capabilities, so it is essential to explore related areas like crisis management and innovation management, as well as other disciplines such as public administration, to understand the capabilities behind individual resilience stages [19]. To address the capabilities and capacities required for organizational resilience, it is important to define the resilience process. To do this, Duchek [19] and Williams et al. [66] drew upon process-oriented studies that highlight the dynamic interaction between organizations and their environment in resilience. From this perspective, resilience involves effectively responding to adverse events not only after they occur but also before, during, and after [19, 66]. Based on this understanding, the three successive stages of the resilience process are proposed as anticipation, coping, and adaptation [19]. Accordingly, each of these stages is accompanied by capabilities.

Anticipation, as the first stage of organizational resilience, pertains to its preventive aspects in response to potential disturbances [19]. It involves the ability to proactively detect crucial developments within the organization or its environment [60]. Anticipation encompasses three specific capabilities: observing internal and external developments, identifying critical developments and potential threats, and preparing for unexpected events [19]. Observation and identification are closely related and involve recognizing early signals of a crisis to respond quickly and prevent escalation [46]. Preparation, a crucial aspect for high-reliability organizations (HROs) operating in high-risk environments, is also vital for resilient organizations [19]. Being prepared means having the necessary resources and recovery plans in place to deal with unforeseen adversity and capitalize on unexpected opportunities [36]. However, preparation also involves intuitive action and ad hoc decisions, as unexpected events may not align with formal plans [54].

Resilience involves not only anticipating and preparing for critical events but also coping effectively with unexpected dangers once they occur [65]. Coping with the unexpected can be referred to by various terms in the literature, such as dealing with unknown hazards or responding productively to significant change [29]. The ability to cope with the unexpected can be further divided into two sub-categories: the ability to accept a problem and the ability to develop and implement solutions [33]. Accepting the problem requires acknowledging and facing reality, which is crucial during crises [26]. Developing the ability to accept problems helps organizations react quickly and effectively in such situations [19]. This acceptance dimension of organizational resilience involves understanding the environment, defining a reference state, and acknowledging system failures [10]. Developing and implementing solutions during a crisis are a combination of sensemaking and acting [64]. Sensemaking is the continuous process of creating order and understanding from ongoing events, enabling effective action [19]. During crises, organizations rely on both formal and informal coordination mechanisms to ensure prompt decision-making and response. Expertise coordination practices help to manage distributed knowledge, while dialogic coordination practices facilitate time-critical responses to unexpected events [23]. The implementation of solutions is equally important, requiring wide acceptance and adoption across the organization [17].

In addition to anticipation and coping, resilience also involves the ability to adapt to critical situations and use change to advance the organization [37]. Adaptation comprises two main capabilities: reflection and learning, and organizational change capabilities [19]. Reflection and learning involve both cognition and behaviour. Organizations must reflect on crisis situations, gain insights, and incorporate this knowledge into their existing knowledge base [19]. Learning is an ongoing process that guides future behaviour, and it can be facilitated through various practices such as problem-solving meetings, project reviews, and informal discussions. Learning can also be enhanced by studying failures experienced by other organizations, as these experiences can offer valuable lessons and prevent similar problems from recurring [16]. However, generating lessons learned is not enough,organizations must effectively translate this knowledge into new behaviours, which requires diversity in perspectives and deeper discussions [25]. Organizational change, or higher-level learning, is necessary for real change to occur [62]. This involves developing new norms, values, and practices based on higher-level insights and adjustments. Kendra Kendra and Wachtendorf Kendra [34] posit that resilient organizations are willing to challenge and question past experiences to address novel features in current troublesome situations. Change management capabilities are vital for successful organizational resilience [6], as two out of three change initiatives tend to fail [56]. Organizations must be aware of potential resistance to change and apply effective change management practices, such as soft managerial practices and the use of change agents, to overcome resistance and enhance resilience [17].

## 3 Methodology

Integrative and systematic literature reviews play a crucial role in showcasing research endeavours regarding emerging topics [32]. Moreover, these reviews involve the comprehensive analysis and synthesis of existing research, while also identifying the obstacles that require attention in the future studies. To effectively manage the substantial volume of information, a systematic review methodology was employed [49]. This methodology focuses on narrowing down the literature to address specific research question of the study. To ensure unbiased results in the literature review, Tranfield et al.'s [61] systematic review process was adopted for this study. This process involves manual filtering and maintains transparency, enabling reviewers to gain deeper understanding and insights into the topic, rather than relying solely on automated filtering methods [11].

The 20 articles selected for this study are classified and research findings are structured into five key issues. This method has proven to be successful and has been utilized by numerous researchers in the field [5, 15, 32, 55].

The classification system utilized in this study is based on the framework introduced by [24]. This system incorporates six distinct steps as follows:

Step 1: Conduct an extensive search of relevant articles.

Step 2: Develop a classification system using a logical structure code.

Step 3: Apply the classification system to categorize the reviewed papers.

Step 4: Present the primary findings derived from the articles.

Step 5: Perform an analysis of any existing gaps in the research.

Step 6: Put forth suggestions for future research endeavours.

By following this systematic approach, the study ensures a comprehensive and organized analysis of the literature while identifying areas for further investigation.

## *3.1 Search of Relevant Articles*

The initial step involved conducting a thorough search of relevant articles and meticulously selecting those deemed suitable for addressing the research question. Multiple searches for articles pertaining to organizational resilience capabilities and capacities were performed on the Scopus database, selected due to its all-encompassing nature and rigorous methodological criteria for content inclusion [22]. To mitigate potential bias resulting from the ongoing updates in the database, the collection and export of selected publications were carried out within a single day [45]. On 6 June 2023, searches for articles related to organizational resilience capabilities and capacities were conducted by using the following keywords:

> "organizational resilience AND capabilities", "organizational resilience AND capacities", "organizational resilience AND drivers", "organizational resilience AND antecedents", "organizational resilience AND strategies", "organizational resilience AND characteristics".

To retrieve a comprehensive dataset, no limitation was imposed on the period of publication. After removing 732 duplicate articles from the multiple searches, the search yielded a total of 2530 publications from the Scopus database published between 1989 and 2023, covering a period of 34 years. However, the articles relevant to the study only spanned the period between 2014 and 2023, indicating the contemporary focus on resilience within the construction industry. The retrieved publications were subsequently evaluated based on suitable inclusion and exclusion criteria.

### 3.1.1 Inclusion and Exclusion Criteria

To ensure a focused research approach, the retrieved dataset was narrowed down using Centobelli et al.'s [11] three specific criteria for selecting research papers for review. Firstly, the abstracts of the retrieved articles were assessed to determine if they addressed the research topic (Criterion 1). Secondly, the relevance of the content to the research question was evaluated (Criterion 2). Thirdly, the relevant references cited in the literature were examined that were not available in the Scopus database (Criterion 3). This is the protocol that was used for the selection of articles reviewed in this study. The selection process and the flow of articles are illustrated in Fig. 1. Only articles discussing the capacities and capabilities required for organizational resilience in the construction industry were included in the study, while unrelated articles were excluded. No articles cited in the literature review were not retrieved from the Scopus database. Consequently, a total of 20 articles remained for further review.

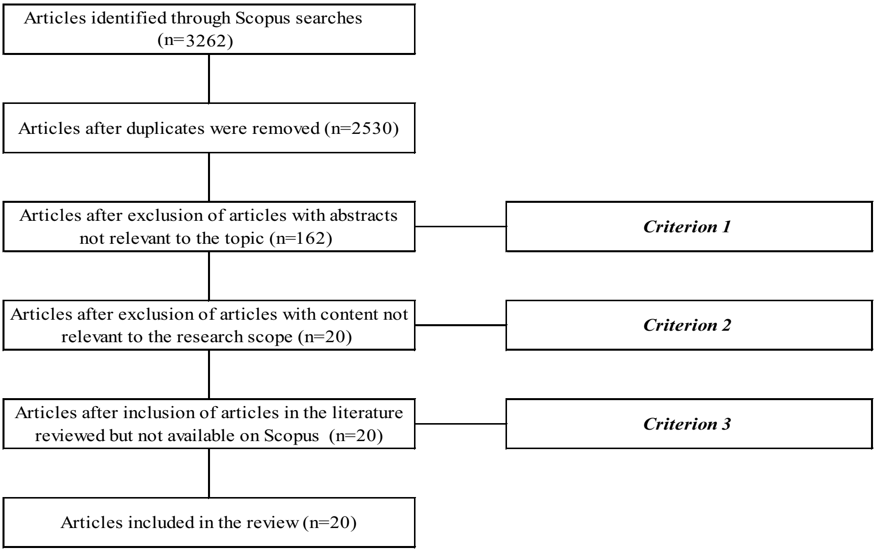


**Fig. 1** Process for selecting sample of articles to be reviewed

## *3.2 Classification of Selected Articles*

Following the selection of articles for the review, a classification framework was developed utilizing number and alphabetic codes to classify the selected articles as illustrated in Table 1. The classification categories consist of the following five elements which were adopted from the works of Amui et al. [5], who conducted a study seeking to systematize the available knowledge on dynamic capabilities for sustainability.

1. National context: The studies were classified on a scale of A to C, based on the works of Jabbour [32], to indicate the specific national context under analysis.
2. Theoretical focus: The coding system, inspired by Lages Junior and Godinho Filho [35], utilized Codes A to D to differentiate between research that focused on dynamic capabilities theory, resource-based view theory, knowledge-based view theory, and research that did not have a theoretical focus.
3. Research methodology: The methodological approach employed in each study was coded on a scale of A to G, drawing from and adapting the work of Lages Junior and Godinho Filho [35].
4. Result areas: The areas of measurement for organizational resilience in the research were coded on a scale of A to B.
5. Capabilities and Capacities: The capabilities and capacities highlighted in the selected articles were coded on a scale of A to N. The basis for the categorization of capabilities and capacities was the research question of the study.

**Table 1** Literature classification framework and coding

| Number | Elements of classification | | Code |
|---|---|---|---|
| 1 | National context | Developed country | 1A |
| | | Developing countries | 1B |
| | | Not applicable | 1C |
| 2 | Theoretical focus | Dynamic capabilities | 2A |
| | | Resource-based view | 2B |
| | | Knowledge-based view | 2C |
| | | Not applicable | 2D |
| 3 | Research methodology | Qualitative | 3A |
| | | Quantitative | 3B |
| | | Mixed-methodology | 3C |
| | | Empirical | 3D |
| | | Theoretical | 3E |
| 4 | Results' area | Organizational resilience | 4A |
| | | Organizational performance | 4B |
| 5 | Capabilities and capacities | Anticipation/sensing | 5A |
| | | Coping/ceasing | 5B |
| | | Adaptation | 5C |
| | | Learning and knowledge management | 5D |
| | | Human resource management | 5E |
| | | Flexibility/agility/transformability | 5F |
| | | Product innovativeness/digital technology | 5G |
| | | Organizational creativeness | 5H |
| | | Leadership and management | 5I |
| | | Project planning | 5J |
| | | Absorptive capacity/redundancy | 5K |
| | | Restorative capacity | 5L |
| | | Corporate social responsibility | 5M |
| | | Financial resource management | 5N |

## 4 Presentation and Analysis of Results

Following the methodology described, 20 articles were selected for classification and coding, as depicted in Tables 2 and 3.

**Table 2** Articles selected for the literature review

| Authors | Title | Journal |
|---|---|---|
| Abdullah et al. [1] | Resilient organization: Modelling the capacity for resilience | International Conference on Research and Innovation in Information Systems, ICRIIS |
| Akgun and Keskin [3] | Organizational resilience capacity and firm product innovativeness and performance | International Journal of Production Research |
| Richtner and Lofsten [50] | Managing in turbulence: How the capacity for resilience influences creativity | R&D Management |
| Duchek [20] | Growth in the face of crisis: the role of organizational resilience capabilities | Academy of Management |
| Sapeciay et al. [52] | Building organizational resilience for the construction industry: New Zealand practitioners' perspective | International Journal of Disaster Resilience in the Built Environment |
| Pascua and Chang-Richards [48] | Investigating the resilience of civil infrastructure firms in New Zealand | Procedia Engineering |
| Sapeciay et al. [53] | Building Organizational Resilience for the Construction Industry: Strategic Resilience Indicators | Earth and Environmental Science |
| He et al. [27] | Resilience for construction project-based organizations: Definition, critical factors and improvement strategies | Proceedings of 22nd International Conference on Advancement of Construction Management and Real Estate, CRIOCM 2017 |
| Baublys [7] | Resilience capacity development: Prerequisites for proactive organizational transformation | Proceedings of the 16th European Conference on Management Leadership and Governance, ECMLG 2020 |
| Rodríguez-Sánchez et al. [51] | How to emerge stronger: Antecedents and consequences of organizational resilience | Journal of Management and Organization |
| Acciarini et al. [2] | Resilient companies in the time of Covid-19 pandemic: a case study approach | Journal of Entrepreneurship and Public Policy |
| Chih et al. [13] | Resilience of Organizations in the Construction Industry in the Face of COVID-19 Disturbances: Dynamic Capabilities Perspective | Journal of Management in Engineering |
| Ma and Lui [39] | Multiple paths to enhancing the resilience of project-based organizations from the perspective of CSR configuration: evidence from the Chinese construction industry | Engineering, Construction and Architectural Management |

(continued)

**Table 2** (continued)

| Authors | Title | Journal |
|---|---|---|
| Matysek-Jędrych et al. [43] | Beyond the COVID-19 pandemic: what builds organizational resilience capacity? | International Journal of Emerging Markets |
| Malik et al. [41] | Resilient Capabilities to Tackle Supply Chain Risks: Managing Integration Complexities in Construction Projects | Buildings |
| Nay Chi and Sirisuhk [44] | Integrative Review of Absorptive Capacity's Role in Fostering Organizational Resilience and Research Agenda | Sustainability |
| Hu et al. [30] | Effective Crisis Management during Adversity: Organizing Resilience Capabilities of Firms and Sustainable Performance during COVID-19 | Sustainability |
| Zheng et al. [68] | Knowledge Management Capability, Organizational Resilience, and the Growth of SMEs | International Journal of Distributed Systems and Technologies (IJDST) |
| Su and Junge [58] | Unlocking the recipe for organizational resilience: A review and future research directions | European Management Journal |
| Madani and Parast [40] | An integrated approach to organizational resilience: a quality perspective | International Journal of Quality and Reliability Management |

## *4.1 National Context*

The systematic literature reviews conducted by Mariano et al. [42] and Jabbour [32] emphasize the importance of considering the national context when analyzing research within a literature review. Figure 2 displays the distribution of national contexts across the selected articles. It is noteworthy that a significant proportion (55%) of the studies reviewed were theoretical papers, and as such, did not incorporate any specific national context due to their nature. On the other hand, empirical studies have accounted for the remaining cases, and their national contexts were taken into account. Among these empirical studies, 35% focused on developed countries, while 10% cantered on developing countries.

Regarding the national context, there is a research opportunity for investigations on developing countries, as they represent only 10% of the published articles.

## *4.2 Theoretical Focus*

The analysis of the data presented in Fig. 3 reveals interesting patterns regarding the consideration of theoretical frameworks in organizational resilience studies. Among

**Table 3** Codification of articles selected for the literature review

| Authors | National context | Theoretical focus | Research methodology | Results area | Capabilities and capacities |
|---|---|---|---|---|---|
| Abdullah et al. [1] | 1C | 2D | 3E | 4A | 5F |
| Akgun and Keskin [3] | 1A | 2B | 3B, 3D | 4B | 5A, 5G |
| Richtner and Lofsten [50] | 1A | 2B | 3C, 3D | 4A | 5H |
| Duchek [20] | 1C | 2A | 3E | 4A | 5A, 5B, 5C |
| [52] | 1A | 2D | 3C, 3D | 4C | 5A |
| Pascua and Chang-Richards [48] | 1A | 2D | 3C, 3D | 4C | 5B, 5I |
| Sapeciay et al. [53] | 1A | 2D | 3C, 3D | 4C | 5C, 5D, 5I |
| He et al. [27] | 1C | 2D | 3A, 3D | 4A | 5A, 5J, 5K, 5L |
| Baublys [7] | 1C | 2D | 3E | 4A | 5F |
| Rodríguez-Sánchez et al. [51] | 1A | 2D | 3B, 3D | 4B | 5E |
| Acciarini et al. [2] | 1A | 2D | 3B, 3D | 4A | 5G |
| Chih et al. [13] | 1C | 2A | 3C, 3D | 4A | 5A, 5B, 5C |
| Ma and Lui [39] | 1B | 2D | 3A, 3D | 4A | 5M |
| Matysek-Jędrych et al. [43] | 1C | 2D | 3C, 3D | 4A | 5N, 5E, 5G, 5K |
| Malik et al. [41] | 1C | 2D | 3C, 3D | 4A | 5D, 5A, 5F |
| Nay Chi and Sirisuhk [44] | 1C | 2A, 2C | 3E | 4A | 5D, 5A, 5F, 5E, 5I, 5B, 5C |
| Hu et al. [30] | 1B | 2A | 3E | 4B | 5N, 5D |
| Zheng et al. [68] | 1C | 2D | 3E | 4A | 5D |
| Su and Junge [58] | 1C | 2D | 3E | 4A | 5A, 5B, 5C, 5D |
| Madani and Parast [40] | 1C | 2B | 3E | 4A | 5C, 5L, 5K, 5A, |

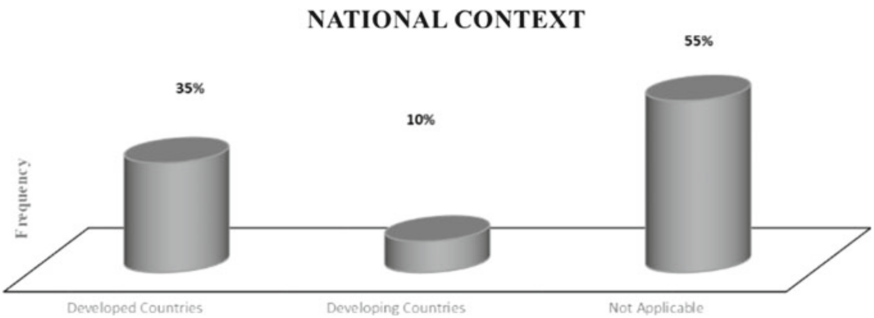


**Fig. 2** Distribution of the national contexts in the selected articles

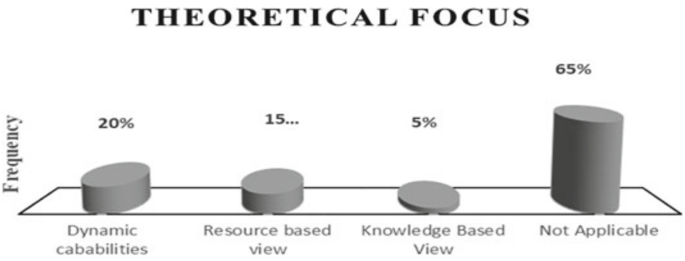


**Fig. 3** Distribution of the theoretical focus in the selected articles

the examined studies, 65% did not incorporate any specific theoretical framework, indicating a significant proportion of research lacking a structured theoretical foundation. This finding raises concerns about the depth and robustness of the insights gained from these studies, as the absence of a theoretical framework may lead to limited understanding and potential gaps in the analysis. On the other hand, 20% of the studies applied the dynamic capabilities theory, demonstrating its popularity as a guiding framework in the examination of organizational resilience capacities. Dynamic capabilities' theory focuses on an organization's ability to adapt, integrate, and reconfigure its resources and capabilities to respond to dynamic environments effectively [59]. Its incorporation in these studies suggests a recognition of the importance of adaptability and flexibility in enhancing resilience. The resource-based view was utilized in 15% of the studies, emphasizing the role of unique and valuable resources as a source of competitive advantage and resilience. This theoretical perspective highlights the significance of resource allocation and utilization for building resilience and sustainability in organizations [28]. The knowledge-based view was employed in only 5% of the studies. This suggests a relatively lesser emphasis on the role of knowledge and organizational learning in fostering resilience, despite its recognized importance in helping organizations anticipate and cope with unexpected events [19].

Overall, the data underscore the need for a more comprehensive and systematic integration of theoretical frameworks in organizational resilience research. By adopting a theoretical lens, scholars can gain deeper insights into the mechanisms and factors that contribute to resilience-building processes, ultimately enhancing the practical implications of their findings for organizations striving to withstand and thrive amidst challenges.

## *4.3 Research Methodology*

The results of the literature review presented in Fig. 3 reveal interesting trends in research methodologies and the nature of studies within the selected literature corpus. Notably, mixed-methodology studies constitute the majority, with a significant 40% share, indicating a growing trend towards integrating both qualitative and quantitative

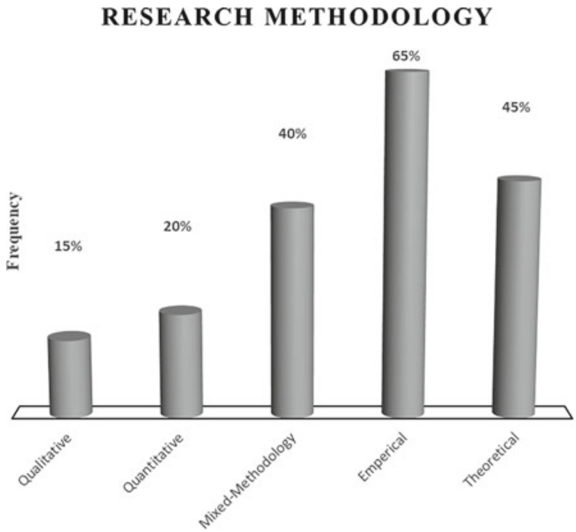


**Fig. 4** Distribution of the research methodology in the selected articles

approaches in research. This suggests a recognition among researchers of the need to capture a more comprehensive understanding of complex phenomena by drawing from multiple data sources and analysis methods.

Empirical research, accounting for 65%, dominates the literature, reflecting a strong emphasis on practical investigation and data-driven inquiry within the field. The prominence of empirical research suggests a commitment to producing evidence-based knowledge that can inform practice and policy. However, theoretical studies, though comprising a slightly smaller share at 45%, still play a substantial role in contributing to theoretical frameworks and conceptual developments within the field. This balanced mix of research methodologies and the strong presence of empirical research collectively demonstrate a robust and multifaceted approach to advancing knowledge in the subject area (Fig. 4).

Overall, this analysis provides valuable insights into the methodological diversity within the literature, emphasizing the prevalence of qualitative and theoretical approaches, as well as the relatively lower utilization of case studies and surveys. Researchers can draw from these findings to inform their own methodological choices when conducting future studies in this domain.

## *4.4 Results' Area*

The analysis of the literature review on the area of measurement of outcomes of organizational resilience presented in Fig. 5 yields significant findings. It is evident that a substantial majority, comprising 85% of the reviewed studies, emphasizes "Organizational Resilience" as the primary area of measurement. This strong focus on

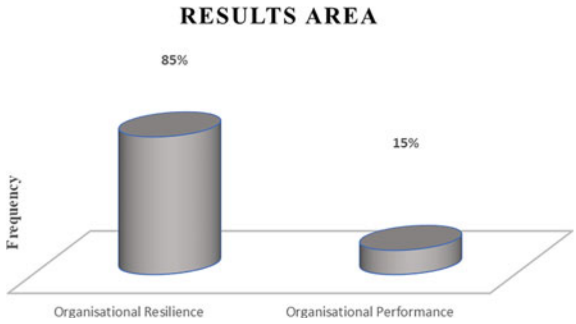


**Fig. 5** Distribution of the results area in the selected articles

resilience underscores the growing recognition of its importance in enabling organizations to withstand and adapt to various challenges, uncertainties, and disruptions. Conversely, the area of "Organizational Performance" represents a relatively smaller proportion of the literature, accounting for only 15% of the studies. This suggests that while organizational performance is still a relevant and essential aspect, it is not as extensively explored as resilience in the context of the reviewed research.

This analysis highlights the critical role of organizational resilience as a dominant area of measurement and reflects the growing significance of understanding and enhancing an organization's capacity to endure and adapt in a constantly changing landscape. Policymakers, leaders, and practitioners can benefit from these insights by prioritizing resilience-building strategies and integrating resilience considerations into their organizational practices and decision-making processes to achieve long-term success and viability.

## *4.5 Organizational Resilience Capabilities and Capacities*

The analysis of capacities and capabilities required by construction firms to be resilient, based on the literature review, reveals a diverse and multifaceted landscape. The most frequently mentioned capacity is "Anticipation/Sensing", appearing in 50% of the reviewed studies. This underscores the significance of construction firms' ability to foresee potential challenges, market trends, and disruptions, enabling them to proactively prepare and respond effectively. Following closely is "Adaptation" and "Learning and Knowledge Management", each with a frequency of 35%. These capacities highlight the importance of construction firms continuously evolving, acquiring new knowledge, and effectively applying it to improve their practices in response to changing circumstances. "Coping/Ceasing" and "Flexibility/Agility/Transformability" were mentioned in 30% and 25% of the studies, respectively. These capacities emphasize construction firms' ability to cope with immediate crises and their flexibility to adjust their operations and strategies in the face of uncertainties. The "Human Resource Management" capacity was identified in 20% of the studies, indicating the critical role of a skilled and engaged workforce

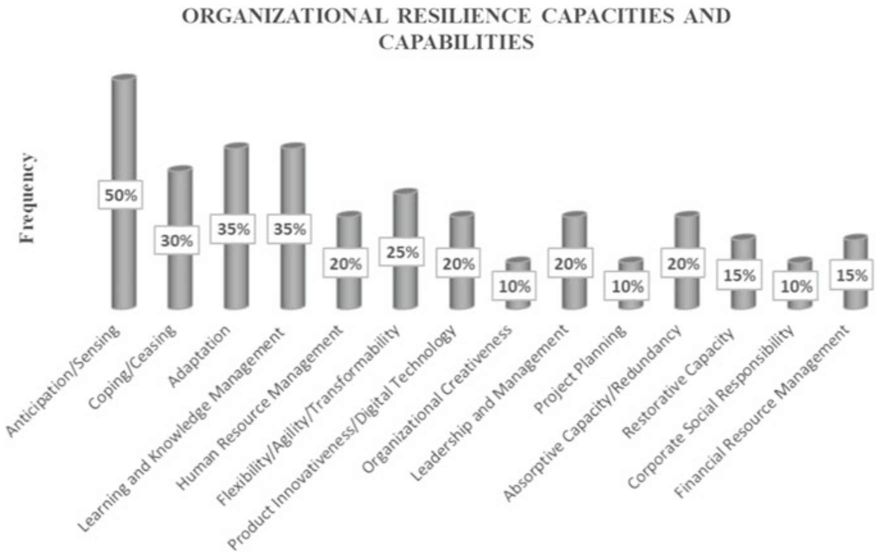


**Fig. 6** Capabilities and capacities of organizational resilience

in building resilience within construction firms. "Leadership and Management", "Absorptive Capacity/Redundancy", and "Financial Resource Management" were each mentioned in 20% of the literature. These capacities highlight the importance of strong leadership, resource management, and the ability to absorb shocks and redundancies to enhance resilience. Other capacities, such as "Product Innovativeness/Digital Technology", "Restorative Capacity", "Corporate Social Responsibility", "Organizational Creativeness", and "Project Planning", appeared with lower frequencies ranging from 10 to 15% (Fig. 6).

Overall, the analysis demonstrates that a wide array of capacities and capabilities contributes to construction firms' resilience. It is clear that a combination of anticipation, adaptation, learning, and flexibility, supported by effective human resource management and leadership, plays a crucial role in fostering resilience in this industry. Construction firms can leverage these insights to prioritize and enhance their resilience-building strategies, enabling them to thrive and endure in a dynamic and challenging business environment.

## 5 Conclusions

In conclusion, this paper systematically examined the capabilities and capacities of construction firms that contribute to organizational resilience. Through classification and coding of selected studies, a comprehensive research agenda with five key issues was developed, highlighting the need for further empirical research in this domain.

The capabilities and capacities contributing to the organizational resilience of construction firms identified in the results of this study correspond to those identified in previous studies undertaken in other industries. Furthermore, the capabilities identified can also be categorized into the three resilience stages which are anticipating, coping, and adaptation.

This study significantly contributes to the literature on construction firm capabilities and capacities required for resilience. By identifying the attributes necessary for enhancing resilience, it provides a solid foundation for future empirical studies aimed at bolstering organizational resilience in the construction industry.

Future research could focus on identifying specific practices employed by construction firms to enact organizational resilience capabilities and capacities. Additionally, organizing the literature based on dimensions such as business strategy, supply chain management, drivers, barriers, and stakeholder roles presents an excellent avenue for further investigation in the development of organizational resilience within construction firms.

**Author Contributions** Zamageda Zungu contributes to conceptualization, methodology, data collection and analysis, draft preparation, manuscript editing, and visualization.

Samuel Laryea contributes to the conceptualization and supervision of the project.

All authors have read and agreed with the manuscript before its submission and publication.

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## References

1. Abdullah N, Noor N, Ibrahim E (2014) Resilient organization: modelling the capacity for resilience. In: International conference on research and innovation in information systems, ICRIIS
2. Acciarini C, Boccardelli P, Vitale M (2021) Resilient companies in the time of Covid-19 pandemic: a case study approach. J Entrepreneur Public Policy 10(3):336–351
3. Akgun A, Keskin H (2014) Organizational resilience capacity and firm product innovativeness and performance. Int J Prod Res 52:6918–6937
4. Alaloul W, Musarat M, Rabbani M, Iqbal Q, Maqsoom A, Farooq W (2021) Construction sector contribution to economic stability: Malaysian GDP distribution. Sustainability 13:5012
5. Amui L, Jabbour C, de Sousa Jabbour A, Kannan D (2017) Sustainability as a dynamic organizational capability: a systematic review and a future agenda toward a sustainable transition. J Clean Prod 142(1):308–322
6. Ates A, Bititci U (2011) Change process: a key enabler for building resilient SMEs. Int J Prod Res 49(18):5601–5618
7. Baublys, G. (2020). Resilience capacity development: Prerequisites for proactive organizational transformation. Proceedings of the 16th European Conference on Management Leadership and Governance, ECMLG 2020.
8. Biörck J, Blanco J, Mischke M, Ribeirinho J, Rockhill D, Sjödin E, Strube G (2020) How construction can emerge stronger after coronavirus. McKinsey & Company, Atlanta
9. Boin A, van Eeten M (2013) The resilient organization—A critical appraisal. Public Manag Rev 15:429–445

10. Catalan C, Robert B (2011) Evaluation of organizational resilience: application in Quebec. Centre Risque & Performance, École Polytechnique de Montréal, Montréal.
11. Centobelli P, Cerchione R, Esposito E (2017) Environmental sustainability in the service industry of transportation and logistics service providers: systematic literature review and research directions. Transp Res Part D: Transp Environ 53:454–470
12. Centobelli P, Cerchione R, Esposito E (2017) Knowledge management in startups: systematic literature review and future research agenda. Sustainability 9(3):361
13. Chih Y, Hsiao C, Zolghadr A, Naderpajouh N (2022) Resilience of Organizations in the construction industry in the face of COVID-19 disturbances: dynamic capabilities perspective. J Manag Eng 38(2):04022002
14. Conz E, Magnani G (2020) A dynamic perspective on the resilience of firms: a systematic literature review and a framework for future research. Eur Manag J 38(3):400–412
15. Costa L, Godinho Filho M (2016) Lean healthcare: review, classification and analysis of literature. J Prod Plann Control 27(10):823–836
16. Daudelin M (1997) Learning from experience through reflection. Organ Dyn 24:36–48
17. Dayton B (2004) Managing crises in the twenty-first century. Int Stud Rev 6:165–194
18. Ditebe K, Aigbavboa C, Oke A, Muyambu M (2018) Factors influencing the performance of the South African construction industry: a case of Limpopo Province. In: Proceedings of the international conference on industrial engineering and operations management, Pretoria
19. Duchek S (2020) Organizational resilience: a capability-based conceptualisation. Bus Res 13:215–246
20. Duchek S (2014). Growth in the face of crisis: the role of organizational resilience capabilities. In: 74th Annual meeting of the academy of management
21. Duit A (2016) Resilience thinking: lessons for public administration. Public Admin 94:364–380
22. Díaz-García C, González-Moreno Á, Sáez-Martínez F (2017) Eco-innovation: insights from a literature review. Innov Organ Manage 17(1):6–23
23. Faraj S, Xiao Y (2000) Coordinating expertise in software development teams. Manage Sci 46:1554–1568
24. Godinho Filho M, Veloso Saes E (2013) From time-based competition (TBC) to quick response manufacturing (QRM): the evolution of research aimed at lead time reduction. J Adv Manuf Technol 64:1177–1191
25. Gressgard L, Hansen K (2015) Knowledge exchange and learning from failures in distributed environments: the role of contractor relationship management and work characteristics. Reliab Eng Syst 133:167–175
26. Hamel G, Välikangas L (2003) The quest for resilience. Harv Bus Rev 81(9):56–65
27. He Q, Zheng M, Wang T (2019) Resilience for construction project-based organizations: definition, critical factors and improvement strategies. In: Proceedings of 22nd international conference on advancement of construction management and real estate, CRIOCM 2017
28. Hillmann J, Guenther E (2021) Organizational resilience: a valuable construct for management research? Int J Manag Rev 23:7–44
29. Horne J, Orr J (1998) Assessing behaviours that create resilient organisations. Employ Relat Today 24:29–39
30. Hu C, Yun K, Su Z, Xi C (2022) Effective crisis management during adversity: organizing resilience capabilities of firms and sustainable performance during COVID-19. Sustainability 14(20):13664
31. Huisingh D (2012) Call for comprehensive/integrative review articles. J Clean Prod 1–2
32. Jabbour C (2013) Environmental training in organisations: from a literature review to a framework for future research. Resour Conserv Recycl 74:144–155
33. Jacques T (2007) Issue management and crisis management: An integrated, non-linear, relational constructs. Public Relations Review 33:147–157
34. Kendra J, Wachtendorf T (2003) Elements of resilience after the world trade center disaster: reconstituting New York City's Emergency Operations Center. Disasters 27:7–53
35. Lages Junior M, Godinho Filho M (2012) Production planning and control for remanufacturing: literature review and analysis. Production Planning and Control 23(6):419–435

36. Lengnick-Hall C, Beck T, Lengnik-Hall M (2011) Developing a capacity for organizational resilience through strategic human resource management. Hum Resour Manag Rev 21:243–255
37. Limnios E, Mazzarol T, Ghadouani A, Schilizzi S (2014) The resilience architechture framework: four organizational architypes. Eur Manag J 32(1):104–116
38. Linnenluecke M (2017) Resilience in business and management research: a review of influential publications and a research agenda. Int J Manag Rev 19:4–30
39. Ma T, Lui Y (2022) Multiple paths to enhancing the resilience of project-based organizations from the perspective of CSR configuration: evidence from the Chinese construction industry. Engineering, Construction and Architectural Management
40. Madani F, Parast M (2023) An integrated approach to organizational resilience: a quality perspective. Int J Qual Reliab Manage 40(1):192–225
41. Malik A, Khan K, Qayyum S, Ullah F, Maqsoom A (2022) Resilient capabilities to tackle supply chain risks: managing integration complexities in construction projects. Buildings 12(9):1322
42. Mariano E, Sobreiro V, do Nascimento Rebelatto D (2015) Human development and data envelopment analysis. A structured literature review. Omega 54:33–49
43. Matysek-Jędrych A, Mroczek-Dąbrowska M, Kania A (2022) Beyond the COVID-19 pandemic: what builds organizational resilience capacity? Int J Emerging Markets
44. Nay Chi K, Sirisuhk R (2022) Integrative review of absorptive capacity's role in fostering organizational resilience and research agenda. Sustainability 14(9):12570
45. Okoro C, Owojori O, Umeokafor N (2022) The developmental trajectory of a decade of research on mental health and well-being amongst graduate students: a bibliometric analysis. Int J Environ Res Public Health 19:4929
46. Ortiz-de-Mandojana N, Bansal P (2016) The long-term benefits of organizational resilience through sustainable business practices. Strateg Manag J 37:1615–1631
47. Parnell J (2011) Article information: strategic capabilities, competitive strategyand performance among retailers in Argentina, Peru and the United States. Manage Decis 49(1):139–155
48. Pascua M, Chang-Richards A (2018) Investigating the resilience of civil infrastructure firms in New Zealand. Procedia Eng 212:286–293
49. Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M, Britten N (2006) Narrative synthesis in systematic reviews: a product from the ESRC methods programme. Lancaster University
50. Richtner A, Lofsten H (2014) Managing turbulence: how the capacity for resilience influences creativity. R&D Manage 44:137–151
51. Rodríguez-Sánchez A, Guinot J, Chiva R, López-Cabrales A (2019) How to emerge stronger: antecedents and consequences of organizational resilience. J Manag Organ 27(3):442–459
52. Sapeciay Z, Wilkinson S, Costello S (2017) Building organizational resilience for the construction industry: New Zealand practitioners' perspective. Int J Disaster Resil Built Environ 8(1):98–108
53. Sapeciay Z, Wilkinson S, Costello S, Adnan H (2019) Building organizational resilience for the construction industry: strategic resilience indicators. Earth Environ Sci 385:012068
54. Seville E, Brunsdon D, Dantas A, Le Masurier J, Wilkinson S, Vargo J (2008) Organizational resilience: researching the reality of New Zealand organisations. J Bus Contin Emer Plan 2:258–266
55. Silva W, Kimura H, Sobreiro V (2017) An analysis of the literature on systemic financial risk: a survey. J Financ Stab 28:91–114
56. Sirkinn H, Keenan P, Jackson A (2005) The hard side of change management. Harv Bus Rev 83:109–118
57. Statista (2023) Statista. Retrieved from www.statista.com, https://www.statista.com/statistics/1290105/global-contsruction-market-size-with-forecasts/
58. Su W, Junge S (2023) Unlocking the recipe for organizational resilience: a review and future research directions. Eur Manage J
59. Teece D, Pisano G, Shuen A (1997) Dynamic capabilities and strategic management. Strateg Manage J 18(7):509–533

60. Teixeira E, Werther W (2013) Resilience: continuous renewal of competitive advantages. Bus Horiszons 56:333–342
61. Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br J Manag 14(3):207–202
62. Visser M (2001) Deutero-learning in organizations: a review and a reformulation. Acad Manage 32:659–667
63. Wang L, Yang X, Zhu F, Klakegg O (2023) How the governance of interorganizational projects develops resilience: mediating role of resource reconfiguration. J Manag Eng 39(2):04022076
64. Weick K (1993) The collapse of sensemaking in organizations: the Mann Gulch disaster. Adm Sci Q 38:628–652
65. Wildavsky A (1991) Searching for safety. Transaction, New Brunswick
66. Williams T, Gruber D, Sutcliffe K, Shepherd D, Zhao E (2017) Organsiational response to adversity: fusing crisis management and and resilience research streams. Acad Manag Ann 11(2):733–769
67. World Bank (2023) Global economic prospects. The World Bank Group, Washington
68. Zheng S, Shen Y, Lui L (2022) Knowledge management capability, organizational resilience, and the growth of SMEs. Int J Distrib Syst Technol (IJDST) 13(4):15

# Communication Strategies and Construction Projects' Outcomes in Nigeria

**Olatunji Joseph Oladiran, Bashir Ibrahim, and Ahmed Mohammed Waziri**

## 1 Introduction

Communication is key in all aspects of life including construction projects. Daniyan [6] asserts that construction projects by its nature require timely and sufficient communication to foster active collaboration and participation of all project participants. Several factors can be attributed to the significance of good communication in the performance or success of construction projects. Some of these factors include the fragmented nature, complexity, huge resources, size and capital intensity of construction projects. Construction projects' performance indicators include three key components, time, quality and cost [5, 10]. All these require effective communication throughout project life cycle to attain.

Boone [4] opines that engagement, information and connection form the three main duties of communication, and connection is done in several ways. Application of collective ideas must be embraced by all involved in effective engagement [4]. Oil and Gas projects function on communication and over 50% of the difficulties in Oil and Gas projects stem from poor communication [12]. In this regard, Kotler [9] posits that receiver and sender are two of the nine segments of the process of communication. Information are passed out in encrypted form through media to receivers in plain form for the receivers to comprehend the message, and replies are given by receivers to the messages. Kotler [9] reveals major determinants of good communication. Senders need to understand their listeners and encrypt the messages properly both in project management and any other profession. Väänänen

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[16] opines that receivers' change of knowledge and perspectives are the expected outcomes of good communication process. However, one-way communications are equally employed in organizations just for the purpose of informing people about their firms, services, goods, products and so on, though this method still require some forms of engagements [4]. Feedback is the best test of communication style in project management.

Moreover, communication can be viewed in three ways [17]. First is internal communication within a firm or person to many receivers. Second is organizational communication and thirdly, public relations. Organizational communication interplays within a firm, whereas public relation entails internal and external public linkage. The senders are saddled with passing correct messages, while the receivers understand and revert appropriately. According to Super-[13], communication has many dimensions: unspoken and verbal, hearing and talking, interior (within the project) and external (outside the project); official (reports, briefings) and unofficial (letters and conversation) and upward (above and below) and even (with mates).

Furthermore, there are three communication routes: face communication; printed media in paper formats and electronic media via gadgets such as email, databases or groupware, which can be easily stored [16]. The scenario in face communication differs from emails which is less engaging [17]. The best-fitted channels for project-oriented firms are electronic due to precision, updating and synchronization. One pertinent feature of project management communication is common language, because project management could sometimes entail lots of technology-related communication and networks [8], though one best communication in inexistent [17]. Corporate communication is key in achieving company goals and production because it unifies the personnel. A lot of things are involved in the success of corporate communication which must all be factored in the choice of communication types and channels [17].

Additionally, Ndihokubwayo [10] posit that critical to project performance is availability of timely and detailed information, circulated and disseminated among project participants constantly. However, it has been opined that the effectiveness of communication is hinged hugely on the strategies employed. Henderson [7] defined communication strategy as the approach, technique, mode and method by which information are spread among project team to prevent ambiguities and errors. Information in the form of scope, designs, drawings, specifications, materials, construction methods and more must be clearly and discretely communicated every point in time for intended purpose to be achieved in projects. Communication strategy therefore forms the measures and approaches through which vital information are communicated to project partners all through implementation phase tailored towards successful delivery. This study aimed at investigating implementation of communication strategies with a view to improve construction outcomes. The specific objectives are to examine the application of communication strategies and to establish the impact of such strategies on projects' outcomes. The significance of the study lies in improvement of construction projects outcomes through the adoption of appropriate communication strategies.

## 2 Research Method

Survey research design approach was considered suitable to carry out this study. The population of the study is construction professionals in construction companies in Lagos State. A sample of 150 was selected using convenience sampling technique. The sample size was considered adequate as stipulated by the rule of thumb, which suggests that sample size which is more than 30 and less than 500 is appropriate for researches. Questionnaires were used to elicit data on demographic information, frequency of use of communication strategies (from 1 to 5) and significant impact of the strategies on the outcomes of projects (from 1 to 5). Descriptive statistics were used to analyze the data.

## 3 Findings and Discussions

### *3.1 Demographic Information*

As many as 34% of organizations' ownership were fully indigenous, 57.9% were fully foreign and 7.9% were partly indigenous and foreign; 19.7% were between 1 and 5 years in the industry, 23% were 6–10 years, 14.8% were 11–15 years and 21.3% each were 16–20 years and above 20 years; 1.3% had annual turnover of less than 5 million Naira, 3.9% had 6–20 million Naira (Nigerian currency), 10.5% had 21–50 million Naira, 14.5% had 51–100 million Naira, 10.5% had 101–250 million Naira and 59.2% had above 250 million Naira. Moreover, 37% of the respondents have 1–5 years' experience, 16% have 6–10 years, 32% have 11–15 years, 10% have 16–20 years and 5% have above 20 years.

### *3.2 Application of Communication Strategies (CS) in Construction Projects*

The frequency of application of 39 communication strategies from previous studies was examined. The strategies are categorized to written and verbal, with the mean scores presented in Table 1.

**Written Communication** The most frequently used in this category is electronic media (i.e. email, websites, etc.) and report. Information regarding projects are therefore commonly channelled via electronic media and reports. Stakeholders in construction projects therefore could be said to consistently communicate by sending emails, accessing websites to draw vital and relevant information and providing details on the progress of projects and other aspects that inform on successful delivery. This outcome portrays that communication among the stakeholders is often time

**Table 1** Application of CS in projects

| Communication strategies | N | 1 | 2 | 3 | 4 | 5 | TS | StD | MS | RK |
|---|---|---|---|---|---|---|---|---|---|---|
| *Written communication* | | | | | | | | | | |
| Electronic media | 76 | 1 | 2 | 10 | 27 | 36 | 323 | 0.881 | 4.25 | 1 |
| Report | 76 | 3 | 4 | 13 | 23 | 33 | 307 | 1.089 | 4.04 | 2 |
| Project plan | 76 | 1 | 8 | 15 | 25 | 27 | 297 | 1.048 | 3.91 | 3 |
| Schedules | 76 | 1 | 5 | 20 | 26 | 24 | 295 | 0.979 | 3.88 | 4 |
| Notice board | 76 | 5 | 5 | 17 | 22 | 27 | 289 | 1.189 | 3.8 | 5 |
| Memo | 76 | 3 | 3 | 23 | 25 | 22 | 288 | 1.037 | 3.79 | 6 |
| Drawings | 76 | 1 | 5 | 26 | 21 | 23 | 288 | 0.998 | 3.79 | 6 |
| Site photographs | 76 | 2 | 7 | 22 | 22 | 23 | 285 | 1.072 | 3.75 | 8 |
| Manuals | 76 | 2 | 6 | 19 | 31 | 18 | 285 | 0.995 | 3.75 | 8 |
| Contract | 76 | 3 | 7 | 30 | 15 | 21 | 272 | 1.111 | 3.58 | 10 |
| Notes | 76 | 5 | 9 | 29 | 11 | 22 | 264 | 1.216 | 3.47 | 11 |
| Minutes | 76 | 3 | 8 | 29 | 23 | 13 | 263 | 1.026 | 3.46 | 12 |
| Phone chat | 76 | 8 | 11 | 25 | 13 | 19 | 252 | 1.288 | 3.32 | 13 |
| Text messages | 76 | 8 | 12 | 24 | 15 | 17 | 249 | 1.271 | 3.28 | 14 |
| Social media tools | 76 | 10 | 12 | 26 | 14 | 14 | 238 | 1.269 | 3.13 | 15 |
| *Verbal communication* | | | | | | | | | | |
| Phone calls | 76 | 1 | 7 | 15 | 14 | 39 | 311 | 1.098 | 4.09 | 1 |
| Formal verbal presentation | 76 | 1 | 3 | 17 | 30 | 25 | 303 | 0.916 | 3.99 | 2 |
| Face-to-face meetings with key stakeholders | 76 | 4 | 5 | 18 | 23 | 26 | 290 | 1.14 | 3.82 | 3 |
| Pictorial interpretations and illustrations | 76 | 2 | 11 | 27 | 21 | 15 | 264 | 1.052 | 3.47 | 4 |
| Posters | 76 | 4 | 12 | 18 | 22 | 20 | 270 | 1.193 | 3.55 | 5 |
| Physical distance | 76 | 3 | 9 | 27 | 25 | 12 | 262 | 1.025 | 3.45 | 6 |
| Webpages | 76 | 7 | 12 | 20 | 18 | 19 | 258 | 1.276 | 3.39 | 7 |
| Symbols | 76 | 7 | 15 | 15 | 20 | 19 | 257 | 1.306 | 3.38 | 8 |
| Social gathering | 76 | 4 | 11 | 30 | 16 | 15 | 255 | 1.116 | 3.36 | 9 |
| On-scene activities | 76 | 3 | 9 | 35 | 16 | 13 | 255 | 1.029 | 3.36 | 9 |
| Workshops | 76 | 4 | 8 | 32 | 21 | 11 | 255 | 1.029 | 3.36 | 9 |
| Signs | 76 | 6 | 10 | 25 | 22 | 13 | 254 | 1.15 | 3.34 | 12 |
| Media | 76 | 9 | 11 | 23 | 13 | 20 | 252 | 1.329 | 3.32 | 13 |
| Facial expressions | 76 | 7 | 19 | 14 | 19 | 17 | 248 | 1.31 | 3.26 | 14 |
| Video chats | 76 | 11 | 9 | 29 | 13 | 14 | 238 | 1.269 | 3.13 | 15 |
| Body language | 76 | 6 | 19 | 23 | 15 | 13 | 238 | 1.204 | 3.13 | 15 |

driven by the use of reports. The project report therefore provides all necessary information needful to keep stakeholders well informed on how project has been going, issues, risks and all other matters pertaining to projects. This helps in keeping the stakeholders updated and making informed decision on project. Nonetheless, social media tools and query are least used because they are engaged occasionally, and their use is therefore not common in construction projects.

**Verbal Communication** Phone calls, verbal presentations and face-to-face meetings with key stakeholders are the most frequently used form of verbal communication. The outcome therefore portrays that stakeholders in construction projects often make calls on phone, arrange for meetings and leverage on the presence of one another to discuss relevant details on projects. Stakeholders therefore meet together to converse on various issues of projects which influence success. Facial expressions, video chats and body language are the least used in this category. It thus depicts that stakeholders also somehow do communicate among themselves through facial expression when need be and as situations demand. The combination of facial expression and body language therefore bears their relevance in projects' communication.

## *3.3 Impact of CS on Construction Project Outcomes*

The significance of the impact of communication strategies on construction projects was examined and the mean scores are presented in Table 2.

**Cost** Outcomes: the highest impact is on meeting cost baseline targets. The outcome therefore depicts that one of the very significant impacts of communication strategies on construction projects is that it assists in meeting cost targets. This helps in achieving cost performance in project, while issues of cost overruns are mitigated. As stakeholders engage diverse communication strategies, information are disseminated promptly and consistently. This guides the implementation process of construction works at every phase, contributing towards streamlining activities towards cost-effectiveness, thereby resulting to meeting overall cost baseline goals, targets or expectations. Cost reduction is one critical area of attention in construction projects to solve house deficit among other reasons [1]. The least impact here is on appropriate management of reworks. The outcome therefore depicts that one of the moderate significant impacts of communication strategies on construction project is that it contributes towards the rework costs been well managed. This is because engaging communication strategies helps in constant and continuous communication among stakeholders as project is ongoing. Issues pertaining to rework if needful can therefore be discreetly channelled such that cost to be incurred is minimized in a way that does not result in undue cost been incurred on project as against the projected cost.

**Table 2** Impact of CS on project outcomes

| Project outcomes | N | 1 | 2 | 3 | 4 | 5 | TS | StD | MS | RK |
|---|---|---|---|---|---|---|---|---|---|---|
| *Cost* | | | | | | | | | | |
| Meeting cost baseline target | 76 | 2 | 6 | 6 | 33 | 29 | 309 | 1.011 | 4.07 | 1 |
| Net profit targets were met | 76 | 1 | 5 | 14 | 35 | 21 | 298 | 0.92 | 3.92 | 2 |
| Well understood markets competition | 76 | 2 | 5 | 10 | 42 | 17 | 295 | 0.923 | 3.88 | 3 |
| Well-managed contingencies | 76 | 2 | 5 | 19 | 28 | 22 | 291 | 1.012 | 3.83 | 4 |
| Rework costs well managed | 76 | 3 | 9 | 17 | 35 | 12 | 272 | 1.023 | 3.58 | 5 |
| *Schedule* | | | | | | | | | | |
| Materials availability was well managed | 76 | 2 | 6 | 15 | 27 | 26 | 297 | 1.048 | 3.91 | 1 |
| Equipment availability was well managed | 76 | 4 | 3 | 15 | 33 | 21 | 292 | 1.046 | 3.84 | 2 |
| Overall project schedule performance was met | 76 | 1 | 8 | 17 | 28 | 22 | 290 | 1.016 | 3.82 | 3 |
| Labour availability was well managed | 76 | 1 | 6 | 20 | 28 | 21 | 290 | 0.976 | 3.82 | 3 |
| Optimization of schedule float management | 76 | 2 | 4 | 21 | 30 | 19 | 288 | 0.97 | 3.79 | 5 |
| *Quality* | | | | | | | | | | |
| Overall project quality met | 76 | 4 | 4 | 13 | 24 | 31 | 302 | 1.131 | 3.97 | 1 |
| Customer satisfaction | 76 | 4 | 5 | 13 | 25 | 29 | 298 | 1.14 | 3.92 | 2 |
| Less reworks | 76 | 4 | 6 | 19 | 22 | 25 | 286 | 1.153 | 3.76 | 3 |
| Achievement of customers' expectations | 76 | 3 | 14 | 19 | 24 | 16 | 264 | 1.137 | 3.47 | 4 |
| *Health and safety* | | | | | | | | | | |
| Overall project safety performance | 76 | 4 | 3 | 17 | 18 | 34 | 303 | 1.149 | 3.99 | 1 |
| Adequate management of hazard measures | 76 | 3 | 7 | 15 | 16 | 35 | 301 | 1.183 | 3.96 | 2 |
| Overall project safety performance | 76 | 4 | 5 | 14 | 24 | 29 | 297 | 1.145 | 3.91 | 3 |
| Good safety craftsmen | 76 | 3 | 4 | 24 | 24 | 21 | 284 | 1.05 | 3.74 | 4 |
| Trades' and personnel's low frequency of complaints or grievances | 76 | 5 | 4 | 25 | 19 | 23 | 279 | 1.159 | 3.67 | 5 |
| *Operating environment* | | | | | | | | | | |
| The deployment of new technologies | 76 | 2 | 5 | 16 | 25 | 28 | 300 | 1.044 | 3.95 | 1 |
| Improved market place qualifications of the organisation | 76 | 3 | 6 | 14 | 27 | 26 | 295 | 1.095 | 3.88 | 2 |

(continued)

**Table 2** (continued)

| Project outcomes | N | 1 | 2 | 3 | 4 | 5 | TS | StD | MS | RK |
|---|---|---|---|---|---|---|---|---|---|---|
| Compliance with project documentations | 76 | 1 | 8 | 18 | 22 | 27 | 294 | 1.063 | 3.87 | 3 |
| Compliance with project schedule | 76 | 4 | 3 | 16 | 31 | 22 | 292 | 1.059 | 3.84 | 4 |
| Proper handling of rework and repair | 76 | 4 | 4 | 20 | 31 | 17 | 281 | 1.046 | 3.70 | 5 |
| *Overall performance* | | | | | | | | | | |
| Project operational performance goals were met | 76 | 3 | 3 | 14 | 31 | 25 | 300 | 1.018 | 3.95 | 1 |
| Good project performance data | 76 | 1 | 7 | 19 | 27 | 22 | 290 | 1.003 | 3.82 | 2 |
| Accurate project performance data | 76 | 1 | 8 | 21 | 25 | 21 | 285 | 1.021 | 3.75 | 3 |
| Predictive performance data (metric) | 76 | 1 | 7 | 23 | 32 | 13 | 277 | 0.919 | 3.64 | 4 |
| Well-established method for managing project performance data (metrics) | 76 | 5 | 6 | 17 | 31 | 17 | 277 | 1.116 | 3.64 | 4 |
| Personnel involvement | 76 | 1 | 8 | 23 | 31 | 13 | 275 | 0.938 | 3.62 | 6 |
| Cognizance of performance measurements throughout the project | 76 | 3 | 7 | 25 | 25 | 16 | 272 | 1.049 | 3.58 | 7 |

**Schedule** Outcomes: the highest impact in this category is on management of materials. The outcome therefore depicts that communication strategies ensure proper management of available materials. Materials management is a critical element on project that cannot be ignored if the completion time must be met. Materials' management concept is a plan adopted during project implementation to foster adequate flow of materials for proper control, which can be ensured by CS. The least impact is on optimization of float management. The outcome therefore depicts that an additional way by which communication strategies impact on construction project is that it optimizes schedule float management.

**Quality** Outcomes: the highest impact in quality category is on achieving overall project quality. The outcome therefore depicts that communication strategies contribute towards meeting the overall project quality objectives. Quality has become a feature that is most expected in projects by clients and cannot be underestimated in fostering clients' satisfaction. To continually meet with the quality standard expected in projects, the imperativeness of communication among stakeholders cannot be undermined. As communication strategies are imbibed by the parties in a project, it systematically fosters quality control in project and dynamically directs construction activities towards the attainment of quality standard set at the onset. Communication strategies therefore function as a systematic approach for setting and meeting quality goals in project throughout construction process. The least impact is on attainment of customers' expectations. The outcome therefore depicts that an additional way by which communication strategies impact projects is that they have a way of ensuring that the customer's true goals and expectations are properly reflected in contract performance incentives. The clients initiate the drive for the implementation of construction project and also take responsibility for the financing with specific expectations.

**Health and Safety** Outcomes: the highest impact in health and safety is on attaining overall project safety performance, resulting in reduced organizations' total recordable injury rate. The result therefore depicts that one of the significant impacts of communication strategies in construction project is that it fosters project safety performance. Construction environment is risky due to a number of reasons; thus, it is the principal responsibility of contractors and other concerned parties to ensure safety on construction sites. Efficient communication channelled through appropriate communication strategies however comes to fore in achieving health and safety on construction sites. The least impact here is opined as trades' and personnel's' low frequency of complaints or grievances. The result depicts that communication strategies spur support of the trades and labour personnel via less complaints or grievances. As different communication strategies are engaged therefore, health and safety can be easily realized during construction.

**Operating Environment** Outcomes: the highest in this category is on the deployment of new technologies for improvements. The result sheds light that CS fosters the deployment of new technologies which improve project performance. As communication becomes efficient among stakeholders, aspects that require attention in project can be easily identified, and through brainstorming or any relevant techniques, solutions can be initiated and obtained. This could therefore lead to deploying new technologies that would contribute towards achieving project performance. The least impact is on appropriate management of rework and repair. The need for rework may not be totally avoided in project construction as it was. However, engaging appropriate communication strategies all through the phases of project construction can minimize rework and repair and ultimately the cost.

**Overall Performance** Outcomes: the highest significant impact is on meeting project operational goals. The result established that CS impacts on every construction process and performance. Stakeholders through communication are able to integrate and synergize for project performance. The least impact is on project personnel remaining cognizant of performance measurements throughout the project. Stakeholders through the various communication strategies inculcated therefore become cognizant of performance measurement as construction is ongoing. At long run, project performance becomes achievable.

Ramalingam et al. [11] opine that communication is a core competency that when properly executed connects every member of a project team to a common set of strategies, goals and actions. Unless these components are effectively shared by project leads and understood by stakeholders, project outcomes are jeopardized stipulating that communication must be properly managed, transferred and understood so that the various aspects of the project can be assembled to attain performance. Similarly, Tourish and Hargie [14] indicated that project outcomes depend on CS adopted, while Akinradewo et al. [2] assert that the communication strategy adopted during project implementation has a unique way of influencing project performance.

## 4 Conclusions and Recommendations

This study aimed at investigating implementations of communication strategies in construction projects, so as to enhance projects' outcomes. The objectives were to examine the application of communication strategies in construction projects and to establish the impact of such strategies on projects' outcomes. The study was carried out empirically among construction professionals, and the findings reveal the most frequently used communication strategies and have established their contribution to projects' outcomes.

It is concluded therefore that electronic media and reports are the most frequently used written communication strategy, while they are phone calls and presentations in verbal strategy in construction projects. The implication of this is that construction projects could experience some level of improvement in delivery due to good communication flow. Communication is very vital on construction projects particularly on complex ones. Thus, the engagement of these strategies frequently is understandable.

Additionally, this study concludes that communication strategy contributes significantly to the realization of desired construction project outcomes. It implies that the strategy employed for communication on construction projects could determine the outcomes. Previous studies, such as Tourish and Hargie [14], have shown the importance of communication on projects outcomes and site productivity. Amusan et al. [3] posit that construction projects combine complex interrelated systems. It is required therefore for practitioners and stakeholders to employ the discovery in this study about the significance of CS in the procurement of construction projects.

In view of the aforementioned, the study recommend that all various verbal and written communication strategies should be frequently implemented in construction projects. This can be achieved by the deliberate action of stakeholders on construction projects. There are several other communication strategies not maximally implemented by construction practitioners, which could limit their inherent benefits and largesses on construction projects. Construction industry is generally slow in adopting new ideas and technology, such as novel CS and sustainable construction [15].

Furthermore, construction practitioners should operate communication strategies to improve the outcomes of construction projects. This can be achieved by attitudinal changes of construction team and personnel. Attitude is key in the application of anything in an industry like construction that is heavily human operated currently. The willingness and readiness of the industry key players are germane to frequent adoption of all the identified communication strategies.

## References

1. Afolabi A, Ojelabi RA, Omuh IO, Tunji-Olayeni PF (2019) 3D house printing: a sustainable housing solution for Nigeria's housing needs. In: 3rd International conference on science and sustainable development (ICSSD), IOP conference series: journal of physics: conference series, vol 1299, p 012012 IOP. https://doi.org/10.1088/1742-6596/1299/1/012012
2. Akinradewo OF, Akinola JA, Ojo LD (2017) A Regression Equation for determining completion period of construction projects in Ondo State, Nigeria. J Nigerian Inst Quant Surveyors 2(1):23–29
3. Amusan LM, Nkolika-Peter J, Charles AK, Oluwatobi A, Omuh IO (2015) Managing retention in residential building projects in selected states in Nigeria In: Laryea S, Leiringer R (eds) Procs 6th West Africa built environment research (WABER) conference, 10–12 Aug 2015, Accra, Ghana, pp 769–785
4. Boone ME (2000) Managing Interactively: executing business strategy, improving communication and creating a knowledge-sharing culture. McGraw-Hill, Blacklick, Ohio
5. Cho KM, Hong TH, Hyun CT (2009) Effect of project characteristics on project performance in construction projects based on structural equation model. Expert Syst Appl 36:10461–10470
6. Daniyan. (2011) The prevalence of barriers to effective communication on project delivery. Department of Quantity Surveying, Ahmadu Bello University, Zaria
7. Henderson L (2008) The impact of project managers' communication competencies: validation and extension of a research model for virtually, satisfaction, and productivity on project teams. Proj Manag J 39(2):48–59
8. Juholin (2008) Communication revolution: discover a new work community communication. University of Applied Sciences, Helsinki
9. Kotler P (1997) Marketing Management – Analysis, Planning, Implementation, and Control, 9th edn. Pretience Hall International, Inc., New Jersey
10. Ndihokubwayo R (2008) An analysis of the impact of variation orders on projects performance. CPUT thesis and dissertations, Papers 33. Retrieved on 28th Oct 2012 from http://dk.cput.ac.za/td_cput/33
11. Ramalingam S, Mahalingam A, Hartmann T (2011) Impact of communication technology on virtual team process and project performance in offshored engineering projects. In: Working paper proceedings, Estes Park, Colorado, 9–11 Aug 2011. Bucknell University
12. Ruuska I, Vartiainen I (2003) Critical project competences—A case study. J Work Learn 15(7):307–312
13. Super Business (2011) Information distribution. Available at http://www.super-business.net/ProjectManagement/Knowledge/Information-Distribution.html. Accessed 29 Dec 2011
14. Tourish, Hargie (2004) Lecture material for Cross-cultural competencies. Source can be found in www-format. https://moodle2.hamk.fi/mod/resource/view.php?id=51101. Read 3 Dec 2009

15. Tunji-Olayeni P, Aigbavboa C, Oke A (2022) Asymmetry in professionals' perceptions of sustainable construction. In: Human interaction emerging technologies (IHIET), vol 68, pp 804–812
16. Väänänen M (2010). Communication in high technology product development projects—Project personnel's viewpoint for improvement. University of Oulu. Source can be found in www-format. http://herkules.oulu.fi/isbn9789514262951/isbn9789514262951.pdf
17. Wiio O (2009) Contingencies of organizational communication: studies in organization and organizational communication. Hki, Helsingin kauppakorkeakoulu

# Intervening Qualities of Building Information Modeling (BIM) on the Adoption of Prevention Through Design (PTD)

**Rimmon Labadan, Kriengsak Panuwatwanich, and Sho Takahashi**

## 1 Introduction

Ensuring safety throughout the project lifecycle is of utmost importance in the construction industry. Adopting a proactive strategy to promptly detect potential safety risks, implement preventive measures, and mitigate threats before they manifest as significant issues is always advisable. Adopting a proactive safety approach, in contrast to a reactive one, entails anticipating incidents, preparedness, expedited reaction times, and reducing injury occurrences. According to Zhang et al. [45], the implementation of construction safety management is feasible prior to the commencement of construction activities. Therefore, prevention through design (PTD) is a viable methodology for conducting safety evaluations in the construction industry. Several studies [1, 17, 40] assert that risks and hazards can be prevented or mitigated during the design phase of a construction project using a safety management strategy known as prevention through design (PTD). However, PTD implementation in the construction industry remains rare due to several obstacles.

Meanwhile, building information modeling (BIM) has strong potential for occupational risk prevention and safety management. BIM represents a novel and innovative approach to design and management based on a complex system of procedures and technologies aimed at defining an accurate three-dimensional intelligent virtual model of the structure/infrastructure and supporting the entire construction process,

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i.e., design, construction, and management throughout its lifecycle [10]. In a BIM-based approach, a 3D model often serves as the primary working tool. BIM can integrate multi-disciplinary data to create detailed digital representations that could be managed in a sharable platform for real-time collaboration. Using BIM gives stakeholders greater visibility, better decision-making, more sustainable options, and cost savings on AEC projects. One area where BIM has been deemed particularly useful is in the PTD approach in construction safety management. Research has showcased BIM's capabilities as a valuable tool for PTD and in construction occupational safety assessment or analysis [17, 19, 21]. Using BIM to integrate safety considerations into the design process, project teams can reduce the likelihood of accidents and injuries, minimize the need for costly redesigns, and create a safer work environment for everyone involved.

The construction industry encounters challenges in terms of adapting and implementing PTD [41]. While many countries such as the United States, Australia, Singapore, and Hong Kong have begun to adopt and enforce the notion of PTD, in numerous other countries, this approach remains relatively novel and is not yet required by law. According to previous research [6, 14, 22, 26], a lack of PTD tools is one of the causes of the slow adoption of PTD. Therefore, determining how BIM technology could be an innovative means of promoting the adoption of PTD necessitates a comprehensive examination of the significance of BIM for PTD. Thus, the study's objective is to determine the intervening qualities of BIM technology that could impact the rate of BIM-based PTD adoption. It aims to quantitatively assess the influence of various factors on adopting a particular system, in this case, the BIM-based PTD. This paper delineates relevant BIM qualities to overcome or address a BIM-based intervention of PTD adoption.

## 2 Theoretical Background

BIM is a methodology and process for creating and managing digital representations of physical buildings and infrastructure projects. While BIM is not a singular technology, its implementation requires a variety of tools and technologies. Adoption of a BIM-based concept requires the implementation of BIM technologies. Since the hypothesis of this study is that BIM technologies can facilitate the adoption of PTD, it is necessary to examine the adoption of BIM for PTD through the lens of technology adoption theories.

There are several theories and models to predict factors that influence the acceptance of new technologies. However, the technology acceptance model (TAM), developed by Venkatesh and Davis [42], is the most prevalently used. TAM has been accepted as a parsimonious and highly predictive model for understanding a user's technology adoption behavior [9, 8, 31, 42]. According to the TAM (Fig. 1), which was first presented to the public in 1989, "perceived usefulness" (PU) and "perceived ease of use" (PEOU) are the two factors that significantly impact an individual user's intention to adopt new technology. PU is defined as the extent to

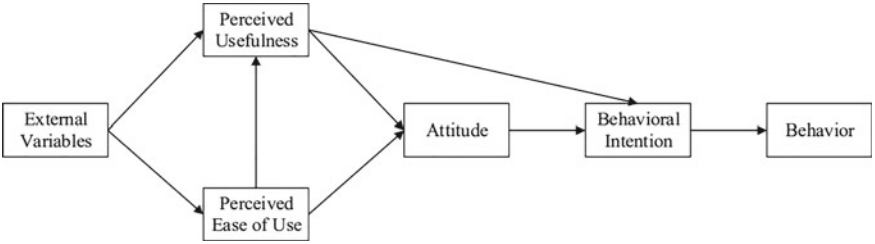


**Fig. 1** Classical technology acceptance model. Adapted from Venkatesh and Davis [42]

which an individual believes that utilizing a particular system will improve his or her job performance. PEOU is defined as the extent to which an individual believes in using the system without putting in a deliberate effort. Since then, multiple experts have consistently validated the TAM in several situations, resulting in its wide use in technology adoption research. TAM has been a reasonably simple model that may be altered or extended in various ways. As a result, several expansions publishing numerous combinations of other theories have been published, which leads to different frameworks.

Behavioral intention is the intent to engage in a specific behavior. It is a factor that influences that behavior and indicates a desire to engage in that conduct with pleasure and a desire to use the service, suggest it to others, and return to use the service again [28]. Behavioral intention to adopt was defined as the strength of an organization's future intention to employ the technology [39]. Wang and Song [44] investigated the impact of five variables on the contentment of BIM users in the AEC industry. Three of these variables were derived from TAM: perceived benefits, perceived convenience of use, and attitude. The remaining two variables were management-related: support from top management and management by objective. The results indicated that perceived usefulness, top management support, and management by objective are substantially associated with BIM user satisfaction, with management by objective having a more significant impact on BIM user satisfaction than perceived usefulness and top management support. Additionally, perceived usability and attitude have a substantial impact on perceived utility.

Furthermore, TAM explains the determinants of technology acceptance in general and traces the impact of external factors on internal beliefs [37]. According to the theory, the adoption behavior is determined by the intent to use a particular system, which is determined by the perceived usefulness and ease of use of that system. However, additional external variables not addressed by TAM could contribute to the variation explained by their study model. Legris [24] suggested that the TAM is useful but needs to be integrated into a broader model that includes other human, technical, and social variables that can indirectly impact the user's attitude and intention to adopt. Therefore, the study includes constructs complementing TAM's two (the PU and PEOU) contracts.

### 2.1 The Perceived Usefulness of BIM for PTD

BIM technology has revolutionized the construction industry. Its usefulness in the construction industry lies in its ability to streamline collaboration, improve decision-making, reduce risks, enhance project visualization, and support efficient project management throughout the lifecycle of a building or infrastructure project. The perceived usefulness of BIM can vary depending on the specific stakeholders involved. Generally, BIM provides a comprehensive digital representation of a building or infrastructure project throughout its lifecycle, from design and construction to operation and maintenance. This enables stakeholders to access and manage project data, including specifications, schedules, costs, and maintenance information lifecycle [10]. BIM facilitates enhanced collaboration and communication among project team members, including architects, engineers, contractors, and owners. It allows for real-time sharing of project information, design and construction activities coordination, and better integration of different disciplines—thereby improving the overall project coordination, increasing efficiency, and reducing errors or conflicts [46].

Designing means "to prepare the preliminary sketch or the plans for a work to be executed, especially to plan the form and structure," for which the usefulness of BIM technologies in designing is unmatched. The concept of PTD is the consideration of safety during the design phase of a project—making BIM technology a suitable tool for PTD. BIM allows stakeholders to visualize and simulate designs in 3D or 4D (3D + time) environments [5, 16], enabling stakeholders a proactive approach to construction of safety assessments. This capability is useful in comprehending spatial relationships, identifying conflicts or interferences, evaluating design alternatives, and depiction of construction hazards for construction safety. It enables more informed decision-making during a project's design and planning phases. Additionally, BIM enables clash detection, where potential conflicts between various building systems (e.g., structural, mechanical, and electrical) can be identified and resolved digitally before construction. This improves risk management and project outcomes by decreasing the likelihood of accidents on the construction site.

### 2.2 The Perceived Ease of Use of BIM for PTD

Technology's perceived ease of use generally refers to how users perceive the simplicity and user-friendliness of tools and processes [4, 29]. The user interface of BIM software plays a crucial role in its perceived ease of use. An intuitive and well-designed interface with clear menus, icons, and navigation options can make it easier for users to interact with the software and access the necessary functions. BIM software is integrated with other commonly used software or tools that can enhance its ease of use. Its tools can import and export data from widely used design software or construction management systems, and users can leverage their existing knowledge and workflows.

Although adequate training and education on BIM tools and processes with comprehensive training programs, workshops, and resources can help them acquire the necessary skills and knowledge to use BIM effectively, BIM tools and processes are more accessible to a broader range of users which can significantly impact the perceived ease of use of BIM for PTD. BIM software provides standardized templates, libraries, and predefined objects that can simplify the modeling process of construction hazards and risks. Several BIM softwares (e.g., Tekla Structures, Autodesk Revit, and Cype) have object-oriented modeling tools that easily include construction safety items. Having readily available components and templates reduces the need for users to create everything from scratch, making it easier and quicker to generate BIM models for PTD assessments.

### *2.3 The Relative Advantage of BIM for PTD*

A product, process, or idea does not need to be original when it is created in order to qualify as an innovation; rather, its freshness can be gauged by how novel it is to the user or implementing unit. According to Rogers, innovations' traits or features—which may be measured—are connected to the adoption and decision-making processes [32]. Innovations can take many different shapes [30]. It might be radical (a scientific or technological advancement brings about a new change), incremental (changes are made gradually in response to prior experience), or modular (an idea is modified inside a specific system's component) [3]. Rogers' [35] study found five perceived features of an innovation that influence its acceptance rate. These are compatibility, relative advantage, complexity, observability, and trialability. According to Moore and Benbasat [27], how people evaluate these innovative qualities predicts how they will respond to the innovation. However, three of the five qualities of innovation—relative advantage, compatibility, and complexity—have repeatedly been recognized as significant factors that affect how people view the application of an innovation [27, 39]. Relative advantage is the perception that the innovation is better than the idea it supersedes, is already in use, or is available. It answers the question: "Is it better?" The cost and social status motivations for innovations are both factors in determining relative advantage. Adoption is increased when a potential user can readily see the benefits of innovation. The more apparent the advantage is to the adopter, the more likely they are to adopt.

One of the advantages of BIM is its ability to improve accuracy and reduce errors [20]. Unlike traditional 2D drawings, BIM provides a detailed 3D model of a building or structure, including all the elements and components, making a BIM-based approach convenient for PTD. This approach enables designers and builders to identify inconsistencies, conflicts, and errors early in the design process, improving the project's quality and reducing the potential for rework. In addition, BIM allows project stakeholders to simulate different scenarios, analyze the impact of design changes, and optimize the building's performance, resulting in cost savings and improved sustainability.

Furthermore, BIM is the most capable tool for PTD [2]. The known visualization capability and its ability to facilitate rule checking and run construction sequence simulations, BIM makes it suitable for hazard prevention analysis before the construction phase of safety planning and even further back during the project's conceptualization and design phase [23]. With BIM's virtual replica of a building that includes 3D dimensions and physical and functional information, the resulting model is a data-rich, intelligent, object-oriented, and parametric digital depiction of the building and building construction process.

### *2.4 The Perceived Benefits of Using BIM for PTD*

In general, perceived benefit refers to the perception of favorable outcomes resulting from a given action [25]. Davis et al. [8] stated that the decision to employ a new technology is governed by the extent to which the consumer perceives it to be more cost-effective than the current way of supplying goods or services. In the construction industry, for instance, the perceived benefits of technology adoption for fundamental design, group collaboration, data visualization, acquisition, and management are demonstrated by the increased work efficiency, productivity, quality, and health and safety to be of the utmost importance [7].

BIM produces high-quality advantages for all stakeholders, both direct and indirect, promoting its adoption within the construction industry. The perceived benefits of BIM by early adopters and the findings of numerous studies indicate that BIM-based strategies aid in delivering projects with lower costs, decreased time, improved quality, and more customer satisfaction [18]. Furthermore, the AEC industry has benefited from using BIM through improved collaboration and communication, which enhance design visualization, streamlined construction management, and efficient facility operations. By embracing BIM, stakeholders can harness its power to optimize project outcomes, reduce costs, save time, and deliver more sustainable, resilient, and functional buildings [36].

Since BIM can facilitate the integration of construction safety aspects of design, it can benefit the designers in conducting PTD analysis. The 3D views and data incorporated in BIM models are appropriate to the designer's need that generate analysis to make PTD decisions and improve construction and give a plus in understanding construction safety even before the construction phase [12].

## 3 Proposed Model

In the context of the current study, the term "behavioral intention to adopt BIM for PTD (BI)" refers to the motivation and self-inclination of designers toward the adoption of BIM-based PTD. "Perceived usefulness of BIM for PTD (PU)" refers to the extent to which designers believe BIM has the potential to enhance and improve evaluations and analyses related to PTD. "Perceived ease of use of BIM for PTD (PEOU)" refers to the designer's subjective perception of the level of effort required and the ease with which they may utilize BIM for PTD purposes. "Perceived relative advantage of using BIM for PTD (PRA)" refers to the extent to which the utilization of BIM for PTD is deemed superior to alternative methodologies for PTD. "Perceived benefits of using BIM for PTD (PB*)*" refers to the extent to which the utilization of BIM is expected to enhance the effectiveness, efficiency, productivity, and overall quality of PTD processes.

The framework designed to address the knowledge gap observed earlier can be seen as illustrated in Fig. 2. The framework was constructed with the designer's level of perception to embrace BIM for PTD as its primary focus, and it was based on TAM (Fig. 1). In this study, a socio-technical perspective on the implementation of PTD is taken, which means that in addition to the technological implementation, the socio-cultural milieu that acts as its framework is taken into consideration. This study intends to position the intervening features of BIM inside the framework, which can assist designers in positioning themselves to adopt the BIM for PTD concept. These qualities (PU, PEOU, PB, and PRA) should also be considered when working toward widespread acceptance of PTD in the construction industry. It is anticipated that the compatibility between the intervening qualities of BIM will either directly or indirectly impact the behavioral intention of designers to use BIM for PTD.

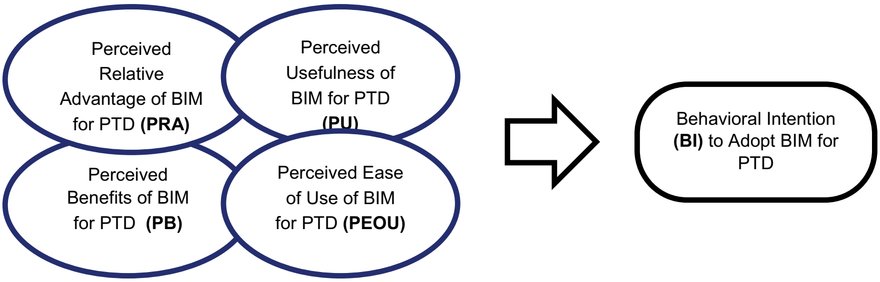


**Fig. 2** Theoretical framework

# 4 Methodology

## *4.1 Analysis Approach*

The objective of this study is to quantitatively assess the influence of various factors on the adoption of a particular system. As a result, the research employed a measurement approach that enables the concurrent examination of a network of associations among numerous dependent and independent variables. Quantitative measurement methods enable the formalization and evaluation of hypotheses concerning the interrelationships among variables. The use of such a methodology is crucial for the advancement and verification of theoretical frameworks.

To attain the study's objective, first, the "measurement model" must be specified and evaluated, and then the "structural model" must be tested to investigate the relationships of the constructs. Only then will the objective of the study be attainable. Using confirmatory factor analysis (CFA), a dependable measurement model was developed prior to the testing phase of the structural model. It is a multivariate statistical method that examines the extent to which observed variables (indicators or items) align with a predefined theoretical framework or construct. Analysis was completed prior to the testing phase. This conclusion was reached due to the subsequent belief that these aggregated components represent identifiers for their respective constructions (Fig. 2). The maximal likelihood estimate (MLE) technique and AMOS software were utilized throughout the CFA operation.

## *4.2 Questionnaire Survey*

A structured questionnaire was developed and aligned with each construct in preparation for conducting CFA. The questionnaire is an essential and extensively used data collection instrument in empirical research. In its most basic form, a questionnaire is a series of questions used to collect information or data from individuals about a specific topic. When the number of respondents is large and geographically dispersed, questionnaires are the most effective method for collecting data [34]. As a direct result, it was determined that a questionnaire survey would be the most efficient approach for achieving the study's objectives. Quantitative questionnaires collect organized, numerical data that can be subjected to statistical analysis [33]. Quantitative questionnaires generally have closed-ended questions that offer predetermined response alternatives. Frequently, these inquiries are intentionally structured to facilitate quantification, employing formats like multiple-choice questions or Likert scale questions. Hence, it was concluded that employing a quantitative questionnaire survey would be the most efficacious approach for achieving the objectives of this research. The questionnaire employed a dispersed format and consisted of two distinct sections. The initial segment comprises five divisions that align with five specified constructs (latent variables), each encompassing three questions as observed variables (e.g., PU1, PU2, and PU3). Each item in all survey parts was evaluated using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The subsequent section encompassed the demographic background information of the participants, including their years of experience and occupational positions.

### *4.3 Research Sampling*

Consistent with the principle of PTD, the designers are assumed to have the central role as the principal agents. Therefore, the individuals selected for this study were professionals working in the field of design. The sample population was restricted to structural engineers employed within the geographical boundaries of the Philippines. Initially, efforts were made to find respondents of approximately 300 engineers to answer the questionnaires.

## 5 Preliminary Results

### *5.1 Respondents Demographics*

The researchers were able to utilize 131 of the received responses. This quantity was selected as a representative sample of the entire population. As a result, every respondent possessed a degree equivalent to a bachelor's. Thirty-two percent (32%) held a master's degree, while 5% held a doctorate. The proportion of respondents between the ages of 26 and 30 represented 43% of the total. Notably, the preponderance of respondents (28%) are senior structural engineers, the same proportion as freelance structural designers.

### *5.2 Data Screening*

Data screening refers to the process of evaluating and examining collected data to ensure its quality, accuracy, and reliability. The first step was doing data screening to determine the suitability of the acquired data for the modeling analysis. The $z$-score is a statistical measure that quantifies the number of standard deviations by which an observation deviates from the mean of a normal distribution. In the event that the data follows a normal distribution, an observation with a $z$-score of 3.29 signifies that it deviates from the mean by more than three standard deviations. This occurrence is considered quite exceptional. The $z$-score threshold of 3.29 is associated with a p-value of 0.001, which is widely employed as a statistically significant level in various academic disciplines. In the current investigation, the scores of all variables were converted into standardized $z$-scores in order to identify any significant variations. According to Tabachnick and Fidell [38], instances exhibiting a z-score absolute value over 3.29, which corresponds to three standard deviations at a significance level of $p < 0.01$, were classified as outliers. Out of the total of 131 responses, it was observed that there were no instances of missing data and none of the $z$-values above the critical value of 3.29. Furthermore, the assessment of normalcy was conducted as the present study's analysis depended on several statistical techniques that presupposed normality. According to Garson [13], skewness and kurtosis values fell within the range of $+ 2.00$ to $- 2.00$, suggesting that the distribution can be characterized as normal. Thus, the results justified the use of MLE in CFA.

### *5.3 Confirmatory Factor Analysis*

This study was conducted using these five prevalent model fit indicators: the normed chi-square ($\chi^2/df$), goodness-of-fit index (GFI), comparative-fit index (CFI), incremental-fit index (IFI), and root mean square error of approximation (RMSEA). The quality of each index was evaluated based on how well it met the criteria suggested by Hair [15]: $\chi^2/df < 3.00$; CFI, IFI, and GFI all equaled 0.90; RMSEA $< 0.08$. In Table 1, the results obtained through the application of the measurement model are detailed. Using the above criteria, it was determined that the model had a satisfactory level of fit ($\chi^2 = 141.82$; $df = 80$; $22/df = 1.773$; GFI $= 0.88$; TLI $= 0.918$; CFI $= 0.937$; IFI $= 0.939$; RMSEA $= 0.077$). According to Hair, each indicator loaded substantially ($p = 0.001$) on their respective constructs, and the loadings of each indicator were greater than 0.50. As a rule of thumb, any items with $R^2$ values that were substantially lower than the commonly accepted criterion of 0.50, may be candidates for elimination from the model. However, the result showed that all the indicators' factor loadings were significant. Thus, it was determined that the measuring model should continue to include every component (Fig. 3).

CFA is a statistical technique used to assess the validity and structure of a measurement instrument or scale. On the basis of these findings, it would appear that the measurement model has adequate convergent validity. Thus, the measurement model can be used to evaluate the subsequent structural model because its fit indices were determined to be adequate.

## 6 Conclusion and Further Study

The investigation uncovered important characteristics and patterns of variables, both of which can be utilized in the construction of a structure for the adoption of BIM for PTD. Following a comprehensive study and synthesis of perceived BIM qualities and technology adoption theories, this research proposed an integrated model

**Table 1** Measurement model results

| Constructs/factors | Loadings | *t*-value* | $R^2$ |
|---|---|---|---|
| Perceived usefulness of BIM for PTD (PU): | | | |
| PU1 | 0.945 | f.p | 0.893 |
| PU2 | 0.89 | 14.137*** | 0.792 |
| PU3 | 0.661 | 8.853*** | 0.436 |
| Perceived ease of use of BIM for PTD (PEOU): | | | |
| PEOU1 | 0.656 | f.p | 0.43 |
| PEOU2 | 0.695 | 5.543*** | 0.483 |
| PEOU3 | 0.534 | 4.709*** | 0.285 |
| Perceived relative advantage of using BIM for PTD (PRA): | | | |
| PRA1 | 0.853 | f.p | 0.727 |
| PRA2 | 0.873 | 10.986*** | 0.762 |
| PRA3 | 0.746 | 9.368*** | 0.556 |
| Perceived benefits of using BIM for PTD (PB): | | | |
| PB1 | 0.748 | f.p | 0.559 |
| PB2 | 0.781 | 6.722*** | 0.61 |
| PB3 | 0.626 | 6.058*** | 0.392 |
| Behavioral intention to adopt PTD (BI): | | | |
| BI1 | 0.858 | f.p | 0.736 |
| BI2 | 0.953 | 13.766*** | 0.907 |
| BI3 | 0.744 | 10.102*** | 0.553 |

*Notes* Model fit indexes: $\chi^2 = 141.82$; $df = 80$; $\chi^2/df = 1.773$; GFI = 0.88; TLI = 0.918; CFI = 0.937; IFI = 0.939; RMSEA = 0.077; f.p., parameter is fixed for estimation purpose; *** *t*-values are significant at $p < 0.001$

to investigate the implications of various constructions that have been taken into consideration. The results of the exploratory study gave a foundation for a more in-depth understanding of adoption behavior in the context of PTD adoption. As a result, the perceived usefulness, perceived ease of use, perceived relative advantage, and perceived benefits of BIM for PTD can influence the possibility that designers working in the construction industry would effectively implement PTD. To confirm and validate the model, a case study was carried out in the Philippines to shed light on the influence of the aforementioned BIM properties on adopting PTD. This paper presented the preliminary results of the conducted data analysis. The results quantitatively confirm the model's constructs for further structural analysis. An analysis of the model will be performed utilizing a structural modeling technique to justify

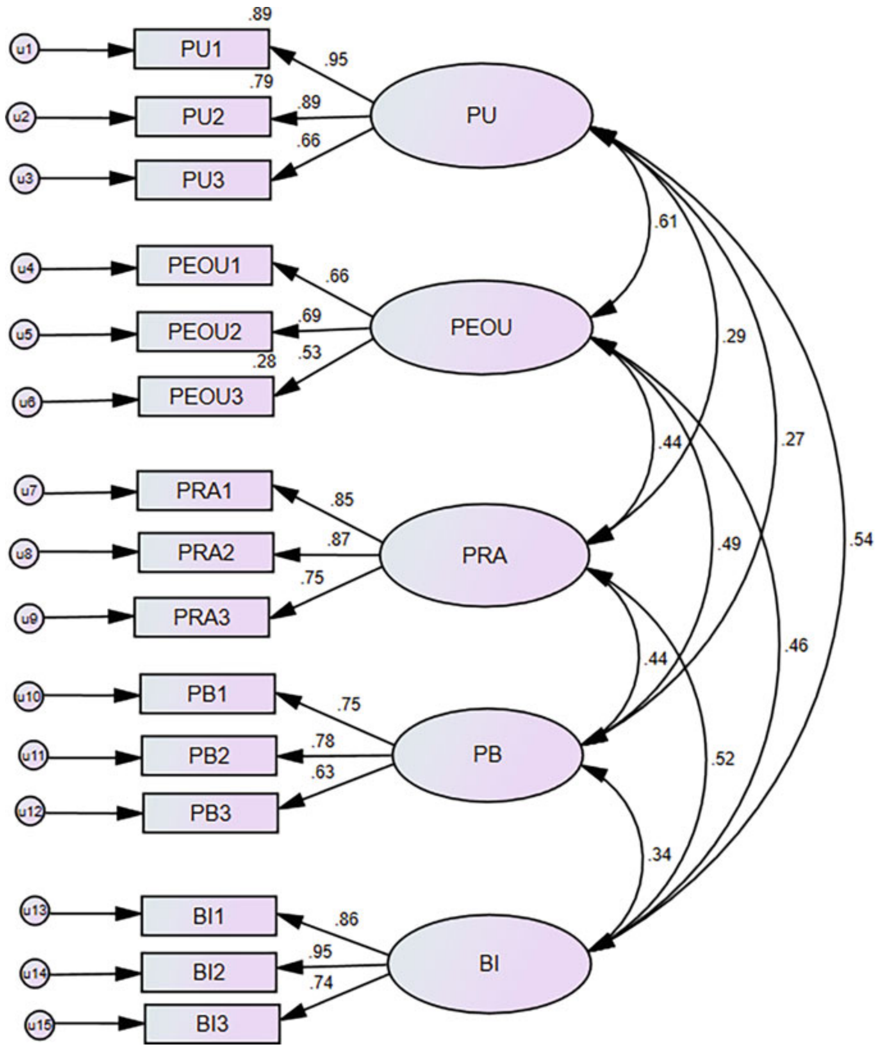


**Fig. 3** Measurement model

the model's correlation of components is now being carried out. After the model is validated, it should be able to shed light on the influence of the features of BIM on the adoption of BIM for PTD.

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## References

1. Abrams AL, Gillen M, Mroszczyk JW, Rinehart RD, Soderholm SC (2008) NIOSH/NORA: why safety and health professionals should be interested in work underway at NIOSH/NORA. In: ASSE professional development conference and exhibition 2008
2. Bansal VK (2011) Application of geographic information systems in construction safety planning. Int J Project Manage 29(1):66–77. https://doi.org/10.1016/j.ijproman.2010.01.007
3. Blayse AM, Manley K (2004) Key influences on construction innovation. In: Construction innovation
4. Bonn MA, Kim WG, Kang S, Cho M (2016) Purchasing wine online: the effects of social influence, perceived usefulness, perceived ease of use, and wine involvement. J Hosp Market Manag 25(7):841–869
5. Buhamdan S, Duncheva T, Alwisy A (2021) Developing a BIM and simulation-based hazard assessment and visualization framework for CLT construction design. J Constr Eng Manage 147(3). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002000
6. Che Ibrahim CKI, Belayutham S (2020) A knowledge, attitude and practices (KAP) study on prevention through design: a dynamic insight into civil and structural engineers in Malaysia. Architect Eng Des Manage 16(2):131–149. https://doi.org/10.1080/17452007.2019.1628001
7. Chen X, Chang-Richards A (2022) Technology implementation status and perceived benefits: a study of New Zealand construction organizations. IOP Conf Ser: Earth Environ Sci 1101(8):82020
8. Davis FD, Bagozzi RP, Warshaw PR (1989) User acceptance of computer technology: a comparison of two theoretical models. Manage Sci 35(8):982–1003
9. Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quart 319–340
10. Eastman CM, Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors. Wiley
11. Gambatese JA, Behm M, Hinze JW (2005) Viability of designing for construction worker safety. J Constr Eng Manag 131(9):1029–1036. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:9(1029)
12. Ganah A, John GA (2015) Integrating building information modeling and health and safety for onsite construction. Saf Health Work 6(1):39–45. https://doi.org/10.1016/j.shaw.2014.10.002
13. Garson GD (2012) Testing statistical assumptions. Statistical associates publishing Asheboro, NC
14. Goh YMYM, Chua S (2016) Knowledge, attitude and practices for design for safety: a study on civil & structural engineers. Accid Anal Prev 93:260–266. https://doi.org/10.1016/j.aap.2015.09.023
15. Hair JF (2009) Multivariate data analysis
16. Hilfert T, Teizer J, König M (2016) First person virtual reality for evaluation and learning of construction site safety. In: ISARC 2016—33rd International symposium on automation and robotics in construction, pp 200–208. https://doi.org/10.22260/isarc2016/0025
17. Jin Z, Gambatese J, Liu D, Dharmapalan V (2019) Using 4D BIM to assess construction risks during the design phase. Eng Constr Archit Manag 26(11):2637–2654. https://doi.org/10.1108/ECAM-09-2018-0379
18. Jäväjä P, Suwal S, Porkka J, Jung N (2013) Enhancing customer orientation in construction industry by means of new technology. In: 7th Nordic conference on construction economics and organisation 2013, pp 215–226
19. Kamardeen I (2010) 8D BIM modelling tool for accident prevention through design. In: Proceedings of the 26th annual conference. Association of Researchers in Construction Management, ARCOM 2010, pp 281–289
20. Khosakitchalert C, Yabuki N, Fukuda T (2019) Improving the accuracy of BIM-based quantity takeoff for compound elements. Autom Constr 106:102891

21. Kim K, Cho Y, Zhang S (2016) Integrating work sequences and temporary structures into safety planning: automated scaffolding-related safety hazard identification and prevention in BIM. Autom Constr 70:128–142
22. Labadan R, Panuwatwanich K, Takahashi S (2022) Awareness of the prevention through design (PtD) concept among design engineers in the Philippines. Eng Manage Prod Services 14(1):78–92. https://doi.org/10.2478/emj-2022-0007
23. Labadan R, Takahashi S, Panuwatwanich K, Hagiwara T (2023) Development of a BIM-based automated fall hazzard identification as prevention-through-design (PTD) tool for structural designers. In: 2023 IEEE 12th Global Conference on Consumer Electronics (GCCE), 214–215
24. Legris P, Ingham J, Collerette P (2003) Why do people use information technology? A critical review of the technology acceptance model. Inf Manage 40(3):191–204
25. Leung Y (2013) Perceived benefits. In: Encyclopedia of behavioral medicine, pp 1450–1451
26. Marefat A, Toosi H, Mahmoudi Hasankhanlo R (2019) A BIM approach for construction safety: applications, barriers and solutions. Eng Constr Archit Manag 26(9):1855–1877. https://doi.org/10.1108/ECAM-01-2017-0011
27. Moore GC, Benbasat I (1991) Development of an instrument to measure the perceptions of adopting an information technology innovation. Inf Syst Res 2(3):192–222
28. Namkung Y, Jang S (2007) Does food quality really matter in restaurants? Its impact on customer satisfaction and behavioral intentions. J Hospital Tourism Res 31(3):387–409
29. Oentoro W (2021) Mobile payment adoption process: a serial of multiple mediation and moderation analysis. Bottom Line 34(3/4):225–244. https://doi.org/10.1108/BL-09-2020-0059
30. Panuwatwanich K, Stewart RA, Mohamed S (2008) The role of climate for innovation in enhancing business performance. Eng Constr Archit Manag 15(5):407–422. https://doi.org/10.1108/09699980810902712
31. Pavlou PA (2003) Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model. Int J Electron Commer 7(3):101–134
32. Poong Y-S, Eze UC, Talha M (2009) B2C e-commerce in Malaysia: perceived characteristics of innovating and trust perspective. Int J Electron Bus 7(4):392–427
33. Queirós A, Faria D, Almeida F (2017) Strengths and limitations of qualitative and quantitative research methods. Eur J Educ Stud
34. Rathi T, Ronald B (2022) Questionnaire as a tool of data collection in empirical research. J Positive School Psychol 7697–7699
35. Rogers EM (2003) Diffusion of innovations. Simon and Schuster
36. Sacks R, Barak R (2008) Impact of three-dimensional parametric modeling of buildings on productivity in structural engineering practice. Autom Constr 17(4):439–449. https://doi.org/10.1016/j.autcon.2007.08.003
37. Son H, Lee S, Kim C (2015) What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions. Autom Constr 49:92–99
38. Tabachnick BG, Fidell LS (2007) Experimental designs using ANOVA (Vol 724). Thomson/Brooks/Cole Belmont, CA
39. Taylor S, Todd PA (1995) Understanding information technology usage: a test of competing models. Inf Syst Res 6(2):144–176
40. Toole TM, Erger K (2019) Prevention through design: promising or perilous? J Legal Affairs Dispute Resolut Eng Constr 11(1). https://doi.org/10.1061/(ASCE)LA.1943-4170.0000284
41. Toole TM, Gambatese J (2017) Levels of implementation of prevention through design in the united states. Proceedings of the Joint CIB W099 and TG59 International Safety, Health, and People in Construction Conference, pp 11–13
42. Venkatesh V, Davis FD (2000) Theoretical extension of the technology acceptance model: four longitudinal field studies. Manage Sci 46(2):186–204. https://doi.org/10.1287/mnsc.46.2.186.11926
43. Venkatesh V, Davis FD (2000) A theoretical extension of the technology acceptance model: four longitudinal field studies. Manage Sci 46(2):186–204

44. Wang G, Song J (2017) The relation of perceived benefits and organizational supports to user satisfaction with building information model (BIM). Comput Hum Behav 68:493–500
45. Zhang S, Boukamp F, Teizer J (2014) Ontology-based semantic modeling of safety management knowledge. Computing in civil and building engineering—proceedings of the 2014 international conference on computing in civil and building engineering, pp 2254–2262. https://doi.org/10.1061/9780784413616.280
46. Zhou W (2014) Knowledge-based collaborative design decision framework for construction safety. In: EG-ICE 2011, European Group for intelligent computing in engineering

# Barriers to the Adoption of Robot-Assisted Construction Approach in the South African Built Environment

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## 1 Introduction

Construction is one of the most essential processes in a construction project life span, and it involves many individuals. The construction industry in most non-industrial nations has various efficiency challenges. These incorporate work shortage, unfortunate efficiency, an excessive amount of wastage, and hazardous working circumstances, which are all for the most part brought about by dreary and work serious jobs [27]. Robots are intelligent mechanisms that might be modified to do exercises autonomously, prompting a wide range of study topics in both well-engineered industrial settings and domain-oriented applications that operate in a dangerous or difficult environment [30]. Robotics has developed and thrived in pretty much every modern area other than civil structure construction since the mid-20th 100 years. The development of robots picked up speed during the 1970s and 1980s in Japan. It was where the establishments for this present reality use of technology in off-site building fabricating, single-task development robots, and locations for automated construction were laid. The construction industry in many countries contributes up to 10–20% of the GNP, making it the biggest financial utilizing area [33].

In constructing sites, robots are often used to help humans work. This technique embodies a decentralized, independent, adaptable, essential, and versatile structure strategy. Accordingly, the development of robots has turned into a well-known concentrate theme in the industry. Construction work is tedious and dangerous, and

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the idea of the errand and materials utilized fluctuate consistently [9]. The presentation of robots in India's development area will work on the industry and give a solution for its shortcomings, like sluggish speed, slow specialist efficiency, and low well-being and quality. The construction site will turn out to be more financially savvy and cutthroat thus. India has a logical outlook and however needs the utilization of robots; yet, there is a negligible exploration of robots in the Indian construction industry [14].

Construction automation and robots are most generally utilized in the creation of cement footers, segments, and blocks. Lasers (for ensuring quality and checking aspects), substantial blenders, cutting and boring mechanized gear, and different advances are utilized in the assembling of construction components [9]. Pre-assembled parts are utilized on the grounds that they are fabricated under severe management and in a controlled climate to stay away from temperature variances that could affect item quality. At long last, assuming that only a tad measure of work is important, the last work is finished nearby. As indicated by Mahbub [20], research endeavours in the construction area in the fields of mechanization and advanced mechanics are arranged into two expansive divisions in light of utilizations: civil infrastructure and building. This research will therefore seek to assess the barriers to the adoption of robot-assisted construction operations in the South African built environment. This is with the aim to provide a reference point for practitioners, policymakers, and researchers in identifying and prioritizing the most critical barriers that need to be addressed for successful implementation of automation and robotics in the South African built environment.

## 2 Adoption of Robots in the Construction Industry

The construction output in some developing countries has grown particularly fast in the recent years, so much so that the growth is often more than the growth rate of the economy, as these countries put their infrastructure in place during the early stages of development [2]. Other countries double their construction outputs and development, therefore creating a rapidly developing industry that needs efficient and innovative solutions to increase the production and quality of work [26]. In many of these industrialized countries, prefabricated components are now manufactured in workshops and erected on site instead of using the conventional building methods due to the fast rise of infrastructure and development in these countries [21]. Construction robots are still being explored in the majority of the world's construction industry, and just a few useful construction robots have been built and put to service [16]. To address issues facing the sector, such as diminishing productivity and quality, as well as onsite accidents, more automation and robotics must be used [26]. The first single-task construction robots for use in real-world applications were created in Japan by the country's largest construction company, Shimizu, and tested in the market [5]. Major advancements in the sector have been made in recent years as new technical advances are gradually being adopted. The adoption of construction automation and robotics would be beneficial to construction industries by increasing production, reducing construction duration, improving quality, lower risks of injuries and fatalities and reducing labour and production costs [1, 5].

Robotics and automation have been adopted slowly in the construction sector, which is a challenge that affects many sectors of the global construction industry, including the South African construction industry. The using of bricklaying robots in the South African construction industry determined the desire and preparedness of construction organizations to embrace this robot as a step in automating their work processes in order to better understand the underlying causes behind this low adoption of automation and robotic technology [13]. By shifting and reassigning labour that was previously done by people to robots, construction robotics helps businesses achieve improved quality while using less resources and less time. [26] work demonstrates that construction robots are self-regulating process by deploying computerized machines to do various building duties. Construction automated machines are created and built to work in accordance with a software that controls the behaviour of the machine and ensures efficiency at all times without causing any risk to humans operating or working nearby.

### *2.1 Barriers to the Adoption of Robot-Assisted Construction Operation in the Construction Industry*

Automation and robots have been widely adopted by many sectors, but not to the same extent in the construction industry. A crucial worldwide sector, construction must solve challenges with productivity, safety, quality, and profitability. On all of these fronts, automation and robots have the potential to make a significant difference, increasing the effectiveness and performance of construction projects. For instance [32], highlighted four main causes for the poor success of robotic adoption in building construction: inadequate development, inappropriate building design, insufficient economic rationale, and management hurdles. Despite the potential for increased productivity, there are several implementation problems. This study seeks to pinpoint some of the major obstacles to the construction industry's use of automation and robots.

One of the obstacles to the application of construction robotics is the high cost of obtaining and maintaining the technology [21]. The high cost of implementing technology in building robots, especially automation technologies which are so expensive [23]. The expense of purchasing and implementing new technologies means that only businesses with strong market rivalry and high turnover can afford them [29]. Additionally, the automation systems require updating and maintenance, and most of them are expensive [23]. Because a specialized professional is required to perform the maintenance work, new robotics equipment often has higher maintenance costs. Construction robotics are difficult to employ since they are expensive, and only big companies with strong market rivalry and turnover can afford them [29]. Because every building process is distinct in its own way and because the same technologies are not suited in every situation, medium-sized and small-sized businesses have limited resources available to them to embrace these technologies. Compared with small and medium businesses, large enterprises have adequate investment capital to implement new technology [26].

Another identified barrier is incompatibility of the technology with present building methods and practices [20, 21]. Due to the unstable and unpredictable nature of the construction environment, workers choose the older, tested solution over newer methods and technology [12]. According to Koskela [18], each project results in a distinctive building and is viewed more as a prototype than a finished product. Kirchberger and Pohl [17] further claimed that for items to be sold to be valuable to society and profitable for the corporation, technology must be included in them. However, research done in the context of developing nations [3, 7, 31] focuses on the transfer of information and skills, building methods, organizational know-how, and management systems on a national level. The backlog is caused by the technology' incompatibility with present building methods and practices. Due to the volatile and unpredictable nature of the construction environment, workers choose the former and tested answer over novel ways and technology.

The project process, whether it uses traditional or new building methods, has a fragmentation problem [24]. The construction business is fragmented, which prevents innovative technology from being adopted [21]. Because of the complex nature of the construction work processes, the creation of construction robots is technically challenging to perform tasks in construction, where strong, adaptable, mobile, and versatile robots are required. Due to the nature of the construction work processes itself and the necessity for durable, agile, highly mobile, and versatile robots, the field of construction is technologically challenging [20].

Due to the complexity of the programme, technologies are difficult to use and comprehend. For construction sector personnel who tend to have less education, the high level of intricacy of the robot control system becomes a more difficult component of their jobs [2]. Robotics technologies are challenging to use in the construction sector because they are complex to regulate, particularly during the programming process. Due to the complexity of the programme, technologies are difficult to use and comprehend [20]. Construction workers, who tend to be less-educated employees, face greater obstacles as a result of the high sophistication of the robot control system. Robotics technologies are complex to manage, particularly the programming process, and introducing them into the construction industry is quite challenging [4].

Workers in workplaces do not readily adopt new technologies. Active labour unions in various nations view this technology as a means of replacing employees [20]. This demonstrates that in order to achieve the desired outcomes, the integration of robots into the building must have the full support of both the workforce and management at all levels [12]. For instance, in Australia, any effort to deploy robots on a construction site must be predicated on a three-way agreement between the workers, management, and the union, with the building union representative having to be persuaded that using robots in construction won't endanger their jobs [20]. According

**Table 1** Identified barriers from reviewed literature

| Barriers to the adoption of robot-assisted construction operations | Source(s) |
|---|---|
| High cost to maintain | Mahbub [22] |
| Expensive to implement | Mistri and Rathod [23] |
| Incompatibility of the technology | Mahbub [22] |
| Construction technological challenges | Mahbub [22] |
| Fragmentation problems | Nawi et al. [25] |
| Complex of technology | Balaguer and Abderrahim [4] |
| Technological usability | Mahbub [22] |
| Poor success of robotic adoption | Yahya et al. [32] |
| Affordable to business with high turnover | Sadique and Mahesh [29] |
| Challenges faced by less-educated employees | Balaguer and Abderrahim [4] |
| Readiness of employees to adopt to technology | Mahbub [22] |
| Educating staff have a negative impact on financial result | Fellows et al. [10] |
| High risk of job loss caused by technology | Robison [28] |
| Time-consuming to educate staff about robotic equipment | Kumar [19] |

to the Economic Planning Unit [8], 93% in the construction industry are low-skilled migrant labourers. So that retraining of construction employees becomes required to upgrade skills for a semi-skilled worker or through seminars and workshops to enhance awareness of the technologies in the sector and on the jobsite [23]. Educating staff on how to use the new robotic equipment will be a time-consuming and expensive process that will have a negative impact on financial results [10]. The contractor must spend significantly on employee education and training in order to prepare the workforce for using the robots [19].

Table 1 gives the identified barriers to the adoption of robot-assisted construction operations from the reviewed literature with the relevant sources.

## 3 Research Methodology

The quantitative strategy accompanied by a literature review is the picked method for this research to accomplish the study goals. The quantitative research approach was used because of the nature of this study. Based on the literature study, a well-structured questionnaire was created because it is quick, allows for broad geographic coverage, and gives respondents enough time to double-check facts and provide correct responses [15]. The research was conducted in the city of Johannesburg municipality, Gauteng, South Africa and the targeted respondent will be professionals in the South African industry. The respondents for this study were construction industry experts in the Gauteng Province of South Africa. Construction managers, quantity surveyors, architects, and project managers are among the responses. Professionals were selected using a purposeful sampling strategy to guarantee that they have sufficient expertise in construction automation and robotics [26]. A well-drafted questionnaire was used to achieve the aim of the research. In accordance with the explanation given by Fellow et al. [11], the use of questionnaire is the application of numerical constants to collect primary data from identified respondents. Since the respondents of this study are professionals in the construction industry, primary data was collected from them, hence justifying the reason behind the research instrument employed in the study. Retrieved data was analyzed using descriptive analysis such as mean item score, standard deviation and normalized mean value. The Cronbach alpha was employed to determine the reliability of the data collection instrument and the result revealed an alpha value of 0.899 which indicates a strong reliability as the value is above the 0.7 threshold.

## 4 Findings and Discussion

### *4.1 Respondents' Background Information*

Based on the results of the analysis, the most common qualification among respondents was Bachelor's Degree (50.79%), followed by Honour's Degree (33.33%), Master's Degree (6.35%), Diploma (4.76%), and Matric (4.76%). Among the participants, 38.10% were civil engineers, 23.81% were quantity surveyors, 19.05% were construction managers, 11.11% were in other professions, 4.76% were mechanical engineers, 1.50% were architects, and 1.59% were construction managers. In terms of work experience, 40.79% had 1–5 years of experience, 1.59% had 10–15 years of experience, 4.76% had 5–10 years of experience, 39.68% had less than 1 year of experience, and 3.17% had more than 20 years of experience in the construction industry. The data presented above provides insights into the qualifications and work experience of the respondents in the construction industry. The implication of the data is that the majority of the respondents hold Bachelor's and Honour's Degrees, indicating a relatively high level of formal education among the participants. Additionally, the data shows that civil engineers, quantity surveyors, and construction managers are the most common professions among the respondents. In terms of work experience, a significant percentage of the respondents have 1–5 years of experience, while a smaller percentage have more extensive experience ranging from 5 to 10 years, 10 to 15 years, and over 20 years. This suggests a mix of experienced professionals and those with limited experience in the construction industry. Hence, their opinion can be relied upon for this study.

### 4.2 Descriptive Analysis Result

Table 2 presents descriptive analysis results for identified barriers related to robot-assisted construction. The mean item score (MIS) is used as a measure of the average rating given by respondents for each barrier, with a higher score indicating a higher level of perceived barrier. Standard deviation (SD) is used as a measure of the variability or dispersion in the responses. NMV represents the normalized value of MIS. The higher the NMV, the higher the perceived significance of the barrier. Rank indicates the ranking of each barrier based on its MIS and NMV value. From the table, it can be observed that the top three perceived barriers are: (1) Risk of job loss caused by technology, (2) High costs of acquiring technology, and (3) High costs of maintaining technology, with NMV values of 1.00, 0.79, and 0.68 respectively. Other barriers with relatively high NMV values and ranking lower on the list include resistance to implementation of technology by workers, high cost of training workers, lack of capital required to implement technology, and the need for constant power supply. On the other hand, barriers such as difficult to acquire technologies due to unavailability, difficult to operate and not easy to understand technology, have NMV values of 0.00, indicating that they are perceived as less significant barriers.

The adoption of robot-assisted construction approaches in the South African built environment is hindered by several identified barriers as given in Table 2. Firstly, there is a risk of job loss caused by technology, as workers in the construction industry may fear that robots and automation technologies could replace human labour, leading to reduced employment opportunities and impacting their livelihoods [2]. This fear of job loss can create resistance and reluctance towards adopting robot-assisted construction approaches. Secondly, the high costs associated with acquiring and maintaining robot-assisted construction technologies pose significant barriers. The upfront costs of purchasing, installing, and integrating these technologies into existing construction processes can be prohibitive, especially for smaller construction companies or contractors with limited financial resources [20]. Additionally, the ongoing costs of maintenance, upgrades, and repairs can add to the overall cost of adopting and implementing robot-assisted construction approaches, making it financially challenging for construction companies to sustain such technologies in the long term [2]. Thirdly, resistance to the implementation of technology by workers is another barrier to the adoption of robot-assisted construction approaches. Workers may be resistant to change, especially if they perceive that these technologies could potentially replace their jobs or require them to acquire new skills [21]. This resistance can hinder the successful implementation and adoption of robot-assisted construction approaches if workers are not supportive or unwilling to work with the new technologies. Furthermore, the high costs of training workers to use and operate robot-assisted construction technologies can be a significant barrier. Training programmes may be required to familiarize workers with the new technologies, teach them how to operate and maintain them, and ensure they can work effectively with the technologies [32]. However, the costs associated with training workers can be prohibitive, particularly for smaller construction companies or contractors with limited training budgets.

**Table 2** Descriptive analysis result for the identified barriers

| Barriers | MIS | Standard deviation (SD) | NMV | Rank |
|---|---|---|---|---|
| Risk of job loss caused by technology | 4.51 | 0.982 | 1.00 | 1 |
| High costs of acquiring technology | 4.30 | 1.042 | 0.79 | 2 |
| High costs of maintaining technology | 4.19 | 0.965 | 0.68 | 3 |
| Resistance to implementation of technology by workers | 4.02 | 1.070 | 0.51 | 4 |
| High cost of training workers | 3.95 | 0.974 | 0.44 | 5 |
| Lack of capital required to implement technology | 3.86 | 1.060 | 0.35 | 6 |
| They need constant power | 3.86 | 1.229 | 0.35 | 7 |
| High cost to update technology | 3.76 | 0.995 | 0.25 | 8 |
| Lack of knowledge on how to operate technology | 3.71 | 1.197 | 0.20 | 9 |
| Causes construction technology fragment | 3.67 | 1.000 | 0.16 | 10 |
| Inadequate compatibility of technologies with current practices | 3.65 | 1.080 | 0.14 | 11 |
| Difficult to understand technology | 3.62 | 1.142 | 0.11 | 12 |
| Time-consuming to educate employees | 3.60 | 1.040 | 0.09 | 13 |
| Difficult to acquire technologies due to unavailability | 3.54 | 1.242 | 0.00 | 14 |
| Difficult to operate and not easy to understand technology | 3.51 | 1.203 | 0.00 | 15 |

In addition, the lack of capital or financial resources required to implement robot-assisted construction technologies is another barrier. Implementing these technologies may require significant upfront investments in terms of purchasing equipment, software, and other infrastructure [23]. The lack of capital can pose a challenge for construction companies, particularly smaller ones, in adopting and integrating robot-assisted construction approaches into their operations. Moreover, the need for a constant and reliable power supply is another barrier to the adoption of robot-assisted construction approaches. These technologies may rely on electricity to function, and the availability of a stable power supply may be essential for their proper operation [12]. However, in regions where there are issues with power outages or unreliable electricity supply, the need for constant power can be a significant hindrance to the adoption of robot-assisted construction approaches. Another barrier is the high cost of updating or upgrading robot-assisted construction technologies over time. Technology is constantly evolving, and updates or upgrades may be required to ensure that the technologies remain effective, efficient, and compatible with changing industry standards [28]. The high costs of updating technology can be a challenge for construction companies, particularly if they lack the necessary financial resources to keep up with the rapid pace of technological advancements. Furthermore, the lack of knowledge or skills among construction workers on how to operate and work with robot-assisted construction technologies is another barrier. Workers may require training or education to understand how to use these technologies effectively [2]. The lack of knowledge or skills can hinder the adoption of robot-assisted construction approaches, as workers may feel ill-equipped or unprepared to work with these technologies. Lastly, the potential fragmentation or incompatibility of different construction technologies can also pose a barrier to the adoption of robot-assisted construction approaches. If different technologies used in construction are not compatible or do not integrate well with each other, it can create challenges in implementing a cohesive and unified robot-assisted construction approach [32].

The data was further subjected to clustering process having examined their interrelatedness and the result presented three clusters which are indicated thus. Cluster 1: Barriers related to cost and financial resources. This cluster includes barriers that are primarily associated with the costs and financial resources required for the adoption of robot-assisted construction approach. These barriers include high costs of acquiring technology, high costs of maintaining technology, high cost of training workers, lack of capital required to implement technology, high cost to update technology, and difficulty in acquiring technologies due to unavailability. These barriers highlight the financial challenges that may hinder the adoption of robot-assisted construction approach in the South African built environment. The costs associated with technology acquisition, maintenance, and training of workers, as well as the availability of capital for implementation and updates, may be perceived as barriers by construction stakeholders, especially smaller firms or those with limited financial resources. These barriers may require careful financial planning and investment strategies to overcome and ensure successful adoption of robot-assisted construction approach.

Cluster 2: Barriers related to human factors and knowledge/skill. This cluster includes barriers that are related to human factors and knowledge/skill requirements. These barriers include the risk of job loss caused by technology, resistance to implementation of technology by workers, lack of knowledge on how to operate technology, difficulty in understanding technology, and time-consuming nature of educating employees. These barriers highlight the importance of addressing the human aspect of technology adoption in the construction industry. Resistance from workers, concerns about job loss, and lack of knowledge or skills to operate and understand the technology may hinder the successful implementation of robot-assisted construction approach. Overcoming these barriers may require effective change management strategies, comprehensive training programmes, and communication efforts to ensure the acceptance and readiness of workers towards the adoption of robot-assisted construction approach.

Cluster 3: Barriers related to technology compatibility and power supply. This cluster includes barriers that are related to technology compatibility and power supply. These barriers include causes of construction technology fragmentation, inadequate compatibility of technologies with current practices, and the need for constant power to operate the technology. These barriers highlight the challenges associated with the compatibility of technology with existing construction practices and the availability of reliable power supply. Construction stakeholders may face challenges in integrating new technologies into their current processes, which may result in fragmentation and incompatibility. Additionally, the requirement of constant power supply for the operation of technology may be a concern in certain regions or construction sites with inconsistent or limited power supply. Addressing these barriers may require thorough assessment of technology compatibility, identification of power supply solutions, and modification of existing practices to ensure smooth integration of robot-assisted construction approach into the South African built environment.

## 5 Conclusion and Recommendation

This research aimed to identify and evaluate the barriers to the adoption of robot-assisted construction operations in the South African built environment. The quantitative research approach was employed, and data was collected through a well-structured questionnaire administered to construction of industry professionals in Gauteng Province, South Africa. The findings revealed the top three perceived barriers to be the risk of job loss caused by technology, high costs of acquiring technology, and high costs of maintaining technology. Other barriers such as resistance to implementation of technology by workers, high cost of training workers, lack of capital required to implement technology, and the need for constant power supply were also identified. The barriers were also clustered into three which are barriers related to cost and financial resources; barriers related to human factors and knowledge/skill; and barriers related to technology compatibility and power supply. Based on the findings, several recommendations can be made to address the identified barriers to the adoption of robot-assisted construction operations in the South African built environment. Firstly, stakeholders in the construction industry, including government, construction companies, and technology providers should work together to create awareness and educate workers about the benefits of construction automation and robotics. This could include training programmes and workshops to familiarize workers with the technology and alleviate concerns about job loss. Secondly, efforts should be made to address the high costs of acquiring and maintaining technology. This could involve exploring options for financing or subsidizing the costs, promoting local manufacturing of construction automation and robotics technologies to reduce import costs, and incentivizing companies to invest in these technologies through tax breaks or other financial incentives. Thirdly, strategies should be developed to address the resistance to implementation of technology by workers. This could involve involving workers in the decision-making process and providing opportunities for them to contribute ideas and feedback, as well as addressing any concerns or misconceptions they may have about the technology. Additionally, training programmes should be developed to provide workers with the necessary skills to operate and maintain the technology, and these programmes should be affordable and accessible to ensure widespread adoption.

While this research provides insights into the barriers to the adoption of robot-assisted construction operations in the South African built environment, there are several areas for future research that could further enhance our understanding of this topic. Future research could be conducted to understand the perceptions and attitudes of workers towards construction automation and robotics, including their concerns, fears, and expectations, and how these perceptions may influence their willingness to adopt and embrace these technologies. In conclusion, this research has shed light on the barriers to the adoption of robot-assisted construction operations in the South African built environment and provided recommendations for addressing these barriers. Further research in the areas outlined above could contribute to the development of effective strategies for promoting the adoption of construction automation and robotics in the South African construction industry, leading to improved productivity, quality, and safety in the construction processes.

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## References

1. Akinradewo O, Oke A, Aigbavboa C, Mashangoane M (2018) Willingness to adopt robotics and construction automation in the South African construction industry. In: Proceedings of the international conference on industrial engineering and operations management, Pretoria/Johannesburg, South Africa, pp 1639–1646
2. Akinradewo O, Oke A, Aigbavboa C, Molau M (2021) Assessment of the level of awareness of robotics and construction automation in South African. In Collaboration and integration in construction, engineering, management and technology. In: Proceedings of the 11th international conference on construction in the 21st century, London 2019, pp 129–132). Springer
3. Bakuli DL (1994) Pitfalls in technology transfer: Kenya's construction industry. World Dev 22(10):1609–1612
4. Balaguer C, Abderrahim M (2008) 'Trends in robotics and automation in construction'. In: Robotics and automation in construction [Preprint]. https://doi.org/10.5772/5865
5. Bock T (2016) The future of construction automation: technological disruption and the upcoming ubiquity of robotics. Autom Constr 59:113–121. https://doi.org/10.1016/j.autcon.2015.07.022

6. Delgado JMD, Oyedele L, Ajayi A, Akanbi L, Akinade O, Bilal M, Owolabi H (2019) Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. J Build Eng 26:100868
7. Devapriya KAK, Ganesan S (2002) Technology transfer subcontracting in developing countries through. Build Res Inf 30(3):171–182
8. Economic Planning Unit (2015) The Malaysian economy in figures. Prime Minister's Department
9. Elattar SMS (2008) Automation and robotics in construction: opportunities and challenges. Emirates J Eng Res
10. Fellows R, Liu A, Fong CM (2003) Leadership style and power relations in quantity surveying in Hong Kong. Constr Manag Econ 21(8):809–818
11. Fellows RF, Liu AM (2021) Research methods for construction. John Wiley & Sons
12. Follini C, Magnago V, Freitag K, Terzer M, Marcher C, Riedl M, Giusti A, Matt DT (2020) BIM-integrated collaborative robotics for application in building construction and maintenance. Robotics 10(1):2
13. Harinarain N, Bornman CL, Botha M (2013) Organisational culture of the South African construction industry. Acta Structilia: J Phys Dev Sci 20(1):22–43
14. Jain S, Phadtare M (2013) A proposed 'model for adoption' of high technology products (robots) for Indian construction industry
15. Jones TL, Baxter M, Khanduja V (2013) A quick guide to survey research. Ann R Coll Surg Engl 95(1):5–7. https://doi.org/10.1308/003588413X13511609956372
16. Kangari R, Halpin DW (1989) Potential robotics utilization in construction. J Constr Eng Manage 115(1):126–143
17. Kirchberger MA, Pohl L (2016) Technology commercialization: a literature review of success factors and antecedents across different contexts. J Technol Transf 41:1077–1112
18. Koskela L (2003) Is structural change the primary solution to the problems of construction? Build Res Inf 31(2):85–96
19. Kumar VSS, Prasanthi I, Leena A (2008) Robotics and automation in construction industry. In AEI 2008: Building Integration Solutions (pp. 1–9)
20. Mahbub R (2015) Barriers of implementation of automation and robotics technologies in the construction industry. Int J Innov Manage 3(1):21–36
21. Mahbub R (2015b) Framework on the barriers to the implementation of automation and robotics in the construction industry. Int J Innov Manage
22. Mahbub R (2008) An investigation into the barriers to the implementation of automation and robotics technologies in the construction industry (Doctoral dissertation, Queensland University of Technology)
23. Mistri PS, Rathod HA (2015) Remedies over barriers of automation and robotics for construction industry. Int J Adv Res Eng Sci Manage, pp. 1–4
24. Nasrun M, Nawi M, Baluch N, Bahauddin AY (2014) Impact of fragmentation issue in construction industry: an overview 3 discussions: fragmentation issue. In: Building surveying, facilities management and engineering conference, vol 15, p 8
25. Nawi MM, Lee A, Azman MNA, Kamar KAM (2014) Fragmentation issue in Malaysian industrialised building system (IBS) projects. J Eng Sci Technol 9(1):97–106
26. Oke A et al (2019) Benefits of construction automation and robotics in the South African construction industry. In: IOP conference series: earth and environmental science. Institute of Physics Publishing. https://doi.org/10.1088/1755-1315/385/1/012063
27. Quintero-Dávila M, Monteiro SN, Colorado HA (2019) Composites of Portland cement and fibers of Guadua angustifolia Kunth from Colombia. J Compos Mater 53(7):883–892
28. Robinson RM, Kothera CS, Wereley NM (2014) Control of a heavy-lift robotic manipulator with pneumatic artificial muscles. In: Actuators Vol 3, No. 2, pp. 41–65, MDPI
29. Sadique A, Mahesh G (2016) Barriers to mechanization and automation in Indian construction industry. Int J Eng Res Sci Technol 3(1):11–14
30. Siegwart R, Nourbakhsh I (2004) Intro to autonomous mobile robots. Intelligent Robots and Autonomous Agents Series, Mit Press. http://books.google.com.br/books

31. Waroonkun T, Stewart RA (2008) Modeling the international technology transfer process in construction projects: evidence from Thailand. J Technol Transf 33:667–687
32. Yahya MYB, Hui YL, Yassin ABM, Omar R, anak Robin RO, Kasim N (2019) The challenges of the implementation of construction robotics technologies in the construction. In: MATEC Web of Conferences Vol 266, p. 05012. EDP Sciences
33. Zavadskas EK (2010) Automation and robotics in construction: International research and achievements. Autom Constr 19(3):286–290. https://doi.org/10.1016/j.autcon.2009.12.011

# Accessibility to the Built Environment for Mobility-Impaired Persons: A Review

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## 1 Introduction

Disabled persons are developing “from invisible citizens to agents of change”, explained [16], but their journey towards their ultimate goal, equal rights with able-bodied people, is very long. This is particularly obvious with accessibility to the built environment (BE). One reason is that buildings are principally designed by non-impaired architects and constructed by able-bodied builders. For mobility-impaired persons, there is often great apprehension when approaching a building for the first time as to whether they can access it. However, now a greater effort is being made by governments to understand the needs of the mobility-impaired community due mainly to the advocacy of disability organisations and their members. Nevertheless, it is almost impossible for able-bodied people to envisage being mobility-impaired, which creates a gap between what disabled people need and what designers and lawmakers perceive is required. Furthermore, in 1998, Imrie and Kumar found regulatory controls which oversee disabled people’s access were weak.

Generalising all people with disabilities in a population is common, whereas each impairment is distinct and has its own needs. People with mobility impairments use wheelchairs, mobility scooters, canes walkers, and other mobility assistance methods. They try to overcome their confining restrictions personally only to be challenged by the attitude of others and architectural barriers in the urban environment, according to Lid and Solvang [33]. As Green [25] pointed out, not all buildings are intentionally inaccessible, many are so, due to a lack of understanding of the mobility-impaired needs. Understanding the range of needs to be considered in accessible buildings can take time and effort. For example, a building which meets the legal existing standards may be inaccessible because mobility scooters cannot

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manoeuvre within the space allowed by those standards [20]. Jackson and Laws believe builders do not understand the differential needs of persons with disabilities.

### *1.1 A Short History of Disability in New Zealand and Internationally*

Historically many disabled persons suffered harsh discrimination. In early New Zealand settlement, Pakeha viewed disability as an individual flaw, whereas Māori saw it as part of human diversity. Only families and charitable aid provided support [30]. Reference [37] referred to the 1899 Immigration Restriction Act, which prohibited immigrants deemed a burden and sought to deter disabled people. Because of this, the BE developed without considering the needs of the disabled [22]. When World War I wounded and disabled soldiers returned, they challenged this cruel theory of eugenics. However, Sullivan and Stace [45] found that little changed until World War II ended, and the Rehabilitation League was established. Finally, for the first time, the nation had to change for disabled people, not vice versa. Despite this view, the Accessibility for New Zealanders Act (ANZA), which was recently announced as a law ensuring accessibility to the BE for the mobility-impaired, has fallen far short of what the New Zealand disability community expected. It states, in s.3, that its purpose "is to accelerate progress towards a fully accessible New Zealand". To that end, s.2 of the ANZA establishes the Accessibility Committee to:

(a) Identify accessibility barriers in New Zealand society;
(b) Progressively work towards preventing and removing accessibility barriers in New Zealand society; and
(c) Progressively work towards growing accessibility practices across New Zealand.

It is, however, a great disappointment to the disabled community as it appears only to provide for the establishment of an advisory committee.

### *1.2 The Progress Made Internationally*

The situation in the U.K. was similar to that in New Zealand; people who were not cared for by family, charities, or medical professionals in institutions simply had to look after themselves [7]. However, things also began to change there with the return of soldiers from the wars, particularly World Wars I and II. This led to the passing of the Disabled Persons Employment Act on 1 March 1944 [36]. This Act introduced compulsory hiring of disabled people, as well as granting power to the relevant ministry to appoint certain employment fields only to be open to disabled people. Although this would be labelled discrimination today, it opened up new avenues and opportunities for disabled persons.

For disabled persons internationally, the progress to emancipation has equalled this struggle. Moyn [40] suggested that human rights were not recognised as grounds for justice until after 1968. People thought of human rights as protection for all people endorsed by the force of international law. Nevertheless, without the United Nations, the forward-thinking Declaration of Human Rights would not have been adopted. Arguments and counterarguments were set forth, often due to the perspective of human rights by the various nations, mainly the Soviet Union [35]. After much debate, the discussions led to the Declaration's final form. Elston [19] noted that it had become more than was claimed when it was finally adopted by the General Assembly of the United Nations in December of 1948. Nevertheless, fifty years after the drafting of the Declaration, political scientists seemed to have no interest in international human rights, and only a few published articles made passing mention of them [23]. The human rights interest did not revive until the adoption of the Convention on the Rights of Persons with Disabilities (CRPD). The CRPD is an international treaty of the United Nations, which came into force on 03 May 2008, and is ratified by 185 countries, "but not the United States", Kanter [31] points out. The 50 articles of the treaty are recognised as the definitive global standards to which all who have ratified them strive to attain. Early endeavours to persuade the General Assembly that a convention concentrating on people with disabilities should be drafted were unsuccessful for decades [15]. However, continual persistence by the global disability population demanding that disability issues become mainstreamed led to interest from other human rights organisations such as Amnesty International and Human Rights Watch although both remained at arm's length with their support [34]. At last, after persistent pressure from the disability community, a committee was set up for a meeting to examine the recommendations for a convention. This was scheduled to meet for the first time in July 2002. All member states were invited. Disabled persons' organisations from all around the world sent representatives, however, right from the first day, it was obvious there was no clear mandate. The Government of Mexico had been pushing for the General Assembly to "develop a human rights convention in relation to persons with disabilities" since 2001, according to Kayess and French [32]. Eventually, Mexico was successful, encouraging other delegates "ready or not" to begin negotiations for a convention. After much debate, and with only minutes until the meeting ended, the Committee agreed to Disability Negotiations Bulletin Vol. 2 No. 6, 23 June (2003). At last, these groups and governments were "sitting at the same table" negotiating a text which would be legally binding [16]. Graham et al. [24] reported that after five years of negotiations, the CRPD was adopted by the United Nations in 2006. One significant problem is the complaints-based enforcement system of the CRPD. Elmas [18] explains that the main challenge is that enforcement decisions are made by a committee which is comprised of various state members. He suggests that these committees may impose the will of their own jurisdictions which may weaken the strength of these decisions. If Article 2 of the CRPD could be changed to an enforcement policy backed by the strength of international law through the International Court of Justices, which is the principal judicial organ of the United Nations, it may strengthen the enforcement power. However, the effectiveness of that court is questionable and has been under scrutiny over the years [29].

### 1.3 The Focus of the Study

This research will examine two aspects of (in)accessibility to the built environment, namely from a compassionate point of view and a legal vantage. For many mobility-impaired, life is a struggle. They often cannot get employment which means they are restricted to living on a benefit which reduces their quality of life. For able-bodied people who make an effort to achieve it, a reasonable standard of living can generally be enjoyed. The law, which is meant to provide accessibility for all, sometimes discriminates against those it is meant to benefit because of the inability of able-bodied people to empathise with the mobility-impaired. Designers and builders seek to cut corners when constructing buildings, which may prevent someone with a disability from accessing the building. It may be a simple matter of putting a few steps in a place where a ramp is needed. This review discusses chronicled experiences of mobility-impaired people and correlates their needs with existing attitudes and current law. Principally, it assesses the ANZA legislation, which is currently progressing through the New Zealand parliament, as to its commensurate ability to meet these needs. This bill is to be reported back to parliament on 22 June 2023 and hopefully will progress to its second reading at that time.

## 2 Method

A content analysis of literature was undertaken, many of which were academic papers written during the last 10 years, comprising information pertaining to accessibility, universal design, mobility impairment, and the built environment. For inclusion in this review, the researchers sought literature that focussed on both accessibility and mobility impairment. Thus, an article which addressed accessibility without referring to disability impairment was not deemed suitable. However, a consideration of one or the other in articles about universal design in the built environment were included in the review. Book chapters were often found not applicable, so most were excluded. The review includes analysis of comparative international law and their applicable standard regulations. Finally, government statistical reports were reviewed with very sparse disappointing results, as mobility-impaired disabled persons were rarely included in census enumeration. The review was restricted only to English-written articles.

## 3 Results and Discussion

The results of researching accessibility for the mobility-impaired to the BE from the two distinct areas, namely the legal aspects, which mandates the rules that designers and building practitioners must meet when constructing the built environment and the practical or functional aspects, which give the mobility-impaired an increased quality of life are presented in this section.

### *3.1 The Law on Accessibility in the Built Environment, New Zealand*

In New Zealand, three documents guide the design of buildings—the Building Act 2004 (also known as the Act), the Building Regulations 1992 (generally referred to as the Building Code and abbreviated as ‘BC’) and the New Zealand Standard NZS 4121:2001. These must be complied with for all building consents.

The Act is the primary legislation governing the New Zealand building industry. It establishes the rules that all construction in New Zealand must meet. This research concentrates on accessibility to the built environment for mobility-impaired persons and the rules found in s.117 to s.120 of the Act. The Act lists the types of buildings which must be accessible in schedule two of section 118(2).

The secondary legislation is the Building Code (BC) which lies directly beneath the Act. The BC details the minimum requirements for buildings to meet by setting performance standards. Being performance-based, the BC does not outline how the buildings must be built but rather how they must perform. The building owner is legally bound only to meet the requirements of the BC.

The third document, New Zealand Standard NZS 4121:2001 on Design for Access and Mobility—buildings and associated facilities provides solutions to various construction features that comply with the performance criteria in section 118(2) of the Building Act.

The issue with these laws is the lack of “enforcement” and loose expectations in the regulations. For example, within the Act are the regulations, which contain prescriptive forms and detailed systems. They define things such as “nearly as is reasonably practicable” in s.115 (a) and (b) of the Act, which are not actions of Parliament but made under the delegated authority of an Act.

These regulations often cause significant problems to consenting authorities (such as council building inspectors) in issuing a building consent, as they must accept evidence of compliance if the Building Code is met. NZS 4121 allows designers and builders to use either verification methods or acceptable solutions that are possibly admissible “as nearly as is reasonably practicable”, also mentioned in s. 112 (1) of the Act. This allows some designers and architects to meet these demands in many original and ingenious ways.

Cox et al. [14] brought to light a common problem today, namely that "many private dwellings now function as businesses". For instance, many day care centres, boutique stores, and even medical and dental surgeries in New Zealand are set up in residential structures. These conversions, often termed refurbishments, are not mentioned in the Building Act 2004 and allow designers and building owners to escape the need to meet the code and the accessibility standards. Researchers have suggested the favoured choice for owners would be to select a dwelling that only needed minor or nil changes to allow disability access. This would cost less, comply with the NZS 4121 standard, and avoid using language to circumnavigate the legal requirement. Such a strategy would comply with the law and cost less to retrofit.

It can be said that the accessibility for New Zealanders Act is more an Act for the purpose of setting up a committee and less for the purpose of designing buildings for accessibility. The 27 sections of the Act are devoted to the committee's establishment, membership, powers (which are only advisory), functions "and other matters". When the legislation was announced, it raised expectations of improved accessibility within the disability community. The Access Alliance (AA), a disability organisation, has been tirelessly campaigning against the legislation in its present form and suggested that legislation with a name such as ANZA should have, as a minimum, the following key principles (Access [1]):

(1) It applies to all; and
(2) It sets a timeline; and
(3) It sets the bar; and
(4) It provides accessibility in all areas of life; and
(5) It sets policy; and
(6) It champions access to all goods, services, and facilities; and
(7) It champions accessible workplaces, employment, education, and government agencies; and
(8) It will charge government with the responsibility to lead, educate, train, inform and review; and
(9) It is enforceable; and
(10) It is made real through regulations; and
(11) It will ensure public funds are not used to create or perpetuate obstacles to full accessibility in all areas of life; and
(12) It is a lens through which to vet legislation; and
(13) It has real force and real effect.

These principles are a very acceptable starting point for an Act given the name "Accessibility for New Zealanders Act". As suggested above, any law which proposes change for a segment of a community should state to whom it applies. A timeline must be given; otherwise, it has little value. It is stated that the bill will come into force on 1 July 2024, if not earlier, but that deadline is for the establishment of a committee focused on making recommendations to the Minister for Disability Issues on how to address accessibility barriers. This seems to be its ultimate goal, as the committee will only have advisory powers.

Also, accessibility legislation must clarify which of the parties are obligated to meet its requirements. It must state what areas, such as employment, education, and justice (to name a few) will be subject to its sanctions. It must also define whether the government is subject to this law and its obligation in that respect. All sections of ANZA must be enforceable, as should any standards which apply to it. The regulations must clearly define the complete compliance steps within the ANZA and have a definitive review period.

The 11th AA principle may be a difficult section to enforce. It will need to be carefully worded because many government departments funded by public money will be obligated parties under this law. Principle 12 is another critical section in that many existing applicable international laws are not updated when new ones are enacted, leaving them open to grounds for dispute. Principle 13 may be superfluous because if all other principles are covered, this one will be incorporated in them.

## *3.2 An Insight into International Laws on Accessibility in the Built Environment*

Although internationally there is law which intends to protect persons with disability, there is very little law that relates specifically to accessibility. This is discussed below, using the USA and the UK as examples.

### 3.2.1 The Americans with Disabilities (ADA) Amendment Act of 2008, USA

In the USA, the ADA Amendment Act of 2008 is an update on the Americans with Disabilities Act of 1990. It is very long and complex, with many cross-references supported by the 2010 ADA standards for accessible design. The standards are enforceable and interspersed throughout the ADA, but with the innumerable cross-references, the law is very difficult to follow. Aldousari et al. [3] pinpointed the main problem with the performance of the 1991 ADA legislation (which had been updated) is that it is underpinned by poor intersectional coordination and inadequacy of capacities. Moreover, it is divided into three sections (called ‘titles’) whose emphasis is concentrated on the non-discrimination of disabled people, rather than accessibility.

Title I centres exclusively on non-discrimination in employment. Title II—Public Services s.201 defines a person who must not be discriminated against as a “qualified individual” and details a complex list of requirements which must be met in order to qualify. Accessibility is first addressed in s.228 (2) (A) of this Act when it states that railway stations “shall be made readily accessible to and usable by individuals with disabilities”. Section 242 (3) deals with single-level coaches, which are required in (D) (A) “to have a restroom which is usable by a person in a wheelchair and can be entered from the station platform”. The only exception allowed is in s.242 II due to "extraordinarily expensive structural changes being needed". Section 245 relates to rail cars which also must be accessible on condition that they are not inconsistent with this section. Title III—Public Accommodations and Services operated by Private Entities follows and commences at s.301. Accessibility, as it applies to mobility-impaired persons, is first found in s.305 in reference to accessibility to buses, cars, and services but refers back to s.304 and forward to s.306. It then leaps to s.506, where it discusses the related standards, the 2010 ADA Standards for Accessible Design. These standards are enforceable if the structure was built after 26 January 1992, according to s.35.151 (a).

### 3.2.2 The Equality Act (EA), United Kingdom

The Equality Act [21] in the United Kingdom requires everyone, including the government, to consider "reducing socio-economic inequalities" whenever cardinal decisions are made [26]. The intent is that this will reduce discrimination and harassment and increase equal opportunity for all, however this law is also complex and does not flow which would be conducive to following and understanding. Accessibility is first voiced in s.88, which directs the reader to schedule 10, where a comprehensive set of rules that provide accessibility for disabled children are detailed. Accessibility is next addressed in s.160 for the Secretary of State to make a regulation that ensures disabled people, as well as those who need wheelchairs, are able to enter, travel, and exit taxis safely with reasonable comfort. Gaining a taxi licence is conditional on these requirements in s.163, while s.164 provides the exemptions if the authority is satisfied that s.163 should not apply. A mobility-impaired person may have a dog with them in a private hire vehicle under s.173 (c) if the requirements of the EA are met. A public service vehicle may not be used on a road unless it has an "accessibility certificate" s.176 (1). Rail vehicles must comply with similar requirements as road vehicles, as detailed in s.182 to s.186. Only two exemptions to the EA apply to rail vehicles in s.183. (1) to (7). Nevertheless, 115 exceptions are referred to throughout the EA, and these are explicit and detailed so that they may encourage frivolous attempts to justify non-compliance and circumnavigate the law. The BS 8300-2:2018 standards also support accessibility to the built environment, but are not linked to the Equality Act.

## *3.3 The Compassionate View*

Notwithstanding that it is fifteen years since the CRPD was adopted, disabled people are still experiencing considerable inaccessibility issues. This is not only in third-world countries but in many of the leading Western economies of the world. Bordas [6] found that architects and planners needed more than a general knowledge of regular barrier-free requirements when designing the built environment. If they had no understanding of the realities of life for disabled people, they would be incapable of meeting their needs beyond the functionality and usability concerns. He thought empathy was essential to success in achieving inclusive architecture. Du and Kim [17] also cautions "that one size does not fit all". This is important to consider when comparing international standards with New Zealand's standards on accessibility for mobility-impaired users.

Other problems arise when making comparisons of accessibility standards in different countries. One reason is that in countries such as the USA, Australia, and Canada, some states/regions have their own separate standards, which often conflict with Federal law. The current standards in New Zealand, America, and Britain for some of the common features of buildings such as ramps, entrances, lifts, stairs, toilets, and washbasins are presented below. In general the standards for three countries are relatively similar but it can be seen that the New Zealand standard allows a much shorter clearance in the ramp landing length (Table 1) which could be a problem for manoeuvring a mobility scooter. Regarding entrances (Table 2), the British standards dictate a longer entrance threshold which would benefit large scooter users. The American standard requires a much larger clear unobstructed floor depth in front of lift doors (Table 3) that would again be most-appreciated for the MI using these assistance devices.

**Table 1** Comparison between New Zealand, American, and British standards for ramp features

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Ramp width (mm) | 1,200 | 1,065 | 1,000 |
| Cross slope | 1:50 | 1:48 | 1:50 |
| Clear ramp landing length (mm) | 1,200 | 1,525 | 1,500 |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

**Table 2** Comparison between New Zealand, American, and British standards for entrance features

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Entrance width | A level threshold or approach space no less than 1200 mm × 1200 mm inside and outside the entrance door | Principal entrances in new buildings should be accessible. Approach should be level and shall be 1220 mm of clear floor space for wheelchairs | The area immediately in front of the accessible entrance (at least 1500 mm × 1500 mm) should be level and have a surface which does not impede wheelchairs |
| Distinguishability | Must be illuminated to be clearly distinguishable from the surroundings | Must be easily distinguishable from the façade | Signs should be obvious and clearly identified by tonally contrasting with the wall |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

**Table 3** Comparison between New Zealand, American, and British standards for lift features

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Clear unobstructed floor depth in front of lift doors (mm) | 1800 | 2030 | 1500 |
| Interior clear space (mm) | 1400 × 1400 | 2030 × 1370 | 1400 × 1100 |
| Door clear minimum opening (mm) | 900 | 900 | 900 |
| Control panel minimum to maximum height (mm) | 900–1350 | 1370 | 900 |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

Each standard mandates handrails on either side of stairs (Table 4) which would only be of use if the stair width was less than the outstretched arm width of an MI able to walk but probably restricted by having to use a cane. Disability toilet sizes vary significantly (Table 5) and are a constant problem for MI persons as most are usually designed only with wheelchairs users in mind. The main problem with washbasins (Table 6) seems to be with soap and towel dispensers that are out of reach of both children and adults. The UK updated its standards in 2018, while in the USA the Access Board which is an independent federal agency continually upgrades standards for people with disabilities. It will be important to identify common grounds and improvement opportunities in future papers.

**Table 4** Comparison between New Zealand, American, and British standards for stairs and handrail features

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Risers | The total rise of any flight of stairs must not exceed 2500 mm. Open risers are not permitted | Risers must be between 100–180 mm high. Open risers are not permitted | Risers must be between 150–170 mm high. Flights should not contain more than 12 risers between landings. Open risers should not be used |
| Design | Spiral stairs not permitted | Spiral stairs not mentioned | Spiral stairs not recommended |
| Handrails | There must be a handrail on either side of the stairs | There must be handrails on both sides of the stairs | There must be handrails on both sides of staircases more than 1000 mm wide |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

**Table 5** Comparison between New Zealand, American, and British standards for toilet features

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Minimum dimensions of compartment (mm) | 1900 × 1600 | 1525 × 1420 | 2000 × 800 |
| Toilet pan distance from back wall (mm) | 700–750 | 1420 | Approximately 600 |
| Height of toilet pan from floor (mm) | 460 | 485 | 480 |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

**Table 6** Comparison between New Zealand, American, and British standards for washbasin

| Feature | New Zealand[a] | America[b] | Britain[c] |
|---|---|---|---|
| Height from floor (mm) | 675 | 635 | 720–740 |

[a] NZS 4121 [42]
[b] ADA [4]
[c] British Building [9]

### 3.3.1 Ramps

Most countries follow accessibility standards that are similar to the NZS 4121 [42] standard and the British Building [9], except for narrow variances in some instances. The U.S.A. follows the ADA [4] requirements that allows a slightly steeper slope on ramps for getting up short distances with small height changes. The accessibility standards for these countries are given in Table 1.

### 3.3.2 Entrances

Accessible entrances in the built environment still need to be improved. While they do provide adequate access to the interior of buildings, little thought is given to how the mobility-impaired can get to the building entrance itself. The approach often requires a long journey around the building to some back entry access ramp. This is something that should be considered by all construction industry stakeholders connected with the construction and design of buildings. Table 2 gives the standards for entrances for New Zealand, America and Britain.

### 3.3.3 Lifts

Thought must be given to the variability of mobility-impaired persons in terms of both their mode of travel and their ability. For example, people using both wheelchairs and mobility scooters should be able to manoeuvre within buildings, particularly when using lifts (since they cannot use stairs). Table 3 compares the standards for lift features.

### 3.3.4 Stairs, Steps, and Handrails

Table 4 compares the standards for stair features. Rounded nosings are recommended because sharp angles on stair edges are a trip hazard. Each standard mandates handrails on either side.

### 3.3.5 Toilets

Table 5 lists the requirements for toilet features. The standards are specific on the distance and pans must be from the back wall. However, the handrail position relative to the pan is not always specified and this can be a problem when wheelchair users transfer.

### 3.3.6 Washbasins

Table 6 gives the standards for washbasin height. Even when washbasins meet the required standards, small children may be too short to reach the basin.

### 3.3.7 The Problem of Public Attitude

One major problem not often researched is public indifference. Zlatanova-Velikova [46] noted that the lack of opportunities for mobility-impaired participation in social activities lies in the complete indifference and ignorance of those without physical limitations. Pascalau-Vrabete [43] found also that a lack of interest from the government "created considerable barriers". She claimed that "no amount of promissory legislation" would change that position until that viewpoint changed. However negative social and institutional attitudes towards disability still prevail, and need to be challenged [43]. Other noted scholars have also mentioned this. In 2011, Seelman et al. noted that the World Health Organisation reported that physical disabilities were dramatically increasing, particularly among the elderly, because they were living longer while becoming frailer and falling frequently. She also found that they were reporting a range of accessibility barriers. This is more noticeable even to the casual observer today, as better health care keeps people alive longer but cannot cure their mobility impairment.

Discussions with elderly mobility-impaired have confirmed this. Distress at declining functional abilities and resultant performance meant they often lost accessibility to favoured destinations. Table 7 summarises the reported problems.

**Table 7** Anecdotal problems faced by mobility-impaired New Zealanders

| Category | Description |
|---|---|
| Stairs | Dental practice on the second floor without a lift. This was inaccessible to a wheelchair user who had to change to a different dentist |
| Escalators | An elderly mobility-impaired person fell while attempting to step on an escalator, hitting another elderly person who also fell. Both were hospitalised with broken bones, which may have added to their impairment |
| Escalators | The speed of the moving stairs is too fast for elderly people and they approach them with increased apprehension |
| Parking | A mobility-impaired person attending an emergency surgery was unable to get a parking space outside the building and had to use the mobility park across a busy street. The council was approached regarding the normal parking outside the building and the mobility parking across the street. Their reply was that it was not council policy to reside parking outside private businesses |
| Wheelchair | A mobility-impaired person in a wheelchair spoke of having to go "all the way around to the back of the building" where there was a small service lift. This person who had arrived in a party felt discriminated against as the other members were able to use the front steps to the foyer and the passenger lift to the floor where they were attending a meeting |
| Empathy | Finally lack of empathy can be a problem for mobility-impaired people who are cared for in their homes as able-bodied carers cannot understand why they take so long to do simple tasks and become impatient with them which causes friction between the mobility-impaired and the carer |

### *3.4 Additional Gaps in Legislation*

Additionally, gaps in disability law are also highlighted. The separation of the NZS 4121 and the law is obvious in New Zealand. This standard is specific in measurement, but it is not the law. It allows designers and builders to use either verification methods or acceptable solutions which are possibly admissible "as nearly as is reasonably practicable", which is also mentioned in s.112 (1) of the Act. However, Mulligan et al. [39] comments that because these standards which exceed the legislation are not obligatory, they are recommendations only. This means that adherence is not mandatory and sometimes not complied with.

The Americans with Disabilities Act of 1990 is very long and complex, with many cross-references supported by the 2010 ADA standards for accessible design. The standards are enforceable and interspersed throughout the ADA, but with the innumerable cross-references, the law is very difficult to follow. Aldousari et al. [3] pinpointed the main problem with the performance of the 1991 ADA legislation (which had been updated) as underpinned by poor intersectional coordination and inadequacy of capacities.

The British Standards are the building regulations [9]. These were updated in 2015, but according to Bright [8], the design guidance for "buildings other than dwellings in AD M: 2015 is substantially the same as those given in the AD M 2004:2013 edition". The wording of the EA has not been updated. It has many protracted legal descriptions. He also noted, that “in terms of simplification, it has been an opportunity missed”.

The Accessibility Act for New Zealanders 2022 (ANZA), which was announced as a law that would ensure accessibility to the BE for mobility-impaired, has fallen far short of what the New Zealand disability community expected. It states in s.3 that its purpose “is to accelerate progress towards a fully accessible New Zealand”, but instead merely establishes the Accessibility Committee tasked with identifying accessibility barriers and working towards improving accessibility. The disability community are dismayed: after years of lobbying for the accessibility specified by Article 9 of the CRPD, they expected robust enforceable accessibility law which would give them that. They felt the government’s intent was simply to establish an advisory committee with little power other than to advise the government on how to action improved accessibility. They feel that accessibility legislation should be the primary driver to assist disabled people to access the built environment.

## 4 Conclusions

Even with the advent of the CRPD, updated disability law, and revised accessibility standards, the current built environment often fails the mobility-impaired person. Yet it is an issue which able-bodied designers and building practitioners rarely address seriously because they are unable to empathise with disability. This aspect is not often considered by researchers. Nevertheless, without empathy, it is difficult for building planners to understand what is needed for mobility-impaired to have a similar quality of life to the able-bodied when accessing the built environment. The apathy of the general public is another factor which must change, for, if indifference to the mobility-impaired persists, they will continue to have accessibility barriers, repeatedly challenging their potential quality of life, which surely is the right of everyone.

Further, long complex law that is mainly incomprehensible to the people it was drafted to protect, is of little use. Imprecise terms such as “as nearly as is reasonably practicable” are open to opinion and can be interpreted to the disadvantage of those it should benefit. We should all have the protection of the law, otherwise it is inadequate. In New Zealand the disability community welcomed the announcement of the introduction of the “Accessibility for New Zealanders Bill” with eager anticipation, feeling that something they had been fighting so long for was finally coming to fruition. When it was introduced and the mobility-impaired people discovered its contents, they were very disillusioned, as all the bill appeared to do was to set up a committee. They were so incensed that they protested strongly until they were heard. The latest reports are that Priyanca Radhakrishnan, the Minister for Disability Issues has stopped all action on the progress on the bill in the term of the present government.

Disability law internationally is fragmented, standards are sometimes divorced from the legislation to which they apply, and the legislation is rarely enforced. The

CRPD is the only existing document that could possibly strengthen the rights of disabled people internationally because it is ratified by 185 countries. Unfortunately it is not ratified by the United States, so that excludes the disabled community within a 300 million population. The complaints-based enforcement system of the CRPD is weakened because decisions are made by committee members who are biased by their own jurisdictions. Enforcement power would be enhanced if it were done through the International Court of Justices which is the principal judicial organ of the United Nations.

This study has focused on a small selection of standards across only three countries. It has not captured all the subtlety and variation of global accessibility standards. The published literature on accessibility does not provide a comprehensive representation of the situation in developing nations [38]. Third-world countries are likely to have much poorer standards, primarily because they are more economically challenged [31]. People with disabilities in those countries are less likely to be employed, less likely to have access to public transport and more likely to live in a state of poverty.

A further limitation of this work is that it assesses a law that has yet to come into force, and the assumptions made of its ultimate outcome may be in error. The focal point of this research is the perceived failings of society and accessibility law to provide the necessary support for mobility-impaired to have the same quality of life which the able-bodied can enjoy. Further research opportunities exist for developing directions for better law enforcement and advancing accessibility guidance to benefit mobility-impaired people. This study may therefore provide the direction for future research into accessibility law.

## 5 Ethics Statement

Not applicable.

**Author Contributions** Margaret Stefanitsis contributes to conceptualisation, methodology, data collection, draft preparation, and manuscript editing. Claire Flemmer contributes to conceptualisation, methodology, draft preparation, manuscript editing, and supervision. Eziaku Rasheed contributes to manuscript review and supervision. Naseem Ameer Ali contributes to manuscript review and supervision. All the authors have read and agreed with the manuscript before its submission and publication.

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## References

1. Access Alliance (2020) Accessibility for New Zealanders Act: Key Principles (2020). Retrieved from Microsoft Word—Accessibility for New Zealanders Act Principles Dec 2020 final.docx (d3n8a8pro7vhmx.cloudfront.net). 3 July 2023

2. Accessibility for New Zealanders Bill (2022). Retrieved from Accessibility for New Zealanders Bill 153-2 (2022) Government Bill—New Zealand Legislation. 3 July 2023
3. Aldousari A, Alghamdi A, Alwadei H (2021) The 1991 Americans with Disabilities Act (ADA) standards for accessible design. Am Res J Humanit Soc Sci 4:59–62
4. Americans with Disabilities Act (ADA) Standards for Accessible Design (2010) United States Department of Justice. Retrieved from https://www.ada.gov/regs2010/2010ADAStandards/Guidance_2010ADAStandards.pdf. 9 Sept 2023
5. Americans with Disabilities Act Amendments Act of 2008 (2008) U. S. Equal Employment Opportunity Commission. Retrieved from The Americans with Disabilities Act Amendments Act of 2008 | U.S. Equal Employment Opportunity Commission (eeoc.gov) 3 July 2023
6. Bordas Eddy M (2017) Universal accessibility: on the need of an empathy-based architecture. Doctoral thesis, Tampere University of Technology, School of Architecture, ISBN 978-952-15-3873-5
7. Borsay A (2004) Disability and social policy in Britain since 1750: a history of exclusion. Bloomsbury Publishing
8. Bright KT (2017) Access to and use of buildings (Part M). The building regulations: explained and illustrated, 17-1, Wiley Online Library. https://doi.org/10.1002/9781119070818.ch17
9. Building Regulations (2010) UK Statutory Instruments, 2010 (2214). Retrieved from https://www.legislation.gov.uk/uksi/2010/2214/contents. 3 July 2023
10. Building Act 2004 (2004) The New Zealand Ministry of Business, Innovation and Employment. Retrieved from Building Act 2004 No 72 (as at 07 September 2022), Public Act—New Zealand Legislation. 9 Sept 2023
11. Building Regulations 1992 (1992) The New Zealand Ministry of Businness, Innovation and Employment. Retrieved from Building Regulations 1992 (SR 1992/150) (as at 15 November 2021) Schedule 1 The building code—New Zealand Legislation. 9 Sept 2023
12. BS 8300-2:2018 (2018) Design of an accessible and inclusive built environment buildings. Code of practice, British Standards Institute, ISBN: 978 0 580 92983 0, 1–232
13. Convention on the Rights of People with Disabilities (CRPD) (2006). United Nations 2006 convention on the rights of persons with disabilities—articles. Retrieved from https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-withdisabilities/convention-on-the-rights-of-persons-with-disabilities-2.html. 9 Sept 2023
14. Cox S, Hocking C, Payne D (2022) Building act reform for building users. Policy Q 18(1):67–76
15. Degener T (1995) Disabled persons and human rights: the legal framework. In: Human rights and disabled persons. E-book ISBN: 978-90-04-47989-0, Brill Nijhoff, 9–39
16. Degener T, Begg A (2017) From invisible citizens to agents of change: A short history of the struggle for the recognition of the rights of persons with disabilities at the United Nations. In: The United Nations convention on the rights of persons with disabilities: a commentary. Springer International Publishing, 1–39
17. Du Y, Kim PH (2021) One size does not fit all: strategy configurations, complex environments, and new venture performance in emerging economies. J Bus Res 124:272–285
18. Elmas KM (2015) Individual complaint mechanism under the unhuman rights conventions: how effective is the mechanism? J Judgments Court Jurisdictional Disputes/Uyusmazlik Mahkemesi Dergisi 6:139–161
19. Elston JL (1973) The Warren Court and Civil Rights: era of positive constitutionalism and egalitarianism. J Thought 8(1):19–39
20. Dutta T, King EC, Holliday PJ, Gorski SM, Fernie GR (2011) Design of built environments to accommodate mobility scooter users: part I. Disabil Rehabil Assist Technol 6(1):67–76
21. Equality Act 2010 (2010) Act of Parliament of the United Kingdom. Retrieved from Legislation.gov.uk 9 Sept 2023
22. Flemmer CL (2022) Improving the built environment for manual wheelchair users: a review. IOP Conf Ser: Earth Environ Sci 1101(3):032031
23. Forsythe DP (1998) Human rights fifty years after the universal declaration. PS: Polit Sci Polit 31(3):507–511

24. Graham LJ, Medhurst M, Malaquias C, Tancredi H, De Bruin C, Gillett-Swan J, Cologon K (2023). Beyond Salamanca: a citation analysis of the CRPD/GC4 relative to the Salamanca Statement in inclusive and special education research. Int J Inclusive Educ 27(2):123–145
25. Green RJ (2011) An introductory theoretical and methodological framework for a Universal Mobility Index (Umobility-impaired) to quantify, compare, and longitudinally track equity of access across the built environment. J Disabil Policy Stud 21(4):219–229
26. Hand J, Davis B, Feast P (2012) Unification, simplification, amplification? An analysis of aspects of the British Equality Act 2010. Commonw Law Bull 38(3):509–528
27. Imrie R, Kumar M (1998) Focusing on disability and access in the built environment. Disabil Soc 13(3):357–374
28. Jackson MA (2018) Models of disability and human rights: informing the improvement of built environment accessibility for people with disability at neighborhood scale? Laws 7(1):10
29. Jennings RY (1995) The international Court of Justice after fifty years. Am J Int Law 89(3):493–505
30. Kain JS (2019) Deportation, Domicile and Mental Deficiency, New Zealand 1899–1930. In: Insanity and Immigration Control in New Zealand and Australia, 1860–1930. Mental health in historical perspective. Palgrave Macmillan, 97–126. https://doi.org/10.1007/978-3-030-26330-0_5
31. Kanter AS (2014) The development of disability rights under international law: from charity to human rights. Routledge. https://doi.org/10.4324/9780203711712,1-359
32. Kayess R, French P (2008) Out of darkness into light? Introducing the convention on the rights of persons with disabilities. Hum Rights Law Rev 8(1):1–34
33. Lid IM, Solvang PK (2016) (Dis) ability and the experience of accessibility in the urban environment. Alter 10(2):181–194
34. Lord JE (2009) Disability rights and the human rights mainstream: reluctant gate-crashes? In: The international struggle for new human rights. University of Pennsylvania Press, 83–92. https://doi.org/10.9783/9780812201345.83
35. Lukina A (2017) Soviet Union and the Universal Declaration of Human Rights. In: Max Planck Institute for European Legal History Research Paper Series, 2017-01, 1–19
36. Malisoff H (1952) The British Disabled Persons (Employment) Act. ILR Rev 5(2):249–257
37. Martens J (2006) A transnational history of immigration restriction: Natal and New South Wales, 1896–97. J Imperial Commonwealth Hist 34(3):323–344
38. Mogaji E, Nguyen NP (2021) Transportation satisfaction of disabled passengers: evidence from a developing country. Transp Res Part D: Transp Environ 98:102982
39. Mulligan K, Calder A, Mulligan H (2018) Inclusive design in architectural practice: experiential learning of disability in architectural education. Disabil Health J 11(2):237–242
40. Moyn S (2012) The last utopia: human rights in history. Harvard University Press. https://doi.org/10.2307/j.ctvjk2vkf, 1–352
41. New Zealand Building Code Handbook (2014) Ministry of Business, Innovation and Employment. Retrieved from Building Code Handbook | Third edition | Amendment 13. 9 Sept 2023
42. NZS 4121:2001 (2001) Standards New Zealand, Design for access and mobility—buildings and associated facilities Wellington New Zealand. Retrieved from NZS 4121:2001: Standards New Zealand on 9 Sept 2023
43. Paşcalău-Vrabete A, Băban A (2018) Is 'different' still unacceptable? Exploring the experience of mobility disability within the Romanian social and built environment. Disabil Soc 33(10):1601–1619
44. Seelman KD (2011) The World Health Organization/World Bank's first World Report on Disability. Int J Telerehabilitation 3(2):11–14
45. Sullivan M, Stace H (2020) A brief history of disability in Aotearoa New Zealand. Office for Disability Issues. Retrieved from A brief history of disability in Aotearoa New Zealand—Office for Disability Issues (odi.govt.nz). 9 Sept 2023
46. Zlatanova-Velikova R (2014) Analysis of disability of persons over 16 years of age in Bulgaria. Econ Bus J 8(1):296–300

# Covid-19 Lockdowns—Effect on Female Worker Well-Being in New Zealand Construction Professions

**David Finnie, Aimee de Klerk, and Nayani Landage**

## 1 Introduction

This study explores the effects on females working in the construction New Zealand (NZ) industry during Covid-19 lockdowns. The way that construction professionals work during the Covid-19 pandemic. The NZ government mandated nationwide lockdowns in 2020 and 2021. Workers for construction companies, other than those undertaking 'essential' work, were required to stay home to slow the rate of infections. Most construction professionals therefore undertook their duties from the isolated constraints of their homes, while trades workers stopped work altogether.

The NZ government is working to implement programmes and improve resources available to promote better mental well-being, and organisations within the construction sector in NZ such as mates in construction (n.d.) are working to increase awareness and improve well-being standards at work. Focusing on the well-being needs of female workers may help improve worker well-being and attract more females in what has historically been a male-dominated industry. Only around 10% of construction industries in most countries are female [16].

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## 2 Literature Review

### 2.1 Women in Construction

Previous studies have found low percentages of women working in construction and that opportunities exist to increase these rates. Regis et al. [16] found that on average worldwide, only 10% of workers on construction sites are women. NZ is working to improve these rates within historically male-dominated industries, but the rates of women joining the construction industry remain very low, with only 13% of the construction workforce population in NZ construction being female [4]. Azhar and Griffin [1] also found opportunities for increasing entrance and retention rates of women in the US construction industry. While the biggest challenge faced was the difficulty maintaining work-life balance, the greatest successes and accomplishments included the increased awareness by both public and private industries to address the issues faced by women in construction. These include a shift in organisational policies to better address the needs of women and increasing leadership roles for women. They recommend that companies partner with women's' organisations to recruit more females into construction and engineering.

Key challenges faced by women working in construction include discriminatory factors, inadequate working conditions, and difficulty maintaining work-life balance. Regis et al. [16] studied the shortcomings, difficulties, and good practices for women working in construction in Brazil and found key challenges to include prejudice, discrimination, sexism and the gender wage gap, and the authors describe how these factors create a negative impression of the construction industry in many women's' minds. Wood et al. [20] also found discrimination barriers faced by women working in UK construction including high rates of harassment on worksites that can make women feel unwelcome and uncomfortable at work, promoting the evasion of female employees. Sarkar [17] found women working in construction trades often face problematic onsite working facilities including unsanitary or non-existent toilets and lack of personal protective equipment in women's' sizes. Findings concluded that due to insufficient work conditions, gender bias, and stigmas, most women in the construction industry avoid working in trades and tend to take up positions in administration, sales, managerial, and speciality professions. Azhar and Griffin [1] found difficulties maintaining work-life balance as the biggest challenge encountered by women while working in the US construction. This aligns with Sherratt and Dainty [18] who found through evaluating health and safety claims in the UK, that poor mental ill-health remains prevalent due to organisational reluctance to change employee work structures, processes, and practices. Similarly Tijani et al. [19] found in Australia through literature review analysing 60 papers from 1989 to 2020 that key stressors relating to mental health in construction include long work hours, time pressures, and work overload. Chan et al. [2] also reviewed literature relating to mental health risk factors in the Australian construction industry and deduced 32 risk factors from 16 journal articles. The most influential were job demand and job control.

## 2.2 Mental Health in Construction

### 2.2.1 Mental Health Risk Factors and Covid

The construction industry features high rates of mental ill-health which worsened during Covid-19 lockdowns. Frimpong et al. [5] found age, personal lifestyle, physical health conditions, social and economic circumstances, and industry socio-cultural norms as key risk factors. Pidd et al. [14] also found age to be a factor with young construction workers in Australia being at greater risk of alcohol and drug-related problems resulting from underlying mental health issues. Psychosocial factors pertaining to mental ill-health in young apprentices included job stress, included workplace bullying, and a lack of workplace social support. While Hanna et al. (2020) found that individuals who lost their jobs in 2020 due to the pandemic, experienced poorer well-being in terms of feelings of happiness, enjoyment, worry, stress, depression, sadness, and anger compared with those who remained employed. However, the above studies have not accounted for gender.

The Covid-19 lockdown meant that many construction professionals worked from home. Prickett et al. [15] found in NZ both positive changes, such as more flexible work hours and less money spent on transit and other work-related expenses, and negative challenges, such as maintaining productivity while dealing with increased home life demands such as homeschooling. However, The Centre for Construction Research and Training (2022) found that during Covid-19 pandemic, construction workers experienced significantly more anxiety and depression than did in 2020 and prior. Changing to a home working environment has been found to affect diet, physical environment, and sleep. Ingram et al. [8] analysed health behaviours across UK participants to determine their relationship with negative mood during Covid-19 lockdowns. Changes in diet, sleep, and physical activity all correlated to negative mood states. Gupta et al. [6] found that sleep quality during Covid-19 lockdowns in India deteriorated across different occupational groups, and reduced sleep periods were associated with depressive symptoms. Oakman et al. [13] found through literature review undertaken in three databases, PsychInfo, ProQuest, and Web of Science, from 2007 to May 2020 the following list of mental and physical health issues associated with working from home. They concluded that employers focus on organisational, co-worker, technical, and managerial support, and address gender inequities to reduce the effects.

- Participant self-reported decreased physical health
- Demands associated the home environment
- Level of organisational support
- Social connections outside of work
- Work overload
- Invasion of privacy
- Role ambiguity
- Lower job autonomy
- Being in constant electronic contact with work (work/life balance).

### 2.2.2 Workplace Support

Unsurprisingly then, allowing more flexibility and building resilience were found key to working effectively through Covid-19. Cogan et al. [3] studied railway worker well-being during the Covid-19 pandemic in the U.K. Developing more adaptive coping strategies and building better and team-based resilience were found to have the best impact. Malinen et al. [10] also concluded that NZ employers should acknowledge the strain placed on employees due to increased workloads and allow more flexible working hours and locations to support worker well-being during a pandemic. They found six key strategies that best-supported employees in NZ during Covid-19:

1. Providing a sense of job security—Consistent hours, sense of safety, continuance of pay,
2. Providing effective communications—Clarity, consistency, regularity, and timeliness of information,
3. Providing recognition—Expressing appreciation for added workload and accommodating changes,
4. Expressing concern for employee's health and well-being—Providing personal protective equipment (PPE) and safe workspaces,
5. Providing support for continued work—Sending out equipment, hiring extra staff to help with the workload, subsidising costs or providing allowances, and
6. Providing flexibility and a sense of job control—Giving employees autonomy, allowing flexible hours. Employers should trust employee's productivity levels when working remotely.

### 2.2.3 Concluding Remarks

Previous studies have tended to analyse the effects on construction workers as a general population and not specific to females. This may be due to authors being male and women only accounting for 10% of the construction industry globally. Much of the research into construction worker well-being has focused on construction workers onsite, and not contractors and consultants who work in offices, and then from home during Covid-19 lockdowns. Most of the research has been conducted overseas and is therefore not specific to the NZ construction industry. Therefore, the survey questionnaire focuses specifically on women in construction, filling the gap in previous studies that have analysed the general construction population. Women can have specific needs over the whole population such as managing childcare and the like. This survey enables women to identify support provisions that would have been most helpful in supporting their well-being during the pandemic lockdowns. It is also specific to the NZ construction industry, whereas most previous studies analysed effects on construction workers overseas. Survey questions focus on the effects of working in isolation on sleep, diet, and exercise.

## 3 Research Methodology

A survey questionnaire was prepared using Qualtrics distributed via the National Association of Women in Construction [12] email database, Facebook page, and LinkedIn profile and was open between 28 September 2022 and 15 October 2022. The survey was divided into three sections. Section 1 collected demographics of participants' profession, age, ethnicity, regional location, and number of any dependents. Section 2 collected data about the participants' work, and any associated changes resulting from Covid-19 lockdowns. Section 3 collected further details about participants' work-life balance, workload and work demands, support from peers and organisations, and overall effects on well-being resulting from working from home during Covid-19 lockdowns. The target sample population was construction workers who identified as female and were required to continue working throughout Covid-19 lockdowns. This primarily focused on female construction professionals who continued their office-based roles for contractors or consultants working from home, while construction sites were closed. A dataset comprising 306 valid responses was collected and analysed. A quantitative approach was adopted as the findings represent a wider population sample, and the literature review established a sufficient range of questions from which to prepare the survey questionnaire.

Due to the anonymity of the results and the method of dissemination, it is possible that some of the responses came from individuals outside of the target population. It is also possible that the data could be skewed by duplicates of responses where individuals may have completed the survey more than once. The survey questions asked participants to provide information relating to feelings and emotions which may have occurred up to two years ago. Data gathered is heavily reliant on accurate recall, particularly as thoughts and emotions may be subconsciously changed in the time between lockdowns and the time at which the survey questionnaire was completed.

## 4 Data Analysis and Discussion

### *4.1 Population Sample*

#### 4.1.1 Ethnicity

Of the 306 responses, the majority (77%) identified as NZ Europeans' Pakeha, 9% identified as Māori, 2.6% identified as Polynesian/Micronesian, 6% identified as Asian, and 3% identified as Middle Eastern/Latin American/African. The survey sample comprised a broad range of professions.

**Table 1** Profession

| Profession | Responses | % of sample | |
|---|---|---|---|
| Other, please specify | 55 | 18.0 | (Education, marketing, and sales, building compliance, facilities management, and law) |
| Quantity surveying | 48 | 15.7 | (QS, contract administration, estimating, bid preparation) |
| Construction management | 47 | 15.4 | (Including 4 regional managers) |
| Architecture/design | 38 | 12.4 | |
| Project management | 25 | 8.2 | |
| Trade and skilled labour | 24 | 7.8 | |
| Engineering | 21 | 6.9 | |
| Health and safety | 16 | 5.2 | |
| People and culture | 13 | 4.2 | |
| No answer | 19 | 6.2 | |
| Total sample | 306 | 100.0 | |

### 4.1.2 Profession

Table 1 presents the composition of professions of those surveyed. The majority comprises quantity surveying, construction management, and project management, totalling 39% followed by architecture and engineering, totalling 19%. Those working in trades and skilled labour made up 7.8% of the survey responses. Further research could focus on those working on construction sites with more targeted questions as their needs would vary from the office-based professions that this study focused on. 18% of respondents selected 'other' professions, specifically naming education, marketing, and sales, building compliance, facilities management, and law. 6.2% did not answer the question.

### 4.1.3 Age

The sample population comprised (33%) aged 31–40, (28%) aged 41–50, (16%) aged 51–50, (10%) aged 26–30, (8%) aged under 25, and (5%) aged 61–70 years old.

### 4.1.4 Locations

The participants were located in Auckland (33%), Wellington (23%), and Canterbury (17%). This aligns with the three most densely populated regions in New Zealand according to recent census data (Stats NZ, 2019). Other participants were based in

Otago (8%), Bay of Plenty (8%), Waikato (5%), Whanganui (2%), and Taranaki, Hawks Bay, and Southland (1% each).

#### 4.1.5 Dependents

170 participants stated caring for dependants compared with 136 who had no dependants. Therefore, there is a relatively even spread of data across this criterion.

#### 4.1.6 Working in Isolation

Participants were asked to identify the extent to which they worked in isolation from others. These included during nationwide alert level 3 and 4 lockdowns; while unwell with Covid-19 or any other illness; when returning from overseas travel (i.e. managed isolation facility); during Auckland-only alert level lockdowns (including extensions into Waikato and Northland); or during a business shut down period relating to the Covid-19 pandemic. Participants then categorised the effect of working in isolation by approximate severity accounting for the on duration, as follows. These are represented in Table 2. Of the participants who spent extensive time working from home because of Covid-19, 88% of them lived in Auckland. The regions where participants spent the least amount of time working from home due to Covid-19 were Bay of Plenty, Hawkes Bay, Otago, and Southland. For many, working from home continued post-Covid-19.

Participants were asked to rate how frequently they continued to work from home after Covid-19 compared with before the lockdowns. Figure 1 shows the extent that workers continued to do so. 63% of participants (192 responses) said that they continued to work from home 'much more' now than they did previously. 24 said that they 'somewhat more' worked from home. 61 responses said, 'no change.' Only 5 responses said that they work less from home after Covid-19 than before the lockdowns. These findings may have changed since the study as more people return to offices over time. See Fig. 1.

**Table 2** Extent and impact of working in isolation

| Reason | Time period | Severity |
|---|---|---|
| While unwell with Covid-19 or any other illness<br>During nationwide alert level 3 and 4 lockdowns | 1–4 weeks | Low |
| During a business shut down period relating to the Covid-19 pandemic<br>When returning from overseas travel (i.e. managed isolation facility) | 4–8 weeks | Medium |
| During Auckland-only alert level lockdowns | 8+ weeks | High |

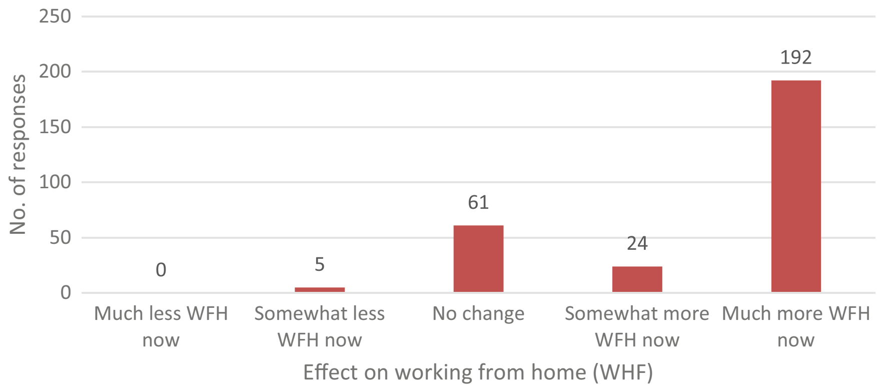


**Fig. 1** Extent that working from home continued after Covid-19 lockdowns

### 4.1.7 Work-Life Balance

When asked to rank the impact of working from home on their work-life balance, 38% of participants reported improvement (117 responses), while 26% reported a negative change (80 responses). 23% said there was no change to their work-life balance (69 responses), and 13% of participants did not answer. These are shown in Fig. 2. See Fig. 2.

By ethnicity, the group which reported the most negative impact was Latin Americans (75% negative), and the group which reported the most positive impact was Africans (75% positive), however these groups were of a very small sample size. Engineers, project managers, and quantity surveyors reported the most positive impacts to their work-life balances when compared with other roles (57%, 65%, and 54% respectively).


**Fig. 2** Impact of working from home on work like balance

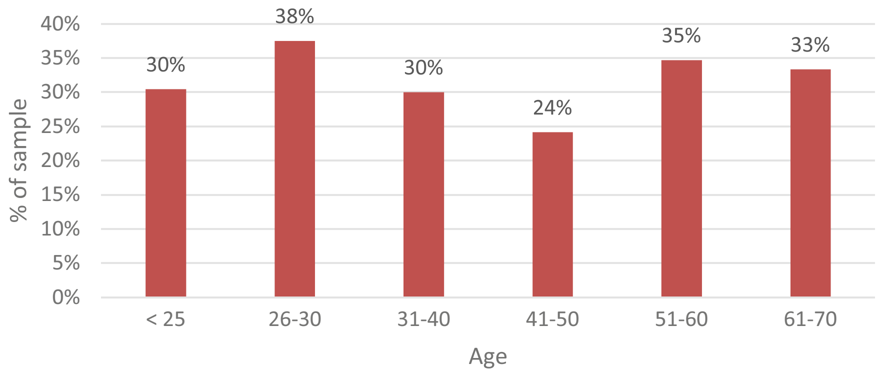


**Fig. 3** Impact of technology issues when working from home

### 4.1.8 Workload and Productivity

Findings about the effect of working from home varied. 34% of participants said that their workload increased while working from home, 36% said that workload remained the same, 36% said that workload decreased, and 14% did not answer. All 9 participants in management reported an increase in workload, making management the most frequently reported role for increased workload during Covid-19 lockdowns. See Fig. 3.

Perhaps unsurprisingly then, responses about productivity also varied. 25% of participants felt that their productivity improved working from home. 38% felt that their productivity reduced. 14% felt that their productivity remained the same. 14% did not answer. Of the factors which negatively impacted participant's ability to work productively from home, the most prevalent was accessibility to other colleagues (reported 37 times), followed by technology capabilities and user-friendliness (reported 23 times), and distractions at home (reported 16 times). Conversely, a few participants commented that home was less distracting and more quiet than their normal workplace, so they felt more productive while working from home. These findings suggest that improving technology and ability to connect with colleagues online may be a key to focus on to reduce workloads and improve productivity while working from home.

Interestingly, the age range of participants who found technology capabilities and user-friendliness an issue while working from home varied, indicating an industry-wide technological shortfall as opposed to a generational gap in computer literacy.

### 4.1.9 Support Systems

The most common support systems provided by workplaces to employees while working from home included regular team well-being check-ins and encouragement (191 instances), flexible working hours (159 instances), increased sick leave or

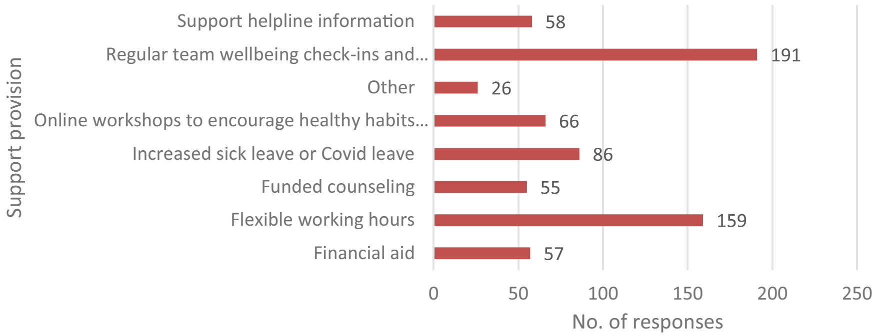


**Fig. 4** Workplace support provided for working from home

Covid-19 leave (86 instances). This demonstrates the need for flexibility in working hours and leave during Covid-19 disruption and close collaborative communication. Online workshops to encourage healthy habits (66) and support helpline information (58) were the next most systems provided. These were followed closely by financial aid (57) and funded counselling (55). For office-based professions who continued their work from home, their costs may have decreased through less travel costs and day care negating the need for financial assistance, hence ranking below other support systems provided. These are shown in Fig. 4.

The most common systems which participants said that they would have liked to be provided during Covid-19 lockdowns were better work equipment and tech support (7 instances), more flexible hours (6 instances), and more frequent well-being check-ins and team catch-ups (5 instances each, 10 total). There were some comments left by respondents who would have liked more support and flexibility in caring for their children, and three comments said that their employees did not provide any support at all.

#### 4.1.10 Health Indicators

Sleep

Like the effects on workload and productivity, the impact of Covid-19 lockdowns on the sleep habits also varied and of the whole participant group demonstrates a normal distribution. 34% reported no change, 24% reported minor negative change, and 14% reported minor positive change. While only 6% reported substantial positive and 4% reported substantial negative change, 18% did not answer. See Fig. 5.

When compared across age brackets, it is evident that in general, younger participants under the age of 30 reported positive effects on their sleep habits, while participants over 30 reported negative impacts under the same circumstances. It is unclear why this is, but possible explanations could be the presence of dependents in the household, higher pressure roles, or physiological factors. See Fig. 6.

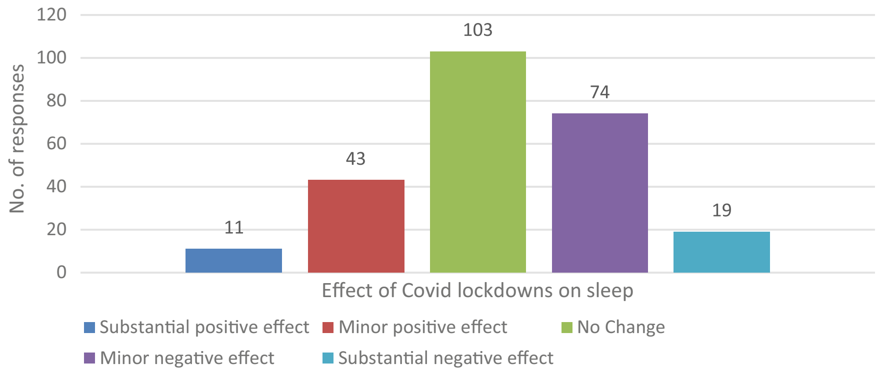


**Fig. 5** Effect on sleep habits

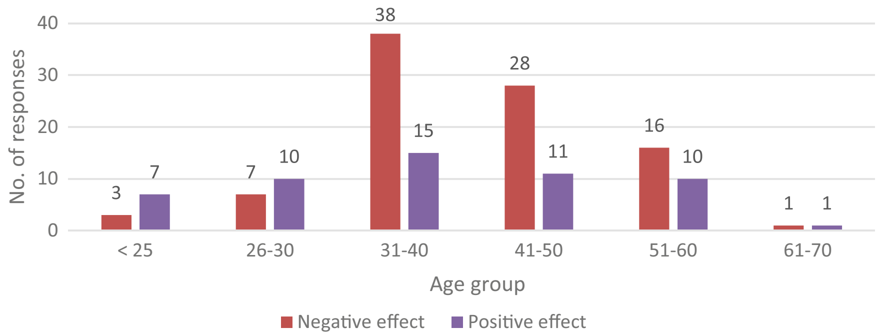


**Fig. 6** Effect on sleep habits per age group

Diet

Nearly half (46%) of the participants reported that their diet was negatively impacted, while 19% reported a positive impact, and 16% reported no change.

Exercise

There was an even spread of impacts on exercise habits resulting from lockdowns, with slightly more (7%) responses reporting a positive effect. This suggests that working from home had variable effects on participant's exercise habits, which may be influenced by many factors such as existing habits prior to lockdown, age, mobility, caring for dependents, and space available in participant's homes. See Fig. 7.

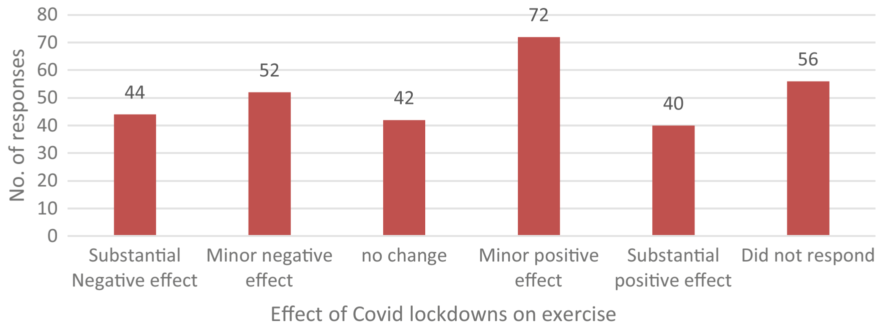


**Fig. 7** Effect on exercise

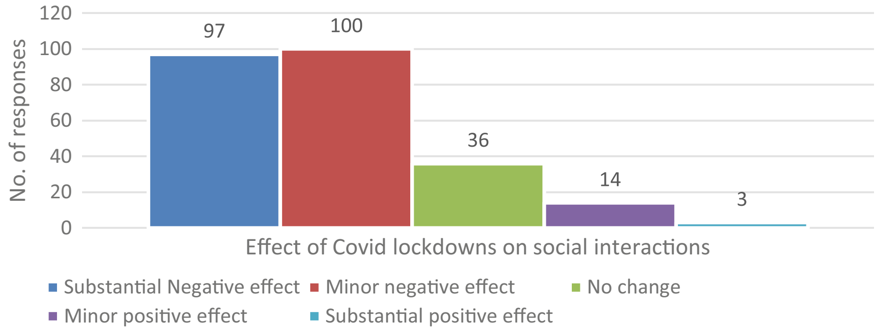


**Fig. 8** Effect on social interactions

## Social

Unsurprisingly, almost two-thirds (64%) of all participants reported negative impact on their social interactions with friends, colleagues, Iwi, and whanau when working from home during Covid-19 lockdowns. See Fig. 8.

This demonstrates a clear correlation between declining social relationships and working from home during lockdown, but it is likely that the negative responses are a result of being in nationwide lockdown, and not a specific product of working from home in general.

## Sense of Well-Being

61% of participants reported negative effects on their general feeling of well-being while working from home during Covid-19 lockdowns. 22% reported a positive effect. Feeling of well-being is a subjective topic and therefore will have varied responses, but the data shows a clear trend of declined well-being in periods of working from home during lockdowns. Again, these findings relate to the nationwide lockdown and not working from home generally.

There was negligible variance in the distribution of reported well-being between participants who spent a long time working from home during lockdowns compared with those who spent the shortest amount of time working from home in lockdowns. Across age brackets, women aged between 31 and 40 reported a negative effect on their well-being when compared with other age groups.

## 5 Discussion

Previous research has studied the effects of working from home on mental health in New Zealand, but not specifically within the group of women in construction. This research used quantitative analysis to find that the well-being of a significant proportion of women in construction are negatively impacted when working from home during lockdowns, as demonstrated by the reported decreased productivity, worsened diet, and decreased frequency of social interactions—all of which are factors which have been identified in previous literature as challenges to overcome while working from home during lockdowns, such as the findings in the U.K. by Ingram (2020).

Participants were asked to identify key resources that were unavailable to them when working from home during lockdowns and felt would have been beneficial to them. These most frequently included better work equipment and tech support, flexible work hours, frequent team catch-ups and well-being check-ins, clear communication on policies, and extended sick leave. Less frequently requested were financial aid, reduced workload, job stability, and childcare. Specific research to develop some or all of these support systems could provide useful knowledge to improve industry practices around working from home. These generally support findings by Oakman et al. [13] that employers focus on organisational, co-worker, technical, and managerial support and address gender inequities to reduce the effects. Also, those findings by Malinen et al. [10] that concluded NZ employers should acknowledge the strain placed on employees due to increased workloads and allow more flexible working hours and locations to support worker well-being during a pandemic. More flexible working hours aligns too with previous studies that found a lack of work-life balance to be a key barrier to working in construction in Australia, the U.K., and the U.S.A [1, 18, 19]. The findings also support those of previous studies that found a mix of positive and negative impacts deriving from working at home during Covid-19 lockdowns in NZ, such as Prickett et al. [15] who found more flexibility, but challenges maintaining productivity. The findings around sleep were more spread than those of previous studies that found impact on sleep an issue. Better technology and communication systems were a factor identified for improvement, which surprisingly did not feature so prominently in previous studies.

It is acknowledged that only 44% of all study participants had dependents to care for. There is scope for future studies to focus on the experiences of caregivers in construction, since there were an overwhelming number of participants mentioning that the presence of children who would ordinarily be in school or day care was distracting and decreased productivity. Individuals not only needed to care for their dependents, but they were required to provide homeschooling, which on top of full-time work is a large and reportedly unreasonable demand.

Participants were asked for any additional comments. Some of the comments implying negative impacts as a result of working in isolation were:

- Increase in alcohol consumption
- Onset/worsening of mental health conditions requiring medication
- Increased requirement for flexibility within role
- Novelty of earlier lockdowns wore off, making later lockdowns harder
- One workplace kept typically female roles in lockdown for longer than other roles
- Unfair workload distribution when workload decreased
- Increased pressure for general managers to check on well-being of staff
- More redundancies
- Difficulty in external communications
- Government restrictions had grey areas which were difficult for businesses to navigate
- Increased H&S plan requirements increased workloads
- Difficulties in managing homeschool alongside work
- Working as a self-employed contractor was more difficult than as an employee
- Financial loss was prevalent, especially for site-based employees and contractors
- Vaccination mandates caused exclusion from the workplace
- Breakdown of company culture and team relationships through lack of communication
- Uncertainty of market was uninspiring
- Lack of trust in employees from management.

Some of the positive comments included:

- Scope to retrain site workers for temporary administrative roles during lockdown
- Learnings from earlier lockdowns eased the impacts of further lockdowns
- Forced break from fast-paced environment
- Lockdowns provided opportunity to change existing systems
- Having a partner as a stay-at-home parent was helpful
- Managers are now more open to staff working from home
- No commute or traffic to deal with
- Isolation allowed for reflection and improvement in all areas of one participant's life.

All these comments are examples of more detailed subject matter which could be studied and expanded upon in further studies to establish the wider relevance to women working in the construction in New Zealand and help support more flexible working home arrangements in general, and build resilience ahead of any future pandemic events. For example, the first two factors, whether alcohol and medication consumption, may be age-related as found to be a factor by [14] with young construction workers in Australia being at greater risk of alcohol and drug-related problems resulting from underlying mental health issues.

## 6 Conclusions

This study explored the effects on female worker well-being in New Zealand construction while working in isolation during the Covid-19 pandemic. This research project aimed to study the challenges and opportunities experienced by women in construction resulting from changes to the workplace caused by the Covid-19 pandemic. It analysed 306 survey responses from participants of varied demographics and professions across NZ who had varied and valuable experiences in the context of this research.

This provides valuable insight into women in construction—a population which is little researched, on a topic which is timely and current. By finding common experiences between women in construction during a time of low morale and declining well-being, specific problems can be identified, and solutions applied to both daily systems under 'normal' circumstances and to future emergency situations where the public is required to remain at home for extensive periods. By improving protocols and demonstrating genuine regard for the well-being of employees, individual businesses and the wider construction industry can continue to improve and evolve towards greater gender inclusivity and equality.

Analysis of the data gathered determined that decreased productivity and negative impacts to diet and social interactions are common challenges for women in construction across all demographics, and that the most desired resources which employees want their workplaces to provide to improve the experience of working from home are better work equipment and tech support and more flexible hours.

This contributes to the body of knowledge by targeting women in construction—a group of people who are not frequently researched. There is scope for further research to expand on prevalent reported issues, particularly the challenges of balancing work and childcare during lockdowns. These findings can help inform government policy for major managing major events such as pandemic events, and help businesses best meet the needs of their employees during such events. Further research could expand the sample to include males working in construction.

## 7 Ethics Statement

This project gained category A ethics approval from the Otago Polytechnic Research Ethics Committee. Category A ethics approval is required for interviewing or surveying human participants where the study involves high risk to participants. This was deemed appropriate as the questions asked participants to recall feelings associated with their mental well-being.

**Author Contributions** Dr David Finnie contributes to conceptualisation, methodology, analysis, investigation, supervision, and manuscript editing. Aimee contributes to data collection, draft preparation, and project administration. Nayani contributes to analysis and editing.

## References


1. Azhar S, Griffin M (2014) Women in construction: successes, challenges and opportunities—a USACE case study. In: 50th ASC Annual international conference proceedings. Associated Schools of Construction. Retrieved from http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT249002014.pdf. 27 July 2023
2. Chan AP, Nwaogu JM, Naslund JA (2020) Mental ill-health risk Factors in the construction industry: systematic review. J Constr Eng Manag 14(3). https://doi.org/10.1061/(asce)co.1943-7862.0001771. Epub 2020 Jan 6. PMID: 33408438; PMCID: PMC7785059
3. Cogan N, McGibbon M, Gardener A, Morton L (2021) Understanding risk and protective factors to UK railway workers' mental wellbeing during the COVID-19 pandemic: a cross-sectional survey. The Lancet. https://doi.org/10.1016/S0140-6736(21)02576-9
4. Ensor J (2020) Coronavirus women in construction: diversifying the sector in a post-COVID-19 world. Newshub. Retrieved from https://www.newshub.co.nz/home/new-zealand/2020/05/women-in-construction-diversifying-the-sector-in-a-post-covid-19-world.html. 27 July 2023
5. Frimpong S, Sunindijo R, Changxin Wang C, Boadu E (2022) Domains of psychosocial risk factors affecting young construction workers: a systematic review. Buildings 12(3). https://doi.org/10.3390/buildings12030335
6. Gupta R, Grover S, Basu A, Krishnan V, Subramanyam A, Nischal A, Hussain A, Mehra A, Ambekar A, Saha G, Mishra K, Bathla M, Jagiwala M, Manjunatha N, Nebhinani N, Gaur N, Kumar N, Dalal P, Kumar P, Midha P, Daga R, Tikka S, Praharaj S, Goyal S, Kanchan S, Sarkar S, Das S, Sarkhel S, Padhy S, Sahoo S, Satyanarayana R, Dubey V, Menon V, Chhabra V, Lahan V, Avasthi A (2020) Changes in sleep pattern and sleep quality during COVID-19 lockdown. Indian J Psychiatry 62(4):370–378. https://doi.org/10.4103/psychiatry.IndianJPsychiatry_523_20
7. Habibi H, C Prickett K, Fletcher M, Chapple S (2020) Work circumstances, job loss, and wellbeing during New Zealand's Covid-19 alert level 4 lockdown. New Zealand Economic Papers, Wellington
8. Ingram J, Maciejewski G, Hand CJ (2020) Changes in diet, sleep, and physical activity are associated with differences in negative mood during Covid-19 lockdown. Frontiers in Psychology, Glascow
9. Iran Z, Edwards D, Peter E (2010) Work stress, support, and mental health in construction. Journal of Construction Engineering and Management, Perth
10. Malinen S, Hoi Ki Wong J, Näswal K (2020) Effective workplace strategies to support employee wellbeing during a pandemic. Journal of Employment Relations, Christchurch: New Zealand
11. Mates in Construction (n.d.) Home. Retrieved from: https://mates.net.nz/. 25 July 2023
12. NAWIC (2023) Home. Retrieved from https://www.nawic.org.nz/. 27 July 2023
13. Oakman J, Kinsman N, Stuckey R, Graham M, Weale V (2020) A rapid review of mental and physical health effects of working at home: how do we optimise health? BMC Public Health 20:1825. https://doi.org/10.1186/s12889-020-09875-z
14. Pidd K, Duraisingam V, Roche A, Trifonoff A (2017) Young construction workers: substance use, mental health, and workplace psychosocial factors. Adv Dual Diagn 10(4):155–168. https://doi.org/10.1108/ADD-08-2017-0013
15. Prickett K, Michael F, Chapelle S, Doan N, Conal S (2020) Life in lockdown: the economic and social effect of lockdown during alert level 4 in New Zealand. Victoria University of Wellington, Wellington

16. Regis M, Alberte E, Lima D, Freitas R (2018) Women in construction: shortcomings, difficulties, and good practices. Eng, Constr Archit Manag. 26(11):2535–2549. https://doi.org/10.1108/ECAM-09-2018-0425
17. Sarkar M (2002) Women in construction. Housing Economics, Washington
18. Sherratt F, Dainty A (2017) UK construction safety: a zero paradox? Policy Pract Health Saf 15(2). https://doi.org/10.1080/14773996.2017.1305040
19. Tijani B, Xiaohua J, Osei-Kyei R (2020) Critical analysis of mental health research among construction project professionals. Sydney. J Eng Des Technol
20. Wood H, Aboagye-Nimo E, Jin R, Wyche K, Collinson J (2018) Women as construction professionals: modern day challenges. In: Joint CIB W099 and TG59 international safety, health, and people in construction conference, 370–378

# Towards the Adoption of Data Management Systems by Quantity Surveyors

**Unarine Ronaldo Phuriwa and Murendeni Liphadzi**

## 1 Introduction

As a new democratic developing country, South Africa still faces major challenges of poverty, unemployment, and inequality; these challenges to some extent were largely created by the socioeconomic ills of the past regime [19]. quantity surveying (QS) profession has faced some hiccups in its development despite its notable landmark in the construction industry [33]. South Africa's troubled construction industry will face a slew of risks and obstacles this year [11]. This finding concurred with Bulbulia [9] who stated that the capital building industry is at a crossroads, with diminishing activity and productivity and a poor future prognosis. The construction sector is important to the economy because it results in the buildup of infrastructure stock/capital, which leads to greater economic, social, and economic activity. South Africa's construction industry is dominated by massive infrastructure projects, which has created a robust job market for construction experts seeking new challenges. Construction companies must begin utilizing more innovative construction technology, especially currently. It is critical for construction companies to employ innovative technologies because it will enable them to win more projects in the first place, Secondly, it will assist them in achieving better financial outcomes for the project. Construction professionals must employ construction technologies to remain competitive in the market.

Quantity surveying practices are key role players in the construction industry, therefore most certainly they also require exposure, application, and continuous development directly aligned with the Fourth Industrial Revolution. Khatleli [19] emphasized that it is crucial to note that there is no chance that the construction industry in South Africa can avoid or escape the fourth revolution. As such, the

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transformation and economic factors will have an impact on the project scope as well as minimising the complexity of the construction projects within the South African construction industry. Schwab [30] describes the Fourth Industrial Revolution or Industry 4.0 as marked by emerging technology breakthroughs in several fields, including robotics, artificial intelligence, blockchain, nanotechnology, quantum computing, biotechnology, the Internet of things, 3D printing, and autonomous vehicles, as well as a fusion of technologies that blurs the lines between the physical, digital, and biological spheres.

Based on existing literature and real-life observations it is clear that the South African exploration of data management practices for quantity surveyors in the fourth industrial revolution era will be of great contribution to the South African quantity surveying profession. Akinshipe et al. [4] reveal that the desire to go digital is present in professional quantity surveying firms in South Africa. However, the adoption of innovative tools within the construction industry has been noted to be relatively slow, for instance, drawings on projects are manually printed, and therefore need to be put into a cloud, etc. Quantity surveyors have control over the accuracy of measuring and enhancing the utilization of Information Technology (IT) and its software related to the quantity surveying profession.

This study aims to assess the factors for the adoption of data management by quantity surveyors in the South African construction industry. In addition, the purpose of this study is to explore the data management systems that are available in the Fourth Industrial Revolution (4IR) era. Lastly, this study aims to contribute to the body of knowledge that exists.

## 2 Literature Review Framework

As stated in Luke chapter 14:28, ‘For which of you, intending to build a tower, sits not down first and counts the cost to see whether he will have sufficient to finish it?’, the profession of quantity surveying can be traced back to the Bible [7]. Moreover, Buys [10] claims that the Henry Cooper and Sons company established the first quantity surveying business in England in 1785. However, the work of the quantity surveyor had to change to keep up with this increased demand and fill gaps across numerous industries due to the constantly shifting market conditions, which have witnessed a trend towards new technology and ‘green’ building. Manikas [22] contends that the quantity surveyor’s function in the building sector looks to have drastically changed. Quantification and documentation, construction cost, pre-tender in together with post-tender management, and lastly, project final account are nonetheless among traditional technical and professional services offered by quantity surveyors. While professional quantity surveying organizations in South Africa have stated a desire to go digital, the advantages of digitalized quantity surveying firms are significant, according to Akinshipe et al. [4]. The South African construction industry is only just beginning to employ digital technologies, though.

## 2.1 *Importance of Data*

The combination of both physical and cyber worlds provides the ability to enable digital twins to establish relationships with other digital twins and with their real-world counterparts, and the ability to extract knowledge is among the things made accessible by data [23]. Also, Raptis et al. [28] stated that with the assistance of data, it is possible to enhance the applications of cycle control and turn it into non-defect manufacturing, and promote apportion with the factory operator of the production sites, or value chains consisting of a variety of stakeholders [28]. Indeed, concepts like common 'data buses' connecting factory environments have already been identified as the single most important enabler of novel Fourth Industrial Revolution (4IR) paradigms, for example, the industrial data space concept (known as International Data Spaces Association) introduced by Otto et al. [25] In the past several decades, large amounts of data have been generated in the industrial environments, through the wide use of neuro-conceptual structures (NCS). Initially, the huge amount that had been discarded for a long period is utilized for in-depth analysis of data and those data are used for regular technological examination. Later, awareness of the importance of extracting information from data has taken a leading role in the 4IR [15]. However, the properties of data must be assessed.

### 2.1.1 Data Properties

This section discussed four (4) properties of data as follows:

**Data volume**—One of the properties to be considered when implementing digital tools is the 'volume' of data that is to be produced. Depending on the size of every application, there might be a variety of data volumes in industrial networked settings. According to Raptis et al. [28], we categorize data into three categories: small volume, medium volume, and large volume. Small volume data includes sensor measurements, medium volume data includes photos or sound files, and large volume data includes videos and in-depth 3D representations.

**Data criticality**—The Fourth Industrial Revolution (4IR) has a strict requirement concerning data. Furthermore, it has been noted that the systems related to monitoring, safety, and control may suffer from data that is not well-maintained in alignment with 4IR requirements. Data that are not managed according to the underlying 4IR requirements may adversely affect the performance of system monitoring, control, and safety, as discussed by Raptis et al. [28]. For instance, in a chemical plant, the chemical leakage must be informed at predefined times [21].

**Data traffic**—Data traffic is caused by the usage of different types of data, the formation of diverse velocities, and the application of different traffic patterns that also participate in the system of industrial networks. Nevertheless, the solution of data traffic is in the process of implementation as the production of traffic regulation has started evolving for different types of data. Moreover, this aligns with the strict Fourth Industrial Revolution (4IR) requirements.

**Data variety**—Depending on the use case, the data's uniqueness might also differ. There are two classes of 'data variety'. The first class is when many types of data are produced, the data variety is then referred to as 'Diverse', whereas the second class is when the same types of data are produced, and the data variety is referred to as 'Uniform'. When seeking efficient solutions for every scenario of use, the data variety can have a substantial impact on algorithmic decisions and service supply [28].

## 2.2 Data Management

Data management is defined as 'a group of activities relating to the planning, development, implementation, and administration of systems for the acquisition, storage, security, retrieval, dissemination, archiving and disposal of data' [24]. Organizations throughout the world collect, store, and analyze enormous amounts of data constantly to make decisions. Data management is an important asset to any enterprise because it supports effective business management [24]. Coleman [12] argues that knowledge, resources, and data management are three components that create resistance towards big data adoption in SMEs. Traditional data management technologies and methods are inefficient, expensive, and not equipped to handle, store, and process large growing volumes of heterogeneous data [2]. Furthermore, Zide and Jokonya [35] indicated that enterprises have had an unwavering need for large amounts of data since the development of big data, nevertheless, the conventional method of storing data is proving to be costly and discouraging for organizations looking to engage in data management solutions.

## 2.3 Factors Influencing Data Management Adoption

Different factors influence data management (DM), though it has been noted that these factors fail DM success. A study conducted by Briggs [8] revealed that factors that fail DM success are divided into three categories which entail environmental, project, and technical. It further indicated that factors that are related to the environment included company acquisitions and takeovers, regulatory changes, organizational politics, challenges in the business environment, and lack of senior management support. Factors related to the project include high expenses, underestimating complexity and workload, challenges with the extraction of quantities, low return on investment (ROI), and dearth of understanding of cost over time, while factors related to technical include data quality, inefficient technology, data integration, poor understanding of DM applications, and lack of common data definition.

Furthermore, a study conducted by Vassiliadis et al. [34] grouped the factors of DM into four categories, which are design, technical, procedural, and socio-technical. The following is a description of each factor group: There is no set standard or

**Table 1** Data management factors in the quantity surveying profession

| Factors | References |
|---|---|
| Availability | Zide and Jokonya [35], Baker [5], Sealmat et al. [31] |
| Predictability | Ramukumba [27] |
| Flexibility | Hammad et al. [12] |
| Accessibility | Hammad et al. [12], Sealmat et al. [31], Ramukumba [27] |
| Scalability | Hammad et al. [12] |
| Limitations | Vassiliadis et al. [34], Briggs [8], Sealmat et al. [31] |
| Cost | Ramukumba [27], Zide and Jokonya [35] Baker [5], Briggs [8], Hammad et al. [12], Sealmat et al. [31] |
| Efficiency | Briggs [8], Ramukumba [27] |
| Operations | Ramukumba [27] |
| Deployment | Vassiliadis et al. [34] |
| Training | Vassiliadis et al. [34] |

commonly used metadata management languages, data engineering techniques, or design processes for DMs that design factors adhere to, as discussed in the study conducted by Hayen et al. [17]. Further indicated that the technical considerations are related to the discrepancy in hardware component selection and evaluation. Procedural problems are the causes of shortcomings in the DM's deployment. And lastly, discussed that the final user needs to be involved in the data management design process and trained on innovative technologies. Because the DM may reconfigure the organization's operations and introduce the functional or subjective domain of the stakeholders, socio-technical elements converge on breaching organizational treaties. From these two studies, the common important aspect is that the factors of DM are related to the 'project', 'technical', and 'environment or social'. Table 1 are factors of data management towards the quantity surveying profession together with the authors that highlighted the variables in their studies.

## 3 Methodology

The study investigated the adoption of data management systems by quantity surveyors. This study was carried out with the intent to determine data management systems that could be of significance to the quantity surveying profession. Due to its effectiveness in comparing current and previous studies as discussed by Ajayi and Osunsanmi [3], a quantitative research approach was used. In support of this, Kothari [20] stipulated that quantitative research, which uses statistics when examining phenomena that may be described numerically, is focused on measuring quantity or amount. Consequently, this study selected the quantitative approach since it focused on comparing the theory (literature) and the current state of data management systems for the quantity surveying profession.

A well-known research approach called ‘quantitative’ was utilized in this study, while employing random sampling for the collection of the data. As such this sampling was utilized because it aligns with the affirmation by Pandey and Pandey [26] who discussed that random sampling gives participants an equal chance of participating. Moreover, the respondents of this study were drawn from Gauteng Province, South Africa. There is a high number of quantity surveyors found within the Gauteng Province when compared with the other eight provinces of South Africa which led to the sample being drawn from this province. A well-structured questionnaire was utilized to collect data, which had closed-ended questions and was distributed to quantity surveyors including junior, senior, and candidate quantity surveyors to name a few. The questionnaires were structured into three phases, with the first phase assessing the biographic information, while the second phase assessed the practice of data management deployed by organizations. Lastly, the third phase of this study reviewed factors towards the adoption of data management systems by quantity surveyors.

An extensive literature review of this study was utilized in the development of variables of the questionnaire related to factors towards the adoption of data management systems by quantity surveyors and practices of data management by organizations. In this study, eighty (80) questionnaires were distributed to quantity surveyors, however only fifty-two (52) questionnaires were collected randomly from the quantity surveyors. Statistical Package for Social Sciences (SPSS) v 29 was utilized in the analysis of the collected questionnaires. In addition, the statistical analysis was represented via frequency, and principal component analysis (PCA). Figure 1 below are the steps for principal component analysis. The analysis revealed that from the collected questionnaires 75% (which is equivalent to 39) represented registered quantity surveyors, whereas 25% (equivalent to 13) represented non-registered quantity surveyors. Consequently, this gives more credibility to the data collected as more registered quantity surveyors contributed to the questionnaire. The response to the questionnaire will be essential as registered quantity surveyors on the factors towards data management systems for quantity surveyors.

## 4 Results and Discussion

This section presents the results and discussion based on the literature review and analysis conducted. This section is divided into three sections, which entail personal characteristics information, practices of data management deployed by organizations, and lastly, factors towards adoption of a data management system.

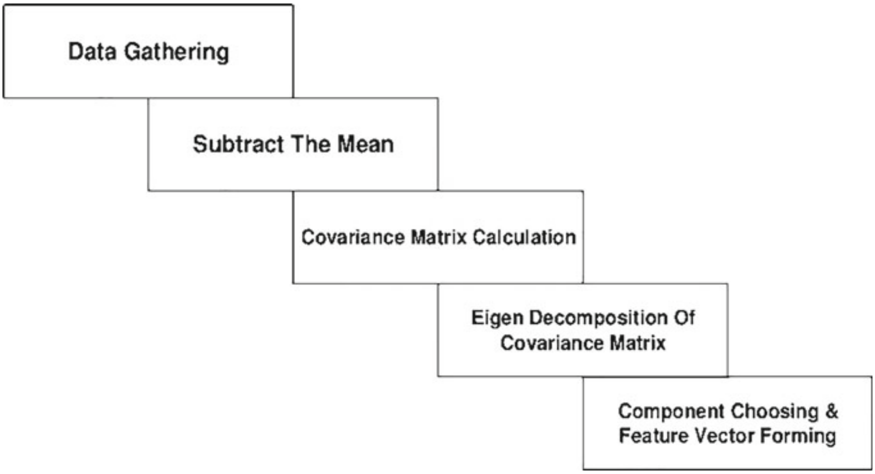


**Fig. 1** Principal component analysis steps [18]

### *4.1 Personal Characteristics Information*

To gain more knowledge on types of data management, respondents were requested to determine the type of data management system used in their organization. As a result, the analysis revealed that 25 respondents used 'Microsoft' in their organization, while 3 respondents utilized 'Oracle'. Moreover, 11 respondents use 'Google' and lastly, 13 respondents apply data management 'In-House' in their organizations. Table 2 illustrates the results related to the type of data management systems that are used in different organizations. The results show that most quantity surveying firms in the South African construction industry have utilized 'Microsoft' as their preferred data management system. Furthermore, this section assessed how respondents of the study manage data within their respective organizations. In this part, respondents had three categories of managing data within an organization including in-house, outsourced, and combined (in-house and outsourced). The analysis revealed that out of 52 respondents, 26 respondents indicated 'In-house', 11 respondents indicated 'Outsourced', whereas 15 respondents indicated 'combined (in-house and outsourced)'. The analysis indicates that half of the organizations manage data internally, whereas the other half prefer outsourcing and combined methods of managing data. Table 2 shows clearly the analysis of how organizations manage data.

### *4.2 Practice of Data Management Utilized by Organizations*

In investigating the practice of data management utilized by quantity surveying organizations, Table 3 reveals that the most significant practice used in data management

**Table 2** Respondents personal characteristics

| Respondents Personal characteristics | | |
|---|---|---|
| | Variables | Frequency |
| *Type of data management systems* | | |
| 1 | Microsoft | 25 |
| 2 | Oracle | 3 |
| 3 | Google | 11 |
| 4 | In-house | 13 |
| *Management of data in organizations* | | |
| 1 | In-house | 26 |
| 2 | Outsourced | 11 |
| 3 | Combined (in-house and outsourced) | 15 |

**Table 3** Descriptive statistics analysis

| Variables | Mean item score | Standard deviation | Rank |
|---|---|---|---|
| File naming | 4.25 | 0.998 | 1 |
| Documentation | 4.12 | 1.016 | 2 |
| Data storage devices | 4.15 | 1.161 | 3 |
| Cataloguing convention | 3.08 | 1.100 | 4 |
| Logic apps | 2.69 | 1.197 | 5 |
| Consider metadata for datasets | 2.63 | 1.314 | 6 |
| BI software | 2.60 | 1.241 | 7 |

is 'file naming' with a mean item score (MIS) of 4.25 and standard deviation (SD) of 0.998. Other practice used in data management by quantity surveying includes 'documentation' with MIS = 4.12 and SD = 1.016, 'data storage devices' with MIS = 4.15 and SD = 1.161, 'cataloguing convention' with MIS = 3.08 and SD 1.100, 'logic apps' with MIS = 2.69 and SD = 1.197 and 'BI software' with MIS = 2.63 and SD = 1.314. Lastly, 'BI software' had been ranked as the last practice used in data management by organizations with MIS = 2.60 and SD = 1.241.

### *4.3 Factors Towards Adoption of Data Management by Quantity Surveyors*

As this study embraced principal component analysis, it is crucial to ensure the suitability and viability of the data that had been collected from the respondents. As presented in Table 4, it can be confirmed that the Kaiser–Meyer–Olkin (KMO) value of this study was found to be 0.844, which according to the study conducted by Garson [14] it can be said that the data collected is 'meritorious' as the KMO lies between 0.8 and 0.9. Consequently, the data is suitable to be used for analysis. In addition, Barlett's test of sphericity revealed that the chi-square of the collected data was found to be 448.168, while the degree of freedom was 78 with a significant value of less than 0.001.

Table 5 indicates the pattern matrix factor of the principal component analysis conducted. From the literature review, 12 variables were identified and grouped into three components utilizing the PCA method. The components were named based on the variables found within the components.

a. Out of 12 variables, six variables were grouped into the first component as indicated in Table 5. Variables found in the first components included 'availability' (80.4%), 'predictability' (78.7%), 'flexibility' (78.2%), 'accessibility' (76.8%), 'schedule' (66.9%), and 'scalability' (64.5%). This component comprises the variables that align with the service that is provided by the system. As a result, this component is named **'technical elements'.** This component is considered to be noteworthy because it was ranked first in comparison with other components. Table 5 indicates that this component has an eigenvalue of 6.924 and a variance of 63.261%
b. Three variables were grouped into the second components as given in Table 5. Three variables include 'limitations' (84.1%), 'cost' (75.2%), and 'efficiency' (63.1%). Consequently, this component was termed **'project factors'** because these variables relate to factors that affect organizations when implementing a data management system. Table 4 reveals that this component has an eigenvalue of 1.254 and a variance of 9.643.
c. In the third component, there are three variables identified, which include 'operations' (83.1%), 'deployment' (79.6%), and 'training' (71.3%). The variables found within this component relate to the usage of the data management system by quantity surveyors. Therefore, this component is labelled **'social services'** with an eigenvalue of 1.213 and a total variance of 9.330% and it was ranked the last as indicated in Table 5.

The analysis of this study grouped the factors of DM into three categories, namely technical elements, project factors, and social services. These results match with the study conducted by Briggs [8] and Vassiliadis et al. [34] who had grouped the factors of adopting data management into categories that involved the technical, project, environmental, or social. Furthermore, the variables found under these components match those of the study by Briggs [8]. Consequently, it has been revealed that the

**Table 4** KMO and Bartlett's test

| | | |
|---|---|---|
| Kaiser–Meyer–Olkin measure of sampling adequacy | | 0.844 |
| Barlett's test of sphericity | Approx. chi-square | 448.168 |
| | Degree of freedom | 78 |
| | Significant value | < 0.001 |

**Table 5** Factor loadings towards the adoption of data management

| Cluster factor groupings | Eigenvalues | Variance percentage (%) | Pattern matrix factor | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| *Component 1—technical elements* | 6.924 | 53.261 | | | |
| Availability | | | 0.804 | | |
| Predictability | | | 0.787 | | |
| Flexibility | | | 0.782 | | |
| Accessibility | | | 0.768 | | |
| Schedule | | | 0.669 | | |
| Scalability | | | 0.645 | | |
| *Component 2—project factors* | 1.254 | 9.643 | | | |
| Limitations | | | | 0.841 | |
| Cost | | | | 0.752 | |
| Efficiency | | | | 0.631 | |
| *Component 3—social services* | 1.213 | 9.330 | | | |
| Operations | | | | | 0.831 |
| Deployment | | | | | 0.796 |
| Training | | | | | 0.713 |
| Total variance | | 72.235 | | | |

main factors that lead to failure in the DM success within the quantity surveying profession are limitations, operations, and availability since they had higher pattern matrix factors, which corresponds to the study by Vassiliadis et al. [34] and Briggs [8]. This has led to a low adoption rate of data management systems by quantity surveying organizations.

The findings align with the factors that were highlighted by the authors from the literature review above. The main variable that was highlighted by many authors was 'cost' as given in Table 1. As such it is crucial to note that cost is an important aspect that was highlighted and the finding in Table 5 revealed cost as a variable under component 2 named project factors. Other factors that are to be taken into consideration are accessibility, availability, and limitations as highlighted by several authors. Accessibility and availability are factors that are found under the technical elements as it has been stipulated by authors mentioned in Table 1 and limitations fall under project factors as it has been discussed in the literature above.

## 5 Conclusion

Finding the variables influencing quantity surveyors' adoption of data management techniques in the South African construction sector was the aim of this study. The literature reviewed revealed that factors that determine the adoption of data management practices for quantity surveyors in South Africa are accessibility, efficiency, and many other factors that affect the adoption of data management practices. The factor accessibility must be important as the data has to be readily accessible if an appropriate data management system is to be developed. Secondly, the data has to be efficient, and the data management system has to be efficient as the data generated is getting bigger in the era of the Fourth Industrial Revolution. It is very important that the data is reliable, and the data management system is reliable, this is so that there is no crashing of the data and the data management system. Security is key for a data management system as there is limited security, this makes it difficult for data to be managed if there is not adequate security for the data generated, thus making the storage of data from the project difficult. Performance is an important factor for the adoption of data management systems, in this era of the Fourth Industrial Revolution, the performance of the data must be important as well as the management system managing the data.

Most importantly, it is key that the personnel managing the data must be constantly trained in the management of data, as there are constant changes to the management of data. The maintainability of the data management system is not easy, and as such it affects the adoption of a data management system. The availability of the data is another factor that affects the adoption of a data management system, if the data is unavailable, it makes it difficult to manage the data. The quality of the data is important, as the quality of the data captured and stored is imperative. The scalability of the data management system is important as data gathered are often in large volumes, so it is important that the data management system can scale up, down, or sideways. The findings are in agreement with the literature and thus the objective of the study was achieved.

This research study was only based on the relevant construction project stakeholders in Gauteng Province, South Africa. The relevant respondents for this study were quantity surveyors within the Gauteng Province. This study only determined the factors affecting the adoption of data management practices for quantity surveyors in the South African construction industry.

## 6 Ethics Statement

Not applicable.

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## References

1. Abdullah N, Ismail SA, Sophiayati S, Sam SM (2015) Data quality in big data: a review. Int J Adv Soft Comput Appl 7(3):17–27
2. Adam K (2015) Big Data analysis and storage. Sage publications
3. Ajayi O, Osunsanmi T (2018) Constraints and challenges in the implementation of total quality management (TQM) in contracting organisations. J Constr Proj Manag Innov 8(1):1753–1766
4. Akinshipe O, Aigbavboa C, Oke A, Sekati M (2021) Transforming quantity surveying firms in south africa through digitalisation. In: Advances in human factors, business management and leadership: proceedings of the AHFE 2021 virtual conferences on human factors, business management and society, and human factors in management and leadership, July 25–29, 2021, USA. Springer International Publishing, pp 255–265
5. Baker J (2012) The technology–organization–environment framework. Inf Syst Theor Explain Predict Our Digit Soc 1:231–245
6. Balachandran BM, Prasad S (2017) Challenges and benefits of deploying big data analytics in the cloud for business intelligence. Procedia Comput Scince 112:1112–1122
7. Bowles JE, Le Roux GK (1992) Quantity surveying: an introduction, 2nd edn. QS Publications, Centrahill
8. Briggs D (2002) A critical review of literature on data warehouse systems success/failure. J Data Warehousing 49(3):1–20
9. Bulbulia T (2018) The struggling construction industry requires intervention but can recover. Retrieved from: https://m.engineeringnews.co.za/article/struggling-construction-industry-requires-intervention-but-can-recover-2018-11-05, on April 2020, 12
10. Buys NS (2004) Building maintenance management systems in South African Tertiary Institutions. Unpublished Ph.D. Thesis, University of Port Elizabeth
11. Cokayne R (2020) Construction sector braces for a stormy year. Retrieved from: https://www.moneyweb.co.za/news/industry/construction-sector-braces-for-a-stormy-year/ on April 2020, 12
12. Coleman SY (2016) Data-mining opportunities for small and medium enterprises with official statistics in the UK. J Official Stat 32(4):849–865. https://doi.org/10.1515/jos-2016-0044
13. Floyer D (2012) Enterprise Big-data. Retrieved on July 2012, 12.
14. Garson GD (2012) Testing statistical assumptions
15. Ge Z, Song Z, Ding SX, Huang B (2017) Data mining and analytics in the process industry: the role of machine learning. IEEE Access 5:20590–20616
16. Hammad KAI, Fakharaldien MAI, Zain J, Majid M (2015) Big data analysis and storage. In: International conference on operations excellence and service engineering, 10–11
17. Hayen RL, Rutashobya CD, Vetter DE (2007) An investigation of the factors affecting data warehousing success. Issues Inf Syst 8(2):547–553
18. Javanmardi N, Kaboli A, Mahdavi I, Shirazi B (2011) An economical multi-criteria decision-making process for supplier selection. Int Rev Bus Res Pap 7(5):168–183
19. Khatleli N (2016) The fourth industrial revolution or Industry 4.0 in South Africa's construction sector: quantity surveying profession adaptation toolkit 11(1):1–16
20. Kothari CR (2004) Research methodology: methods and techniques. New Age International

21. Kumar A, Shankar R, Choudhary A, Thakur LS (2016) A big data MapReduce framework for fault diagnosis in cloud-based manufacturing. Int J Prod Res 54(23):7060–7073
22. Manikas M (2017) Achieving better value infrastructure for NSW (internet) construction procurement guidelines. Australian Institute of Quantity Surveyors, Sydney, Australia
23. Mashegoana G, Khatleli N (2018) The fourth industrial revolution or Industry 4.0 in South Africa's construction sector: quantity surveying profession adaptation toolkit
24. Olajide V (2019) Introduction to data management. This presentation introduces the data management life cycle and concludes with a tentative syllabus for the training in data management and analysis
25. Otto B, Jürjens J, Schon J, Auer S, Menz N, Wenzel S, Cirullies J (2016) Industrial data space. Digital Sovereignty Over Data
26. Pandey P, Pandey MM (2021) Research methodology tools and techniques. Bridge Center
27. Ramukumba T (2014) Overcoming SMEs challenges through critical success factors: a case of SMEs in the Western Cape Province, South Africa. Econ Bus Rev 16(1):2
28. Raptis TP, Passarella A, Conti M (2019) Data management in industry 4.0: state of the art and open challenges. IEEE Access 7:97052–97093
29. Russom P (2011) Big data analytics. TDWI Best Practices Report, Fourth Quarter 19(4):1–34
30. Schwab K (2017) The fourth industrial revolution: what it means and how to respond. World Econ Forum, 2–6
31. Selamat SAM, Prakoonwit S, Sahandi R, Khan W (2019) Big Data and IoT opportunities for small and medium-sized enterprises (SMEs). In: Handbook of research on Big Data and the IoT, 77–88
32. Slack E (2012) Storage infrastructures for big data workflows. Storage Switchland, LLC, Tech Rep
33. Smith P (2011) Information technology and the quantity surveying practice. Constr Econ Build 1(1):1–21
34. Vassiliadis V, Antonopoulos CD, Zindros G (2015) Automating data management in heterogeneous systems using polyhedral analysis. In: Proceedings of the 19th Panhellenic conference on informatics, pp 317–322
35. Zide O, Jokonya O (2022) Factors affecting the adoption of data management as a service (DMaaS) in small and medium enterprises (SMEs). Procedia Comput Sci 196:340–347

# Investigation of the Effects of Supply Chain Disruptions on Offsite Construction Projects

**Sanaz Nesarnobari, Wajiha Shahzad, Mostafa Babaeian Jelodar, and Monty Sutrisna**

## 1 Introduction

Offsite construction is described as the process of creating construction elements offsite in a specifically designed manufacturing plant, similar to a factory [35]. The numerous benefits of OSC to all industrial sectors contribute to the recent surge in interest in the usage of offsite buildings. Despite its advantages, OSC application remains restricted, undeveloped, immature, and sluggish [32] owing to a lack of understanding of important problems. One of the most significant barriers to adoption is supply chain fragmentation. The supply chain is an integrated network of enterprises and supplier-distributor connections [33]. The supply chain is a product transformation mechanism that transforms raw materials into inventories, work-in-process inventory, and finished items [34]. Control of the supply chain is a long-term competitive advantage and one of the businesses' most important success criteria [4]. The supply chain has become crucial because construction activities have been decentralized [46]. OSC works with current businesses (such as suppliers) that are moving to industrialization and their level of engagement in the offsite housing supply chain. Controlling the supply chain to guarantee sustainability is critical and complex because of the differences between OSC and traditional supply networks [2].

Risk events are a continual source of frustration for supply chain and logistics management. Uncertainty impedes companies' capacity to create economic value by causing overreactions and unnecessary interventions and increasing the likelihood of delays and quality difficulties [7]. Furthermore, it increases supply chain complexity, which should be avoided or eliminated [7]. The five most prevalent risk classification approaches are process, control, demand, supply, and environment [35]. In 2019,

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Luo et al. completed the most recent SCR investigation for an offshore construction project in Hong Kong. They give a more in-depth understanding of SCRs in offsite buildings by considering linked stakeholders and dynamic risk interactions to solve the limitations of traditional static risk analysis [28]. The capacity to respond to and manage these risk events puts a firm ahead of its competition and reduces long-term commercial damage. Respond, efficiency, and dependability are the essential characteristics of supply chain profitability [15]. Supply networks must respond quickly to external and internal risk events while being efficient and dynamic in order to remain profitable.

Risk in the supply chain is created by uncertainty about future risk occurrences, which can occur at any point in the supply chain. Risk events occurring at various levels of the supply chain system may have a negative impact on supply chain performance. Supply chain risk management is the management of such incidents, and it has become a significant component of corporate strategy. Risks can induce unexpected changes in the supply chain's material flow, manufacture, transportation, and assembly. Recognizing many types of risks and the events and conditions that cause these risks is the first step in risk management in the supply chain. As a result, it is critical to detect various sorts of hazards along the supply chain. A thorough examination of the literature is necessary for this goal. As a result, this evaluation research aims to better understand the supply chain disruptions for offsite construction, particularly in terms of enhancing management. By evaluating Scopus database papers on offshore building supply chain hazards, this study will also help scholars propose future research recommendations. Scientometric research is characterized as a "quantitative study of science, science communication, and science policy" [16]. This work offers a scientometric review using the scientometric technique to examine and map the literature on disruptions associated with supply chain of OSC. This paper's findings highlight the significant subjects in the gap literature and give a better knowledge of current research priorities.

## 2 Methodology

Conducting a scientometric review can facilitate the identification of pertinent authors and countries, thereby aiding in discovering research gaps in the field. To meet the aims of this review research, relevant scholarly papers on OSC confronted with risk/disruptions were obtained from an online dataset. As a result, a list of scholarly papers was culled from the Scopus database. Setting research limitations is critical to circumvent the problem of scanning every related article (Van Eck 2014). In this paper, scientometric studies are performed on data from the Scopus online database, utilizing scientometric methodology and a scientific mapping technique. Figure 1 depicts the methodological process structure for this enquiry.

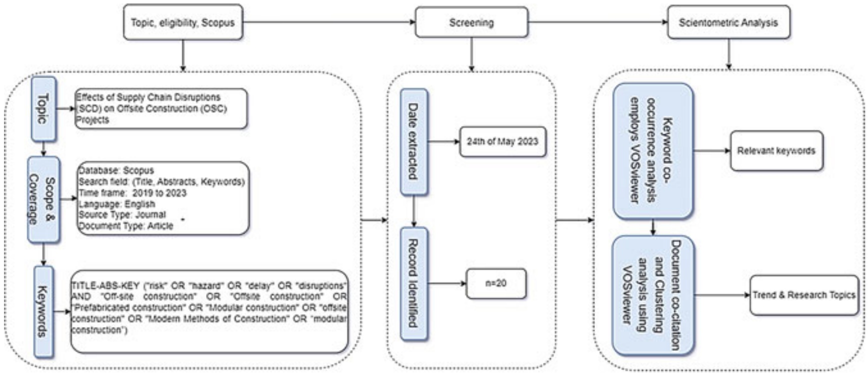


**Fig. 1** Scientometric approach

## 2.1 Framework

The article's primary objective is to conduct a comprehensive scientometric analysis of how disruptions and risks impact various phases of offsite construction projects. It also aims to identify the response strategies employed by project participants thoroughly. Additionally, the paper explores strategies to promote sustainable growth in the supply and demand of offsite construction, along with the valuable management lessons the construction industry can glean from handling disruptions and risks.

The paper effectively clarifies the scientometric review methodology used to assess research related to disruptions and risks in the OSC sector. In this study, the authors utilized science mapping techniques within VOSViewer [44] to create visual representations of the offsite construction landscape. VOSViewer's growing popularity is noted for its role in facilitating literature reviews in construction engineering and project management, including fields such as public–private partnerships [40], building information modeling (BIM, as demonstrated by [14]), and building control [37]. Furthermore, its applicability extends to various other research domains, as indicated by Zhao (2017).

## 2.2 Screening

The Scopus database was searched by using the keyword combinations like "risk" OR "hazard" OR "delay" OR "disruptions" words. The others are: "off-site construction" OR "offsite construction" OR "prefabricated construction" OR "modular construction" OR "offsite construction" OR "modern methods of construction" OR "modular construction." Finally, 20 articles were selected. Inclusion Criteria: This research investigates the impact of disruptions on offsite construction projects and the strategies to mitigate them. Therefore, this study includes papers that specifically address these subjects. Exclusion Criteria: Any literature unrelated to the offsite construction process or does not pertain to the influence of disruptions in this context will be excluded from this research.

## 3 Finding

### *3.1 Co-occurrence Analysis*

A keyword co-occurrence analysis was conducted, involving a total of 791 keywords initially. After applying a predefined minimum threshold, 76 keywords were identified and screened for relevance. Duplicate and irrelevant keywords were subsequently removed from this list. Consequently, 59 valid keywords remained, forming the basis for generating the scientific map displayed in Fig. 2. In this visualization, the associations between keywords and clusters of phrases are color-coded using the VOSViewer visual analysis tool. Each distinct color corresponds to a different collection of keywords. It's important to note that the distance between two keywords on the map reflects the strength of their cross-reference link. More considerable distances indicate weaker connections, while shorter distances suggest a higher likelihood of clustering co-occurring phrases.

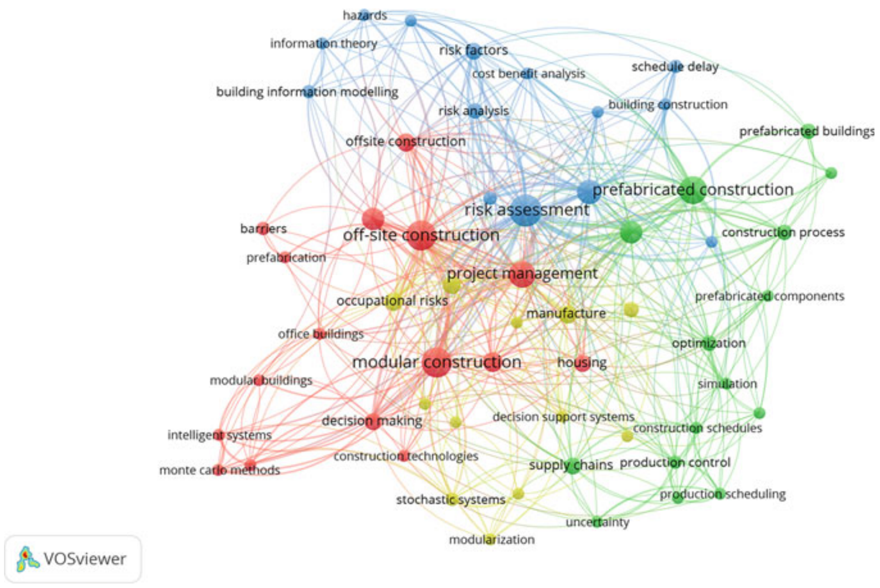


**Fig. 2** Keywords co-occurrence map of references

Figure 2 provides an overview of ten distinct clusters, with "risk assessment" being the most extensively researched keyword. This keyword frequently co-occurs with others such as "off-site construction," "modular construction," "risk management," "cost," and "occupational risk." The size of each node in the figure indicates the frequency of co-occurrence of keywords. The 59 keywords are roughly categorized into four groups based on their node colors. Red Nodes: These keywords are primarily associated with decision-making, barriers, and cost research in offsite construction (OSC). They contribute significantly to understanding how OSC decisions are made, the challenges faced, and the associated costs. Green Nodes: Keywords in this category relate to optimization techniques, risk management, production control, and genetic algorithms. These are commonly used to enhance the optimization of offsite construction processes, focusing on efficiency and risk reduction. Purple Nodes: Simulation is a prominent keyword in this group, often employed to study ways to enhance the adoption of OSC and reduce costs related to risk management. It focuses on simulating OSC scenarios to gain insights into its potential improvements. Blue Nodes: Keywords here center around risk analysis and risk assessment, particularly concerning OSC's cost, risk, and delay. Researchers often use these terms to examine the impact of risks on OSC projects. Yellow Nodes: This category encompasses keywords related to decision support systems, supply chain management, and stochastic models, which are commonly used to manage risks in OSC. These keywords highlight strategies for effectively navigating risks within the OSC context. In summary, Fig. 2 provides a visual representation of keyword clusters in OSC research, offering insights into the major areas of study and their interconnections, with a strong emphasis on risk assessment and management, cost analysis, and optimization.

Keyword analysis serves as a valuable tool for identifying the core content of publications, enabling us to effectively pinpoint key research topics in risk research within offsite construction (OSC). As illustrated in Table 1, aside from "risk assessment," other frequently mentioned keywords encompass "offsite construction," "prefabrication," "risk management," "cost," and "risk factors," with 19, 17, 11, 8, and 6 occurrences, respectively. This suggests that these topics are central to the OSC risk research landscape. Furthermore, it's notable that numerous studies, particularly in China, delve into various aspects of OSC-related risks. These studies address multiple issues, such as risk identification [55] and cost management [8]. This indicates a significant interest in understanding and managing risks associated with OSC projects in China, specifically focusing on risk identification and cost control.

### *3.2 Countries Studying Risks*

This section analyzed the nation or region data from the 85 articles to discover which countries are presently receiving more attention in the researched field. Table 2 shows that ten countries are conducting research on the subject of research. Figure 3

**Table 1** Summary of mostly studied keywords

| Number | Keyword | Occurrence | Total length |
|---|---|---|---|
| 1 | Risk assessment | 22 | 140 |
| 2 | Offsite construction | 19 | 106 |
| 3 | Modular construction | 19 | 74 |
| 4 | Prefabricated construction | 17 | 82 |
| 5 | Project management | 15 | 91 |
| 6 | Risk management | 11 | 78 |
| 7 | Costs | 8 | 44 |
| 8 | Occupational risk | 7 | 55 |
| 9 | Manufacture | 7 | 47 |
| 10 | Offsite manufacturing | 7 | 47 |
| 11 | Offsite construction | 7 | 41 |
| 12 | Risk factors | 6 | 41 |
| 13 | Supply chain | 6 | 29 |
| 14 | Risk analysis | 5 | 21 |

illustrates that the majority of specialists, with a total of 35 publications, have undertaken significant studies in China. China has excited international interest as the first country to announce the concerns. Scholars should look at China's contributions to risk reduction through offsite projects. There are 19 relevant studies in Australia and 9 in the United Kingdom. Apart from China, Australia, and the United Kingdom, there are 8 in Hong Kong and 11 in the United States. Varied countries implemented varied standards for epidemic prevention policies, resulting in varying effects and techniques.

Table 2 shows that experts from China, Australia, and the United States rank first, second, and third in terms of the number of publications, respectively. Furthermore, China has the highest total connection strength in SCD research connected to OSC. However, China is at the forefront of global leadership in this area.

**Table 2** Country active analysis

| Country | Documents | Citations | Total Strength |
|---|---|---|---|
| China | 35 | 535 | 1463 |
| Australia | 19 | 312 | 1357 |
| United States | 11 | 225 | 324 |
| United Kingdom | 9 | 213 | 740 |
| Hong Kong | 8 | 261 | 553 |
| South Korea | 8 | 131 | 206 |
| Malaysia | 7 | 35 | 159 |
| Canada | 6 | 108 | 219 |
| Turkey | 3 | 24 | 221 |
| Indonesia | 3 | 15 | 104 |

**Table 3** List of disruptions adopted from recent works

| Disruptions | Sources |
|---|---|
| Material shortage | [11, 21] |
| Non-standard building material | |
| Issues related to project permitting | [9, 18, 21, 25, 52] |
| Legal and regulatory challenges | |
| Resilience performance | |
| Joint design for connecting offsite components | |
| Site storage and security for offsite manufactured components | [9, 18, 21, 25, 49] |
| Safety and function of temporary structures onsite | |
| Poor understanding of process plans/system failure | |
| Lack of knowledge and expertise and low levels of skilled labor | |
| Inclement weather | [1, 11, 49] |
| Lateness in delivering | |
| Unsuitability of project delivery method | |
| Early arrival and wrong delivery of modules onsite | |
| Limitation of onsite space | [1, 11, 49, 51] |
| Quality damage of components | |
| Transportation restrictions (size & weight) | |
| weather | |
| Experience of employees in OSC projects | [1, 51] |
| Lack of relevant safety education | |
| Stakeholder fragmentation and management complexity | |
| Poor supply chain integration and disturbances | [1, 11, 51] |
| Supply chain information gap and inconsistency | |
| Poor cooperation and communication among project | |

## 4 Discussion

During the various stages of offsite construction including design, manufacturing, transportation, and installation disruptions can occur. Disruptions in any stages of offsite construction projects affect the projects and lead to delays in the planned schedule [17, 23, 53], delivery [36], and an increase in the total cost [30, 31].

Previous research has identified various design-related risks in offsite construction (OSC) projects, including: The absence of design codes can lead to specific concerns during the design stage, particularly regarding the performance of connections between prefabricated structural components [43]. Risks associated with design uncertainty in joints between prefabricated components can subsequently impact construction [25]. OSC designs that inadequately account for local conditions, such

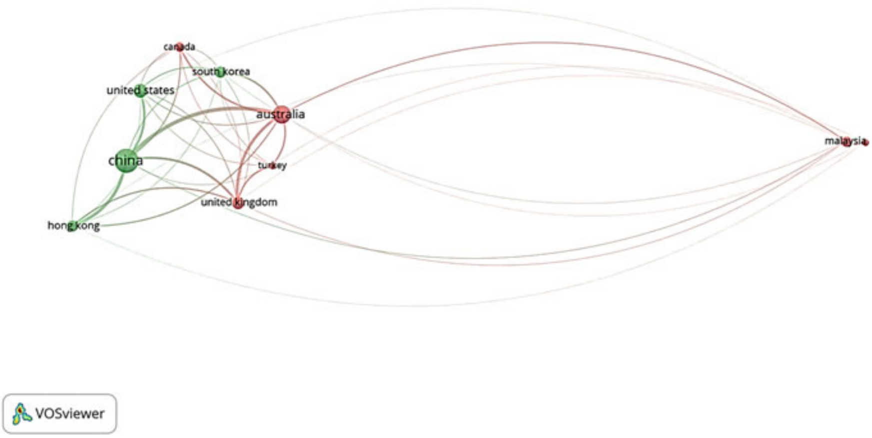


**Fig. 3** Country active analysis

as supply chain management [18, 55]. Insufficient knowledge or experience among industry professionals involved in the design, construction, or management of OSC projects [27].

Communication challenges within OSC project teams, including coordination issues between architects and contractors [19, 29, 39]. In prefabricated building projects (PBPs), typical lifecycle stages include feasibility study, design, manufacturing and transportation, construction, and operation and maintenance [47, 48]. Eze et al. [12] conducted a quantitative survey, identifying contractor-related and design-related causes as the primary categories of rework risk triggers, focusing on management problems and stakeholders [12]. These risks if not addressed early will lead to contractual risks which could be detrimental for working relationship and develop into, or serious disputes [20]. Du et al. [10] developed a multi-agent-based model to quantitatively assess how design change management strategies can enhance project performance. Sutrisna and Goulding [41] explored risks throughout the design stage to facilitate the adaptation of OSC [41]. One significant factor hindering organizations from achieving value in OSC is uncertainty, which can lead to potential delays and issues due to unnecessary interventions and overreactions [54]. This complexity is particularly prominent in the supply chain [54]. As a result, recognizing risk factors becomes crucial. Yang et al. proposed a framework for identifying uncertainties with multifaceted, interconnected, and context-specific features to address this. This framework assesses the probability and impact of these sources of uncertainty. Kim et al. [24] proposed a dynamic model for production scheduling in precast concrete projects. They utilized discrete-time simulation and a new dispatching rule that considers the uncertainty of due dates to minimize delay in response to real-time changes [24].

Furthermore, researchers have made concerted efforts to identify and prioritize the causes of project timeline delays within the realm of offsite construction (OSC) projects. For instance, Wuni et al. (2019) undertook a comprehensive literature review to pinpoint the primary risk factors influencing modular integrated construction projects, which represent a comprehensive form of OSC [50]. Additionally, Wuni and Shen [52] underscored the significant relationship between early-stage project decisions and project success in prefabricated prefinished volumetric construction projects. In a similar vein, Luo et al. [28] conducted a meticulous investigation to uncover supply chain risks (SCRs) responsible for delays and cost overruns in precast concrete (PC) projects. Their approach involved a combination of literature analysis, interviews, focus group meetings, case studies, and social network analysis to dissect SCR-related issues tied to various stakeholders [28]. Cho et al. [5] delved into 19 instances of precast concrete (PC) construction projects in Korea during 2021. They employed fuzzy-set qualitative comparative analysis to explore the connection between early-stage PC project conditions and actual schedule delays [5]. In 2020, Chang et al. developed a dual-objective optimization model aimed at minimizing security risks within systems and controlling costs to reduce the extent of construction safety risks associated with prefabricated structures [3]. Additionally, in 2021, Liu et al. introduced an innovative real-time scheduling and tracking-based dynamic optimization technique tailored for the transportation and storage of precast concrete component [26]. Jeong and Jeong [22] conducted an evaluation of accidents related to modular construction that occurred in the United States between 2000 and 2018. Their study focused on safety risk factors, including accident types and causes [13]. Moreover, Hsu et al. proposed a mathematical model for optimizing the logistics stage, encompassing manufacturing and assembly phases, to refine the risk-averse logistics configuration for modular construction projects operating under conditions of operational uncertainty [38]. The forthcoming table will present a detailed list of risks gleaned from the latest research in this field (Table 3).

## 5 Conclusion

The OSC is related to lifecycle cost reductions, decreased construction waste, increased flexibility, lower carbon emissions, and building process simplicity. However, OSC's unique design, engineering, supply chain, stakeholder mix, and management need to provide a broader range of risks and uncertainties that might jeopardize the aforementioned benefits. In response, empirical research has been conducted in several nations to investigate the numerous risks connected with OSC. Due to the focus of more studies on distinct risk components of OSC, it is necessary to synthesize the empirical study findings in order to establish a research framework for the essential elements associated with OSC. A thorough review of 20 empirical recent research on the dangers of OSC was undertaken in this study.

The analysis of recently published articles has revealed that risk factors in offsite construction impact all supply chain stages and are not limited to a specific phase. The findings suggest that seven key factors significantly influence project timelines. These factors are: (1) Shortage of skilled and experienced laborers. (2) Late design changes. (3) Poor site attributes and logistics. (4) Unsuitability of design for modularization. (5) Contractual risks and disputes. (6) Lack of adequate collaboration and coordination. (7) Challenges related to tolerances and interfaces. These factors affect project timelines and contribute to increased project costs. While some elements may primarily impact a single stage of the construction process, others have repercussions across multiple locations. Consequently, it is crucial to analyze and identify risks associated with offsite construction thoroughly. By doing so, we can enhance the adoption of offsite construction methods over traditional in situ construction, recognizing the benefits of the new approach.

The results of this study may significantly value and benefit academics, policymakers, and advocates in the construction industry seeking empirical quantitative proof and explanations of the recent risks and repercussions needing response solutions. A comprehensive understanding of the implications of demanding response methods is critical for effectively combating the pandemic. The awareness of consequences was closely associated with reaction approaches that might enable politicians and activists to establish response plans that minimize the negative impacts of the offsite building sector.

## References

1. Arashpour M, Heidarpour A, Nezhad AA, Hosseinifard Z, Chileshe N, Hosseini R (2019) Performance-based control of variability and tolerance in off-site manufacture and assembly: optimization of penalty on poor production quality. Constr Manage Econ 38(6):502–514
2. Bankvall L, Bygballe LE et al (2010) Interdependence in supply chains and projects in construction. Supply Chain Manag: Int J 15(5):385–393. https://doi.org/10.1108/13598541011068314
3. Chang C, Wu X et al (2020) Multiobjective optimization of safety risk of prefabricated building construction considering risk correlation. Math Probl Eng. https://doi.org/10.1155/2020/3923486
4. Chiang Y-H, Chan EH-W et al (2006) Prefabrication and barriers to entry—a case study of public housing and institutional buildings in Hong Kong. Habitat Int 30(3):482–499. https://doi.org/10.1016/j.habitatint.2004.12.004
5. Cho K, Seungjun Ahn AMA et al (2021) Schedule delay leading indicators in precast concrete construction projects: qualitative comparative analysis of Korean cases. Am Soc Civ Eng 37(4). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000915
6. Christopher M, Peck H (2004) Building the resilient supply chain. Int J Logist Manage 15(2):1–14. https://doi.org/10.1108/09574090410700275
7. Davis T (1993) Effective supply chain management. Sloan Manage 34(4):35–46
8. Ding X, Liua K et al (2020) Risk assessment of strategic cost management based on grey model for prefabricated buildings. Int J Performability Eng 16(9):1478–1487. https://doi.org/10.23940/ijpe.20.09.p17.14781487
9. Ding X, Liu K, Shi S (2020) Risk assessment of strategic cost management based on grey model for prefabricated buildings. Int J Perform Eng 16(9):1478. https://doi.org/10.23940/ijpe.20.09.p17.14781487
10. Du J, Jing H, Castro-Lacouture D, Sugumaran V (2019) Multi-agent simulation for managing design changes in prefabricated construction projects. Eng, Construct Architect Manag 27(1):270–295. https://doi.org/10.1108/ECAM-11-2018-0524

11. Ekanayake EMAC, Shen GQP, Kumaraswamy MM, Owusu EK (2022) Identifying supply chain vulnerabilities in industrialized construction: an overview. Int J Const Manag 22(8):1464–1477. https://doi.org/10.1080/15623599.2020.1728487
12. Eze EC, Idiake JE, Ganiyu BO (2018) Rework risks triggers in the Nigerian construction industry: a view of built environment professionals. Independent J Manag Prod 9:448–472
13. Gilsu Jeong HK, Lee H-S, Park M, Hyun H (2022) Analysis of safety risk factors of modular construction to identify accident trends. J Asian Archit Build Eng 21(3):1040–1052. https://doi.org/10.1080/13467581.2021.1877141
14. He Q, Wang G, Luo L, Shi Q, Xie J, Meng X (2017) Mapping the managerial areas of building information modeling (BIM) using scientometric analysis. Int J Project Manage 35:670–685
15. Hendricks KB, Singhal VR (2003) The effect of supply chain glitches on shareholder wealth. J Oper Manag 21(5)
16. Hess DJ (1997) Science studies: an advanced introduction. NYU Press.
17. Hola B, Schabowicz K (2010) Estimation of earthworks execution time cost by means of artificial neural networks. Autom Constr (19):570–579
18. Hong J, Shen GQ, Li Z, Zhang B, Zhang W (2018) Barriers to promoting prefabricated construction in China: a cost–benefit analysis. J Clean Prod 172:649–660. https://doi.org/10.1016/j.jclepro.2017.10.171
19. Ismail Z-A, Mutalib, A, Hamzah N (2016) Case study to analyse problems and issues in IBS building maintenance. Int J Appl Eng 11(1)
20. Jelodar MB, Yiu TW (2012) Evaluation of relationship quality in construction cases using a process model of conflict and disputes in project management. Paper presented at the 8th international project management conference (IPMC2012), Tehran-Iran
21. Jeong G, Kim H, Lee H, Park M, Hyun H (2022) Analysis of safety risk factors of modular construction to identify accident trends. J Asian Archit Build Eng 21(3):1040-1052. https://doi.org/10.1080/13467581.2021.1877141
22. Jeong J, Jeong J (2021) Novel approach of the integrated work & risk breakdown structure for identifying the hierarchy of fatal incident in construction industry. J Build Eng, 41.
23. Kaplinski O (2008) Planning instruments in construction management. Technol Econ Dev Econ 14:449–451
24. Kim T, Kim Y et al (2019). Dynamic production scheduling model under due date uncertainty in precast concrete construction. J Clean Prod 257. https://doi.org/10.1016/j.jclepro.2020.120527
25. Liao L (2018) Experience analysis on the design, manufacture and construction of fabricated concrete structure. Fujian Constr Technol 2
26. Liu D, Li X et al (2020) Real-time optimization of precast concrete component transportation and storage. Adv Civ Eng. https://doi.org/10.1155/2020/5714910
27. Luo J, Zhang H, Shen W (2017) Insights into architects' future roles in off-site construction. Constr Econ Build 17(1)
28. Luo L, Qiping Shen G et al (2019) Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong. J Manag Eng 35(2). https://doi.org/10.1061/(asce)me.1943-5479.0000675
29. Luo LZ, Mao C, Shen LY, Li ZD (2015) Risk factors affecting practitioners' attitudes toward the implementation of an industrialized building system a case study from China. Eng Construct Architect Manag 22(6)
30. Mao C, Shen QP, Shen LY, Tang LYL (2013) Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: two case studies of residential projects. Energy Build 66(11):165–176
31. Mao C, Shen QP, Pan W, Ye KH (2015) Major barriers to off-site construction: the developer's perspective in China. J Manag Eng 31(3)
32. Marjaba GE, Chidiac SE (2016) Sustainability and resiliency metrics for buildings. Build Environ 101:116–125
33. Mostafa S, Dumrak J et al (2014) Offsite manufacturing in developing countries: current situation and opportunities. Paper presented at the 5th international conference on engineering, project and production management

34. Nesarnobari S, Shahzad W et al (2022a) Mapping supply chain to enhance capability and capacity of prefabricated housing supply in New Zealand. Paper presented at the 7th New Zealand built environment research symposium, creating capacity and capability for the future of the built environment, Auckland, New Zealand
35. Nesarnobari S, Shahzad W et al (2022b) The Status Quo of prefabricated housing: an investigation into New Zealand construction sector. Paper presented at the Proceedings of the 22nd CIB world building congress, 27–30 June, RMIT University, Melbourne, Australia
36. PMI (2013) PMBOK guide: a guide to the project management body of knowledge, 5th edn. Project Management Institute. Project Management Institute, Delaware, PA
37. Park JY, Nagy Z (2018) Comprehensive analysis of the relationship between thermal comfort and building control research. Sustain Energy Rev 82
38. Pei-Yuan H, Aurisicchioa M et al (2019) Risk-averse supply chain for modular construction projects. Autom Constr 106. https://doi.org/10.1016/j.autcon.2019.102898
39. Pozin MAA, NawiM NM, AzmanM NA, Lee A (2017) Improving communication in managing industrialised building system (IBS) projects: virtual environment. Malays Constr Res J 2
40. Song J, Zhang H, Dong W (2016) A review of emerging trends in global PPP research, analysis and visualization. Scientometrics 107(3)
41. Sutrisna M, Goulding J (2019) Managing information flow and design processes to reduce design risks in offsite construction projects. Eng Constr Archit Manag 26(2):267–284. https://doi.org/10.1108/ecam-11-2017-0250
42. Tam VWY, Tam CM, Zeng SX, Ng WCY (2007) Towards adoption of prefabrication in construction. Build Environ 42
43. Vaghei R, Hejazi F, Taheri H, Jaafar MS, Ali AAA (2016) A new precast wall connection subjected to monotonic loading. Comput Concr 17(1)
44. Van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538
45. Van Eck NJ, Waltman L (2014) Visualizing bibliometric networks. In: Measuring scholarly impact, pp 285–320
46. Vrijhoef R, Koskela L (2000) The four roles of supply chain management in construction. Eur J Purchasing Supply Manag 6(3):169–178. 10.1016/ S0969-7012(00)00013-7
47. Wang Z, Hu H, Gong J, Ma X, Xiong W (2019) Precast supply chain management in off-site construction: a critical literature review. J Clean Prod 232:1204–1207
48. Wu H, Qian QK, Straub A, Visscher H (2019) Exploring transaction costs in the prefabricated housing supply chain in China. J Clean Prod 226:550–563. https://doi.org/10.1016/j.jclepro.2019.04.066
49. Wu H, Qian QK, Straub A, Visscher H (2019) Exploring transaction costs in the prefabricated housing supply chain in China. J Clean Prod 226:550-563. https://doi.org/10.1016/j.jclepro.2019.04.066
50. Wuni IY, Shen GQP (2019) Holistic review and conceptual framework for the drivers of offsite construction: a total interpretive structural modelling approach. Buildings
51. Wuni IY, Shen GQ (2020) Fuzzy modelling of the critical failure factors for modular integrated construction projects. J Clean Prod 264:121595. https://doi.org/10.1016/j.jclepro.2020.121595
52. Wuni IY, Shen GQ (2021) Exploring the critical success determinants for supply chain management in modular integrated construction projects. Smart Sustain Built Environ. https://doi.org/10.1108/SASBE-03-2021-0051
53. Yang JBT, DLA (2011) Construction risk modeling and assessment: insights from a literature review. Built Hum Environ 4:87–97
54. Yang Y, Pan M et al (2022) Integrated offsite logistics scheduling approach for high-rise modular building projects. Am Soc Civ Eng. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002280
55. Zhang L (2020) Influence diagrams for off-site construction manufacturing risk assessment
56. Zhao X, Feng Y, Pienaar J, O'Brien D (2017) Modelling paths of risks associated with BIM implementation in architectural, engineering and construction projects. Archit Sci Rev 60

# Examining Infrastructure Pipelines Information for Their Relevance in Construction Organizations' Strategic Decision-Making

**Taofeeq Durojaye Moshood, James Olabode Bamidele Rotimi, and Wajiha Shahzad**

## 1 Introduction

The construction industry in New Zealand helps to expand the nation's economy by boosting gross domestic product (GDP) per person, generating jobs and fostering company growth [53]. In 2019, the construction industry contributed 6.7% to New Zealand's GDP, and in the first quarter of 2021, it employed more than 170,000 people [32]. The industry has raised its goals to satisfy the government's desire for housing and infrastructure that are secure, cheap, healthy, and sustainable [81]. The government gives the construction industry special priority and wants to boost its capacity [88]. Improving the power and capabilities of the construction sector creates opportunities for investment and infrastructural advancements while increasing the sector's activities [67]. Construction business performance requires improving the quality of information to decide on a project, productivity, workforce, risk management, and ensuring value for money [81]. However, the instability of the construction sector may depend on infrastructure pipeline uncertainties and strategic decision-making. The information provided by infrastructure pipelines assists in the creation of a forward view of projects, guides the construction industry, the government, and stakeholders, including contractors, and answers questions regarding when, how, where, and at what cost investments will be made within New Zealand so that the construction

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industry can deliver on those investments. A consistent and dependable infrastructure pipeline may be developed by investigating when, how, and where investments are made, as well as the total amount.

The construction industry is subject to increased stress and risk due to the unpredictability surrounding the information and strategic decision-making process regarding the delivery of significant pipes [90]. Every day, choices are made about a building project, beginning with the tendering phase, and continuing through the closing process. In the construction industry, decision-makers are tasked with creating a wide variety of choices, including whether or not to accept a project, the type of technical solution to be implemented, the amount of risk reserve to be considered concerning cost and schedule, whether or not to perform in-house construction or to subcontract it out, whether to make or buy, lease or rent, which supplier to buy from, which person to hire, and a multitude of other choices, as well as hundreds of different options [87]. In order for the person to have the best chance of making the best choice, they should have access to all of the relevant information, including the facts, the repercussions, and the predictions of the decision [75]. On the other hand, the quality of the information that stakeholders get in the decision-making process might increase the likelihood of achieving desirable results. This does not, however, imply that the outcome of the choice will be exactly as anticipated [98].

However, the relevance of pipeline data in making strategic decisions needs to be examined to guarantee that the data and information provided are accurate, comprehensive, and presented in a timely manner [46]. Many researchers have concluded that executives make strategic decisions by following a methodical process that requires careful consideration of the circumstances, alternatives, and consequences [19]. This strategy is referred to as a "rational process". Despite this, strategic decision-making necessitates taking into account a variety of additional contextual viewpoints, including those of top management (a choice that may be strategic or managerial), decision-specific features, environmental determinism (environmental characteristics), and organizational characteristics [28]. Executives must have access to information that is both accurate and pertinent for them to be able to make informed judgments on the company's strategic direction. This information may be obtained by collecting and examining data from various sources using infrastructure pipeline data. By utilizing this data, executives can obtain insights into market trends, client behaviour, and operational efficiency, which may inform their decision-making process [28]. The research indicates that information plays a significant part in making strategic decisions and that data on infrastructure pipelines may efficiently convey this information to decision-makers. On the other hand, aspects of the function of information in the decision-making process receive very little attention in management research. As a result, the purpose of this research is to assess the infrastructure pipelines projects and identify the influence the information quality on strategic decision-making within the context of pipeline construction project management.

## 2 Methodology

In order to facilitate the analysis and screening of the collected studies, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) procedure is employed [57]. The PRISMA process flow, consisting of four sequential steps, is illustrated in Fig. 1. This study meets the criteria for a systematic review [80]. A scientific procedure that can be replicated, known as a systematic review, is used to locate, select, and assess all published research pertinent to a given quality level [13]. One of the benefits of utilizing this methodology is that it makes it possible to research a specific area using a more logical and standardized technical approach [45]. As a result, the results can be presented to readers objectively and transparently [36]. There are some problems with the technique. Because journals tend to publish publications with findings that have a substantial influence, valuable studies with outcomes that are not significant, as well as articles written in a language other than English, will be overlooked [45]. Following the technique for conducting a systematic literature review presented in Fig. 1, the articles found were subjected to screening, filtration, and validation to determine whether or not they should be included in the analysis.

Following the prescribed guidelines for conducting a systematic review [45, 80], this study employs a rigorous methodology to assess a specific quality and quantity of research on the topic of infrastructure pipelines—a critical information aspect for construction companies in strategic decision-making. The review provides readers with an unbiased, transparent, and standardized technical roadmap, outlining database selection, study retrieval, and criteria for selecting target studies. Furthermore, this systematic approach is designed to be replicable and updatable. The key components of this systematic strategy include: (1) formulating a research question, (2) aggregating pertinent studies; (3) selecting and appraising relevant research; (4) performing a content analysis of the chosen studies; and (5) summarizing the findings and presenting recommendations.

### *2.1 Search Strategy and the Selection of Studies*

The researcher searched for relevant literature using the Scopus and government documents. In addition, we want to address the concerns and examine infrastructure pipeline information for their relevance in strategic decision-making within New Zealand construction firms. As a result, this research decided to use well-known datasets as the source databases. The database researcher chose to use Scopus because it is widely regarded as the one that houses the most abstracts and citations anywhere in the world. Scopus covers 15,000 journals published by 4000 publishers, including Elsevier, Emerald, Taylor and Francis, John Wiley, Springer Nature, and EPPM [45]. They include sufficient and relevant literature in terms of number and quality to make them helpful in conducting a comprehensive review of the evolution of infrastructure

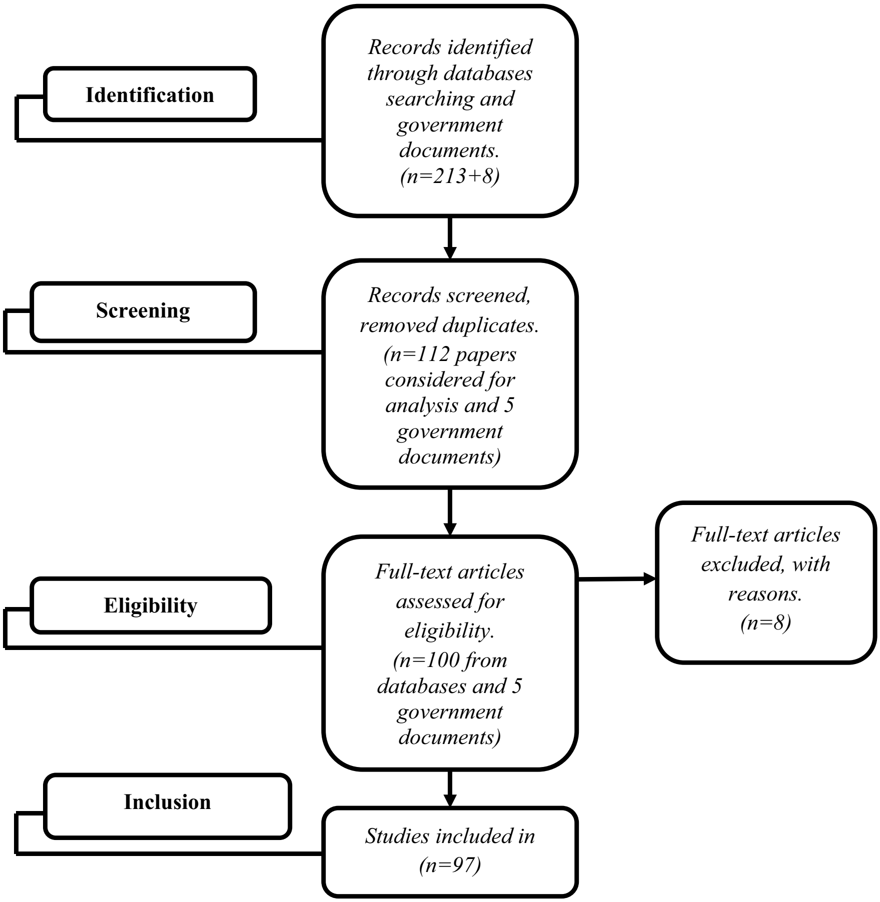


**Fig. 1** Methodology framework

pipelines for their relevance in strategic decision-making within construction firms. Both "Strategic decision-making", "Information quality", and "Quality of information" were included in the titles of all scholarly publications published in reputable journals and relevant keywords.

Infrastructure pipelines undergo a thorough examination to assess their relevance in strategic decision-making within construction companies, covering various key stages. The assessment process is meticulously structured around segments focusing on processes, findings, and discussion, allowing readers to track the data production process and comprehend the implications of the findings. The articles underwent a rigorous screening, filtering, and checking process, employing an iterative selection technique in line with the systematic literature review strategy presented, determining their inclusion in the study. To identify and conclude the aspects of information quality impacting decision-making processes, a meticulous elimination of duplicates, verification of eligibility based on abstracts, and a comprehensive review of the full content of outstanding papers were conducted in alignment with the study's objectives. Adhering to the systematic literature review guidelines, all 97 papers were individually examined and verified, leading to the decision to employ the ATLAS.ti 9 software for efficient organization, categorization, and evaluation of the study material [58]. Recognized as a potent tool for qualitative analysis, especially with extensive textual and graphical data, ATLAS.ti 9 facilitated the systematic review process. Duplicates were systematically removed, eligibility was validated through abstracts, and the entirety of exceptional articles was assessed against research concerns to determine the suitability of infrastructure pipeline information for strategic decision-making within the investigated construction firms. Employing a systematic literature review approach, all 97 articles underwent meticulous evaluation and were confirmed as authentic.

## 3 Literature Review

### *3.1 Overview of Infrastructure Pipeline Projects in New Zealand*

Over the years, the New Zealand government has significantly emphasized infrastructure development, residential construction, and non-residential building projects. The pipeline projects in the country are categorized into three main types: public projects, private projects, and public–private projects [83]. Each project owner determines the payment method, contract nature, and level of risk expected for contractors or suppliers involved. The construction pipeline project information describes and analyzes all large-scale pipeline projects and spending across New Zealand's regions [53]. The analysis includes details on the planned project spending type, the timing and value of significant projects, and a regional element of project spending [64]. The pipeline project data is specific information and statistics related to the various projects within a pipeline. It includes a range of data points relevant to the planning, project descriptions, implementation, timelines, project value, location, and monitoring of the projects. Pipeline projects create a forward view of all building and construction works [53]. Consistency in the project pipeline process is vital to establishing agreed-upon timelines, allocating team members to specific tasks, maintaining clear project statuses, and ensuring accurate project information [52].

The goal of constructing pipeline project data encompasses a wide range of tasks, including strategic planning, investment scheduling, coordination of project execution, and collaboration between businesses and government entities [53]. Establishing a clear project pipeline is of utmost importance as it enhances awareness among government and industry stakeholders, providing valuable insights into potential projects and the required workforce and resources to complete specific tasks

[12]. Research conducted by Larsen et al. [42] further emphasizes that effective pipeline project planning enables a comprehensive understanding of the project and its resource requirements while minimizing the likelihood of unexpected obstacles that may hinder or delay project completion.

Moreover, pipeline projects facilitate the government and the construction sector in formulating future plans for timely and cost-effective project completion. They contribute to streamlining efficiency and offering precise insights into project forecasting and construction patterns [18]. Additionally, identifying and locating these projects can improve construction quality, productivity, and employment opportunities for both skilled and unskilled workers and provide valuable insights into the procurement process [53].

Adopting a forward-looking approach to planning and project execution can result in an average profit margin increase of 23% for projects [41] while concurrently reducing risks and enhancing quality. As highlighted by Leon et al. [44], a well-organized pipeline project enables precise monitoring of project performance, ensuring that all project goals are achieved. Furthermore, forecasting pipeline projects is pivotal in early monitoring and trend detection, enabling proactive decision-making to prevent anticipated project delivery delays [18]. Failure to prioritize the development of a highly skilled workforce that can effectively meet the demands of pipeline construction projects and quality of information, coupled with a lack of strategic decision-making in this domain, can result in an industry boom that lacks the essential knowledge and resources required for its sustainability [6]. Without investing in workforce training and development, the industry may face a shortage of qualified personnel, hindering project execution and compromising overall quality. Furthermore, without strategic decision-making processes, the industry may struggle to anticipate and adapt to changing market dynamics, leading to inefficiencies, delays, and cost overruns [89]. It is crucial to recognize the significance of nurturing a skilled workforce and making informed decisions to ensure the long-term viability and success of the pipeline construction industry.

### *3.2 Sources of Infrastructure Pipelines Project Information in New Zealand*

In New Zealand, various sources provide valuable information on ongoing and pipeline projects. As illustrated in Table 1, these sources play a crucial role in capturing and disseminating project data.

These sources collectively contribute to the availability of comprehensive information on ongoing and pipeline projects in New Zealand. They are essential references for industry professionals, policymakers, investors, and the general public, informing them about current and upcoming projects, their scope, timelines, and the stakeholders involved [53]. It is worth noting that the accuracy and currency of

**Table 1** Sources of infrastructure pipelines project information

| Organizations | Sources |
|---|---|
| Government agencies | – Ministry of Business, Innovation, and Employment (MBIE)<br>– New Zealand Transport Agency (NZTA)<br>– Department of Conservation (DOC)<br>– Ministry of Education (MOE) |
| Local government | – City councils<br>– Regional councils<br>– District councils |
| Industry associations | – Construction Industry Council (CIC)<br>– Infrastructure New Zealand<br>– Master Builders Association |
| Private organizations | – Pacifecon NZ Ltd.<br>– Infometrics<br>– Statistics New Zealand |
| Media outlets | – Newspapers<br>– Online news platforms<br>– Industry-focused magazines |

project information may vary across different sources, and it is advisable to cross-reference multiple sources for a complete and up-to-date understanding of the project landscape. Therefore, New Zealand benefits from various sources providing project data, allowing stakeholders to access vital information on ongoing and pipeline projects. The availability of such information fosters transparency, supports informed decision-making, and promotes collaboration among various parties involved in the construction and infrastructure sectors.

Each source of information on construction pipeline projects in New Zealand offers distinct advantages and disadvantages based on the type of information provided. Coordinating and tracking all pipeline construction projects in the country is time-consuming, prompting the government to prioritize establishing reliable and accessible sources for project information [53]. However, it is essential to note that specific future construction projects may be politically classified or subject to regulatory time frame restrictions before public disclosure and publication. To enhance the availability of project information, the Ministry of Business, Innovation, and Employment (MBIE) commissioned Pacifecon (NZ) Ltd and BRANZ to produce the annual national construction pipeline report in 2021 [53]. Pacifecon (NZ) Ltd specializes in providing pipeline construction project data across non-residential, residential, and infrastructure constructions [69].

Additionally, in 2019, the New Zealand government established the New Zealand Infrastructure Commission (NZIC), intending to ensure quality infrastructure investment to improve the construction sector's sustainable long-term economic performance and social well-being [92]. The NZIC provides information about infrastructure pipeline construction projects, emphasizing certainty and project phasing details [63]. These initiatives by the government and the involvement of specialized organizations contribute to a more comprehensive and reliable information ecosystem for construction pipeline projects in New Zealand. Stakeholders can access data from the national construction pipeline report, Pacifecon (NZ) Ltd., and the NZIC to obtain valuable insights into ongoing and upcoming projects across various sectors [69]. However, it is crucial to consider that the availability and accuracy of information may evolve, and cross-referencing multiple sources is advisable for a comprehensive understanding of the project landscape.

### 3.3 Strategy Management in Construction Industry

Defining strategy proves challenging due to its intricate nature encompassing various processes and activities within an organization [65]. Bakar et al. [7] offer a multifaceted perspective, presenting strategy as a plan, play, position, pattern, and perspectives. While each of these viewpoints contributes to understanding strategy, none is individually adequate to grasp its entirety. Scholars have sought to provide nuanced interpretations of the concept, with Pamulu [70] defining it as the long-term direction and scope of an organization, achieving advantages by configuring resources and competencies to meet stakeholder expectations in a dynamic environment. [91] emphasize strategy as delineating objectives and providing a roadmap to achieve them. Mintzberg and Rose [56] conceptualize strategy as creating a distinctive and valuable position through a unique set of activities. Ng'andu [65] asserts that strategy involves aligning internal organizational characteristics with the external environment, emphasizing the development of core competencies and strengths to navigate threats and capitalize on opportunities [25].

While these definitions offer clarity, the practical essence of any business strategy lies in an overarching plan of action defining the firm's competitive position [65]. Organizational strategy is often characterized as a deliberate set of actions aimed at attaining a competitive advantage, providing coherence and direction to the organization [65].

### 3.4 Levels of Strategy

There are three levels at which strategy is practised in organisations;

- Corporate levels
- Business strategies or competitive strategies
- Functional strategy or operational strategies.

Corporate strategy involves the structuring and management of business activities, encompassing the definition of the firm's overall mission and objectives. It plays a pivotal role in validating suggestions from organization and functional levels and allocating resources based on strategic priorities [33]. In the construction industry, corporate strategies like subcontracting and joint ventures (JVs) are instrumental for growth and business development [2]. Joint ventures, particularly with established larger businesses, provide opportunities for construction companies to expand domestically and secure contracts through the bidding process that might be challenging to win independently [1]. Diversification in the construction industry involves exploring related markets like property development, housing, building materials supply, plant and equipment hiring, and mechanical and electrical engineering. This strategic approach aims to enhance market presence and facilitate business expansion [1].

The second tier of strategic planning involves business strategy, which focuses on sustaining a competitive advantage within each strategic business unit [68]. Coulter et al. [23] explain that business strategies involve how an organization competes within a specific industry, focusing on critical success factors and outperforming competitors [68]. In construction, strategies include adopting generic approaches like cost leadership, differentiation, and focus. [1] assert that a differentiation strategy is appropriate when a business can distinguish its products along valued attributes at a cost lower than the anticipated extra revenue. The goal is to make customers perceive the product's value as significantly exceeding its cost compared to other alternatives [14]. This strategy aims to reduce the price sensitivity of the business's products, wherein customers prioritize factors other than price in their purchasing decisions [1].

The third level involves functional or operational strategy, as delineated by [27]. Functional strategies encompass short-term goal-directed decisions and actions in various organizational functional areas, including marketing, operations, production, finance, and human resources. To bolster business and corporate strategy, the company must uphold a competitive strategy across each functional area [85]. In the construction industry, an effective functional strategy involves a robust marketing campaign for products and services. Despite the available options for functional strategies in construction, choosing the most suitable approach remains challenging due to the unclear literature on the subject [24]. Ehlers and Lazenby [27] echo the complexity of strategy-making styles among owner-managers and entrepreneurs, emphasizing the tendency to prioritize aspects closest to home, such as competencies, capabilities, and resources [65]. This insight highlights the challenges inherent in deciding on the optimal strategy within the construction industry, given the dynamic landscape and diverse strategic options available.

- **Competencies:** Referring to activities that an organization excels in, often deemed as "core" competencies, these are the actions employees undertake to generate profit or establish a competitive advantage [65].
- **Capabilities:** Collections of competencies systematically linked and synergized to yield strategic outcomes, competitive advantages, or superior profitability constitute capabilities [65]. In the construction industry, organizational capabilities often involve the aggregation of competencies cantered around specific skills or tasks, stemming from the entrepreneur's vision of the "right" core competence. This knowledge is then transferred to other staff members, contributing to the

development of capabilities, the multiplication of which enhances profitability and growth [24].

- **Resources:** Tangible and increasingly intangible aspects of the organization's infrastructure that support competencies and capabilities constitute resources. For burgeoning small businesses, effective resource management is crucial, as limited resources can impede the availability of necessary cash and assets for sustaining initial development [65]. Hence, guided by the resource-based view theory, the construction industry's strategy selection depends on the competencies, capabilities, and resources, both tangible and intangible, available to the owner and the organization to some extent.

### *3.5 Infrastructure Pipelines Information as a Factor in Strategic Decision-Making*

As the world becomes increasingly interconnected, businesses face a growing amount of data that they must analyze and interpret to make strategic decisions [47]. One area where this is particularly important is infrastructure pipelines. This infrastructure pipeline information is critical for construction firms, and their efficient operation can significantly impact a company's bottom line [99]. Information's role in making strategic decisions is rarely acknowledged, discussed, or analyzed as such in management research publications. This is likely because management information is viewed as an easily accessible production factor and is frequently "taken for granted" in studies on organization performance [10].

In strategic decision-making, information input is often discussed in terms of considering factors like the business environment, internal and external issues, and changing conditions [9]. However, the characteristics of information in strategic management, including its quality, sources, and actual use during decisions are frequently overlooked [72]. Various scholars in information management [21, 31, 59, 60, 74] have explored the role of information in managerial choices.

According to [17], an organization operates as an open system that absorbs information from the external environment, transforming it into knowledge, processes, and structures to generate commodities or services. Information is strategically utilized for decision-making, knowledge creation, innovation, and understanding environmental changes [30]. Pertinent information for strategic choices encompasses internal organization dynamics, market structures, competitors, consumer attitudes, technology, legislation, public affairs, as well as best practices and trends in these areas [3, 20, 54, 59, 60]. Additionally, assessing market opportunities, threats, and risks is crucial. Formalized routines, as per Robert and Wally [78], improve information flow across the organization, expediting strategic decision-making. Yet, there's a need to balance information gathering costs and time against expected benefits to prevent diminishing returns and ensure efficient decision-making [84, 99].

### 3.6 Data/Information Needs and Strategic Decision-Making in the Construction Industry

Companies typically rely on the experience and intuition of their management when making decisions. This strategy hasn't worked well, especially when no digital form data is available [96]. By failing to implement a new approach to analyze their underutilized fragmented data and produce meaningful information systematically, organizations risk losing their ability to compete in the market [16]. According to Lu et al. [51], managers should aim to pursue informed and sensible judgements rather than entirely accurate ones. This indicates that decision-makers should be aware of their actions' facts, impacts, and implications, even if the final results are less favourable than anticipated. Additionally, Du et al. [26] assert that three constraints are placed on judgements by the limited rationality theory, as illustrated in Fig. 2. First, there is a lack of information regarding potential options and their effects, followed by a capacity issue with the information presented, and ultimately, there is a decision-making time issue.

Considering the three restrictions, the bounded rationality theory logically describes how people make decisions in the actual world [48]. The two types of rationality boundaries are external and internal, respectively, according to Herbert Simon's 1955 bounded rationality theory [49]. The external constraint, or so-called uncertainty, arises from the imperfection of our knowledge of the outside world. This indicates that people don't use their free time, if they have it, to learn about all the factors that could impact their choices and results. Instead, they presumably receive the data that is thought to be the most pertinent for choosing a certain amount of time [48]. The restrictions to compute and handle a lot of data are, on the other hand, internal limitations. Because of the temporal and internal cognitive constraints

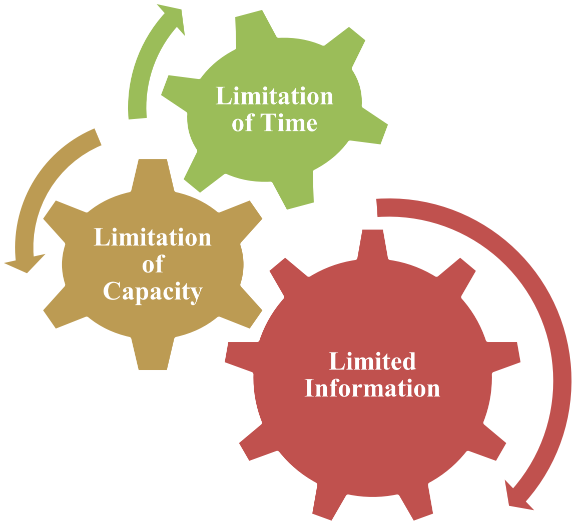


**Fig. 2** Constrained rationality theory

that characterize human reason, even if we know all relevant facts and inputs for a particular topic, we cannot process them all [50].

Moreover, the approach is influenced by both internal and external constraints. Marwala [55] characterizes rational decision-making as "a process of making decisions based on relevant information in a logical, timely, and optimized manner". The process initiates with an examination of the decision-making context, proceeds to identify the necessary pertinent information, and culminates in a logical and coherent presentation of this information to the decision-maker [55]. However, as Simon [86] argues that the three boundaries make a perfectly rational choice practically impossible, these limitations can only be partially overcome by utilizing cutting-edge information processing techniques [55]. When the boundaries of reason are enlarged in this situation, the theory of limited rationality is changed to the theory of flexibly bounded rationality.

## 3.7 Strategic Decision-Making Under Quality of Information

According to [15], the information and data created during the lifetime of construction projects become increasingly extensive in terms of volume and variety as the projects themselves get more complicated and more extensive. According to Kliuchnikova and Pobegaylov [40], as a result of this, it isn't easy to handle all of this information in an efficient and trustworthy manner. According to Chassiakos and Sakellaropoulos [15], one practical and effective strategy for overcoming this obstacle would be to use databases and other online information management technologies. According to Nisar et al. [66], the decisions made by project leaders during all phases of the project, but particularly during the pre-construction phase, are seen as a crucial component in determining whether or not the project will be successful. According to Al et al. [4], managers should ensure that all of the relevant information is right and can offer the appropriate inputs to the decision-making process during these phases. This will help managers avoid potential risks and difficulties. It is common practice for businesses to defer to highly compensated managers who have amassed a wealth of expertise throughout their careers when there comes time to make choices about their operations [16].

This is particularly true when data is unavailable or requires a significant investment to acquire in digital format. This method of decision management, which places reliance on the intuitive reasoning of leaders, has been demonstrated to be insufficient [40]. It is necessary to move towards making judgements based on facts to improve the quality of decisions and the pace at which they are made [16]. Consequently, the total performance will improve in the intermediate and long-term periods. According to Safa and Hill [79], having readily available and easy-to-understand data can make it more conceivable for construction leaders to uncover patterns, relations, and facts that could improve the steady development of the project. According to Murphy and Seriki [61], management can know more about the current state of their company and take appropriate action based on the information they have gathered, linked,

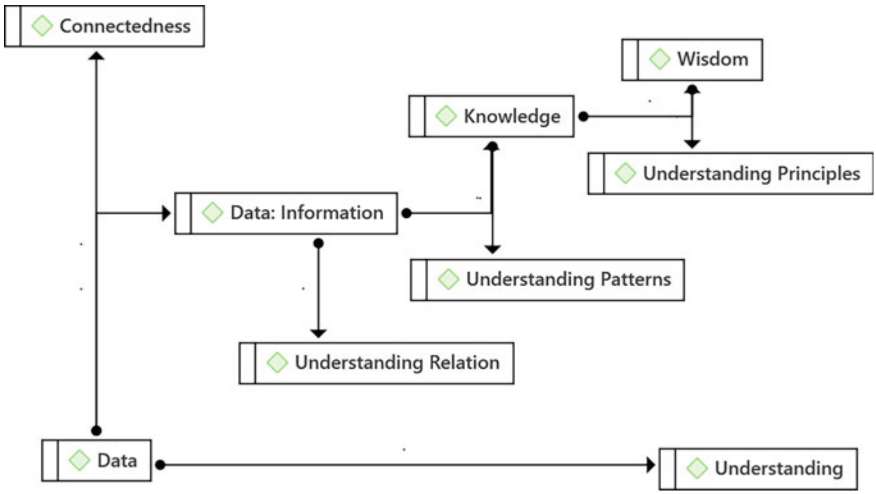


**Fig. 3** Data, information, knowledge, and wisdom

and analyzed from raw data. According to Basar [8], big data analytics produce valuable information and knowledge, which can help humans make better decisions. According to Pan et al. [71], businesses can transform the outcome of processing data into actionable information, knowledge, and ultimately wisdom when they use particular and automated procedures. Raw data can take the form of a numerical formula or simple facts, as illustrated in Fig. 3. Information may be gleaned through the systematic analysis of this unstructured material. On the other hand, knowledge is produced via the justification of information.

In order to make intelligent judgements that are grounded in reality, one must have information that is accurate and up to date. According to Alnuaimi et al. [5], an increasing number of businesses are moving away from an intuitive method of gathering strategic data in favour of a more comprehensive and systematic one. According to Cheng and Lok [16], digital facts-based systems make it possible to bring disparate and piecemeal services together under a single Big Data platform. In this environment, managers get integrated reports that include both an overview of the work that has been performed and the current state of the task. Because of this, they are better equipped to make judgements based on reasonable considerations [37]. In addition, Jansen et al. [34] assert that businesses' ability to make decisions more expediently may be an essential aspect of their ability to benefit from market competition. According to Mutale et al. [62], making decisions more quickly by delivering the appropriate data in the proper time and in the suitable format to the relevant decision-maker is possible.

### 3.8 Challenges in Quality of Information for Strategic Decision-Making

The infrastructure pipeline project is beset with data gaps, missing data, and inadequate information. The key information management problem for organizations is evaluating and enhancing data quality for strategic decision-making, and practitioners are very concerned about the quality of the data they deal with [73]. This study distinguishes between non-random systematic error (also known as bias) and random non-systematic error in scientific measures [35]. Random mistakes might result from unanticipated and uncontrollable occurrences, noise in the measurement or data-gathering environment, or other factors. Systematic errors, often known as bias, can result from persistent structural issues that tilt a measurement in a particular direction [93]. Every measurement has random mistakes, which may be rectified by repeatedly using the same measurement strategy. Systematic mistakes (also known as biases) cannot be rectified using repeated measurement procedures since they do not change between measurements but remain consistently skewed [29].

Given the unpredictable nature of random errors arising from operational constraints, shifting circumstances, technological glitches, and individual capabilities in data collection, it becomes essential to delineate between non-systematic and systematic errors (bias) to uphold the quality of information management [39]. Systematic bias can stem from underlying structural issues like historical, social, and political disparities or organizational and environmental [38, 95]. Biases have the potential to distort representations of social groupings, geographic regions, or concerns, impacting decision-making in both operational and strategic contexts within construction enterprises [73]. The interplay between systematic and non-systematic data inaccuracies across various organizational levels is illustrated in Fig. 4, indicating the profound impact on the system.

This study made a distinction between systematic and non-systematic data biases. Biases that cascade across the kind of data required to make decisions at various organizational levels can subtly influence how the data are understood throughout the system. This study addresses the need for a thorough knowledge of how information quality emerges in intricate strategic decision-making in construction organizations [95]. To the best of our knowledge, there hasn't been a thorough evaluation of data bias in strategic decision-making in construction organizations. In the past, researchers were primarily concerned with how much a model estimator deviated from the actual value of the estimated parameter in the real world when studying the quality of information [76]. The scientific discussion around information bias has grown dramatically with artificial intelligence and machine learning development.

In addition to computer science, sociology and the humanities are now studying the origins and effects of information bias more often due to deliberately skewed training data [43]. In this study, the term "quality of information bias" characterizes datasets that, whether intentionally or unintentionally, deviate from the actual real-world phenomena they intend to represent. Biased datasets exhibit a "divergence between

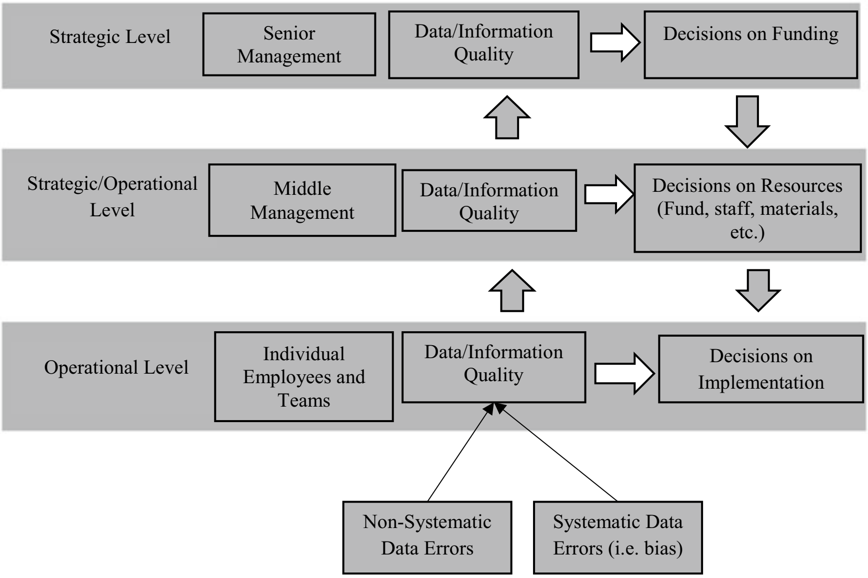


**Fig. 4** Information-decision-interdependences within the multi-actor system

the true distribution and digitized input space" [38]. While prior research has identified factors influencing information quality, it hasn't explicitly linked these factors to potential biases that consistently impact information quality. Previously documented issues include format incompatibility, data shortage/overload, low information priority, source identification challenges, storage media-activity misalignment, unreliability, and unwillingness [77, 97].

According to Bharosa et al. [11], organizations face difficulties sharing information since they are eager to gather knowledge but fail to share it with actors who need it. According to Schwendimann [82], access restrictions brought on by political and bureaucratic involvement, security and safety concerns, and capacity limitations impede data collecting. To address challenges related to information uncertainty, ambiguity, and time constraints, [94] delved into the concept of information delays and breakdowns, emphasizing the utility of fragmentation as a crisis-coordinating method. Comes et al. [22] underscored the fragmented nature of dynamic organizational networks, wherein data exchange occurs primarily among organizations within specific sub-networks, neglecting potential benefits from sharing information with entities outside these networks.

## 4 Discussion

The study highlighted the indispensable role of infrastructure pipeline information in shaping strategic decision-making within the construction industry, particularly within the unique context of New Zealand's economy. New Zealand's construction industry stands as a linchpin in propelling the nation's economic engine. It yields a substantial contribution to the country's GDP and offers a plethora of employment opportunities. These endeavours align harmoniously with the government's overarching objectives, which encompass the promotion of secure, affordable, sustainable, and healthful housing and infrastructure for its citizens. Evidencing its unwavering commitment, the New Zealand government prioritizes the construction sector, granting it a distinctive and priority status. This strategic focus aims to bolster the industry's capacity and facilitate infrastructural progress, consequently fostering lucrative investment prospects and driving robust economic growth. Nevertheless, amidst its significant stature, the construction sector grapples with inherent instability, primarily attributed to uncertainties surrounding infrastructure pipeline information and the intricacies of strategic decision-making. Within the realm of construction, decision-makers are confronted with a multitude of intricate choices, and the calibre of information they access undeniably wields substantial sway over the outcomes of these pivotal determinations. At the heart of this intricate dynamic lies infrastructure pipeline data, a veritable compass that provides a forward-looking perspective on projects. This indispensable resource acts as a guiding light for stakeholders across the construction spectrum, including government bodies and dedicated contractors. This data is the key to unravelling critical inquiries pertaining to project timing, location, budgetary considerations, and the scope of investments within New Zealand's diverse landscape.

Strategic decision-making within this industry emerges as a multifaceted and intricate process. It fuses rational and contextual elements, with the rational facet entailing meticulous scrutiny of circumstances, alternatives, and their repercussions. Concurrently, the contextual dimension considers top management's insights, decision-specific intricacies, environmental determinants, and the quirks of organizational characteristics. The quality of information serves as the lynchpin of sagacious strategic decision-making. Infrastructure pipeline data is a trove of insights into market trends, consumer behaviour, and operational efficiencies within this construct. Such data empowers decision-makers to embark on well-informed journeys, even when pursuing absolute accuracy remains a formidable challenge in today's rapidly evolving digital landscape. The construction sector employs a triad of strategic tiers encompassing corporate, business, and functional strategies. Corporate strategies delineate the overarching mission and objectives of the organization, while business strategies are tailored to secure competitive supremacy within specific markets. Concurrently, functional strategies are oriented towards steering short-term decisions across diverse functional domains, encompassing marketing, operations, and finance. These strategic choices pivot on the bedrock of competencies, capabilities, and the available resource arsenal within the organization. These integral components collectively shape the trajectory of strategic vision within the construction industry.

In today's digital epoch, data-driven decision-making ascends in prominence as a transformative imperative. Construction enterprises must harness data to illuminate their decision-making path, even amidst the inherent complexities that accompany the pursuit of absolute precision. Data access unveils invaluable patterns and empirical insights that propel project development and overall performance. Regrettably, infrastructure pipeline projects grapple with data voids, absent information, and lacunae within their datasets. Distinguishing between systematic and non-systematic errors (commonly termed bias) within these datasets emerges as a pivotal facet of information management. Systematic biases, rooted in structural and contextual anomalies, exert profound and far-reaching ramifications on decision-making, thereby necessitating vigilant redress. The pivotal role of information quality reverberates across the organizational echelons, governing decisions ranging from everyday operational choices to the formulation of overarching strategic blueprints. Acknowledging and rectifying data biases emerges as a non-negotiable imperative, ensuring that decisions are grounded in wisdom and accord with the hallowed goals of the organization. Therefore, infrastructure pipeline information stands as the bedrock upon which strategic decision-making in the construction industry is anchored. The accessibility and quality of data wield profound influence, shaping the trajectory of the industry's growth and its resonating impact on New Zealand's robust economy. As we navigate this dynamic landscape, the profound recognition of the criticality of accurate, timely, and comprehensive information reverberates as the cornerstone of long-term success and sustainability in New Zealand's construction landscape.

## 5 Conclusion

In conclusion, infrastructure pipelines play a crucial role in the strategic decision-making process of construction firms. However, pipeline data's relevance in decision-making must be examined to ensure accuracy, completeness, and timeliness. This study has presented insights for improving infrastructure pipeline data and their significance in strategic decision-making, incorporating insights from a literature review, content analysis of articles, and interviews with construction firm executives in New Zealand. The construction industry in New Zealand is a significant contributor to the nation's economy, boosting GDP per person, generating jobs, and supporting company growth. It is essential to improve the capacity and capabilities of the construction sector to meet the government's goals for secure, affordable, healthy, and sustainable housing and infrastructure. The quality of information plays a vital role in strategic decision-making, and infrastructure pipelines provide valuable data that informs decision-makers about market trends, client behaviour, and operational efficiency. The research indicates that information from infrastructure pipelines can effectively support the decision-making process, but its function in decision-making requires more attention in management research. Companies often rely on the experience and intuition of their management for decision-making, but this approach may be insufficient, particularly when dealing with fragmented or underutilized data. Organizations must adopt strategies to systematically analyze their data and derive meaningful information to enhance their competitive advantage. The infrastructure pipeline project faces challenges such as data gaps, missing data, and inadequate information. Ensuring data quality for strategic decision-making is a critical concern, and practitioners are highly aware of the importance of data quality. It is necessary to differentiate between random and systematic errors (bias) in data measurement, as biases can influence decision-making and lead to misrepresenting social groupings, geographic regions, or concerns. Recognizing and rectifying biases in data is crucial to avoid operational and strategic issues in construction enterprises. Systematic and non-systematic data inaccuracies can impact the decision-making process and the organization's overall performance. Information plays a significant role in strategic decision-making, and infrastructure pipeline data can effectively convey relevant information to decision-makers. However, the position of information in the decision-making process requires further attention in management research. This study focuses on understanding the types of information construction executives require and how they utilize it to make strategic decisions for their organizations. By improving the quality of information, addressing data quality issues and biases, and leveraging infrastructure pipelines, construction firms can enhance their operational efficiency, reduce costs, and make more informed decisions about ongoing and future projects.

## 6 Institutional Review Board Statement

Not applicable.

**Author Contributions** Conceptualization: Taofeeq Durojaye Moshood and James Olabode Bamidele Rotimi; Writing—original draft preparation: Taofeeq Durojaye Moshood and James Olabode Bamidele Rotimi; Writing—review and editing: Wajiha Shahzad, James Olabode Bamidele Rotimi, and Wajiha Shahzad; Methodology: Taofeeq Durojaye Moshood and James Olabode Bamidele Rotimi. All the authors have read and agreed to the published version of the manuscript.

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## References

1. Adendorff C, Appels G, Botha B (2011) Strategic management: an Eastern Cape construction SME case study. Acta Structilia 18(2):40–63

2. Afrifa A, Ofori-Frimpong K, Acquaye S, Snoeck D, Abekoe MK (2009) Soil nutrient management strategy required for sustainable and competitive cocoa production in Ghana. In: 16th International Cocoa conference, Bali
3. Al Hijji KZ, AlHarrasi NH, Alissaee HS (2018) The role of information in strategic planning and decision-making: overview on economic organizations in Oman. J Econ, Bus, Accountancy Ventura 21(1):143–150
4. Al Shobaki MJ, Abu Amuna YM, Abu-Naser SS (2016) The impact of top management support for strategic planning on crisis management: case study on UNRWA-Gaza strip
5. Alnuaimi MA, Alzubi HM, Alzoubi AA, AL-Shinewi MW (2015) The impact of managers efficiency on quality of strategic decision-making under crisis management: an empirical study on private hospitals in Baghdad-Iraq. Eur J Bus Manag 7:156–165
6. Amirmehdi A (2019) Public-Private Partnership Pros & Cons Benefits and Disadvantages of PPP Contracts
7. Bakar AHA, Tufail MA, Tufail MNYMA, Virgiyanti W (2011) Implementation of strategic management practices in the Malaysian construction industry. Pak J Commer Soc Sci (PJCSS) 5(1):140–154
8. Basar P (2018) The analytic hierarchy process method to design strategic decision making for the effective assessment of supplier selection in construction industry. Res J Bus Manag 5(2):142–149
9. Belay S, Goedert J, Woldesenbet A, Rokooei S (2022) AHP based multi criteria decision analysis of success factors to enhance decision making in infrastructure construction projects. Cogent Eng 9(1):2043996
10. Belhadi A, Kamble S, Fosso Wamba S, Queiroz MM (2022) Building supply-chain resilience: an artificial intelligence-based technique and decision-making framework. Int J Prod Res 60(14):4487–4507
11. Bharosa N, Lee J, Janssen M (2010) Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: propositions from field exercises. Inf Syst Front 12:49–65
12. Blair P (2019) Updated pipeline a sign of progress for infrastructure commission
13. Booth AP, Papaioannou D, Sutton A (2012) Systematic approaches to successful literature review. Cornwall, SAGE Publications Inc.
14. Chan APC, Darko A, Ameyaw EE (2017) Strategies for promoting green building technologies adoption in the construction industry—an international study. Sustainability 9(6):969
15. Chassiakos AP, Sakellaropoulos SP (2008) A web-based system for managing construction information. Adv Eng Softw 39(11):865–876
16. Cheng VTP, Lok P (2015) Strategic decision-making criteria and process of top management on technology adoption in the travel agency industry. Inf Technol Tourism 15:189–208
17. Choo CW, Bontis N (2002) The strategic management of intellectual capital and organizational knowledge. Oxford University Press
18. Christopher R (2018) Forecasting cost to complete on major projects
19. Citroen CL (2011) The role of information in strategic decision-making. Int J Inf Manage 31(6):493–501
20. Citroen ChL, Hooghoff P (2003) Informatie in bedrijf: Externe informatie.[w:] M. van Eck Popp (red.). Informatie in Bedrijf: Werkboek Voor Succesvol Informatiebeheer, Otto, Amsterdam, 48–66
21. Coakes E, Amar AD, Granados ML (2010) Knowledge management, strategy, and technology: a global snapshot. J Enterp Inf Manag 23(3):282–304
22. Comes T, Van de Walle B, Van Wassenhove L (2020) The coordination-information bubble in humanitarian response: theoretical foundations and empirical investigations. Prod Oper Manag 29(11):2484–2507
23. Coulter A, Parsons S, Askham J, Organization WH (2008) Where are the patients in decision-making about their own care?
24. Demirkesen S, Ozorhon B (2017) Measuring project management performance: case of construction industry. Eng Manag J 29(4):258–277

25. Dobrovič J, Urbański M, Gallo P, Benková E, Čabinová V (2018) Balanced scorecard concept as a tool of strategic management and its usage in the construction industry. Polish J Manag Stud 18(2):59–72
26. Du L, Feng Y, Lu W, Kong L, Yang Z (2020) Evolutionary game analysis of stakeholders' decision-making behaviours in construction and demolition waste management. Environ Impact Assess Rev 84:106408
27. Ehlers T, Lazenby K (2004) Strategic management: Southern African concepts and cases. van Schaik publishers
28. Elbanna S, Thanos IC, Jansen RJG (2020) A literature review of the strategic decision-making context: a synthesis of previous mixed findings and an agenda for the way forward. M@n@gement 23(2):42–60
29. Eweje J, Turner R, Müller R (2012) Maximizing strategic value from megaprojects: the influence of information-feed on decision-making by the project manager. Int J Project Manage 30(6):639–651
30. Fang Z, Lu Q, Chen L, Meng J, Ye Z, Pitt M (2023) Creating an open data city for healthcare: a critical review of data management strategy and development in China. J Manag Eng 39(2):3122004
31. Galliers R, Leidner DE (2014) Strategic information management: challenges and strategies in managing information systems. Routledge
32. Granwal L (2021) Construction industry in New Zealand—statistics & facts. R. https://www.statista.com/topics/5725/construction-industry-in-new-zealand/#dossierKeyfigures
33. Hax AC (2010) The delta model: reinventing your business strategy. Springer
34. Jansen RJG, Curşeu PL, Vermeulen PAM, Geurts JLA, Gibcus P (2013) Information processing and strategic decision-making in small and medium-sized enterprises: the role of human and social capital in attaining decision effectiveness. Int Small Bus J 31(2):192–216
35. Jato-Espino D, Castillo-Lopez E, Rodriguez-Hernandez J, Canteras-Jordana JC (2014) A review of application of multi-criteria decision making methods in construction. Autom Constr 45:151–162
36. Jesson J, Matheson L, Lacey FM (2011) Doing your literature review: traditional and systematic techniques
37. Jing G, Jin C (2009) The innovative university library: strategic choice, construction practices and development ideas. Libr Manag 30(4/5):295–308
38. Jo ES, Gebru T (2020) Lessons from archives: strategies for collecting sociocultural data in machine learning. In: Proceedings of the 2020 conference on fairness, accountability, and transparency, 306–316
39. Kavale S (2012) The role of data in strategic decision-making process. Int J Curr Res 4(04):1–7
40. Kliuchnikova OV, Pobegaylov OA (2016) Rationalization of strategic management principles as a tool to improve a construction company services. Procedia Eng 150:2168–2172
41. Larsen JK, Lindhard SM, Brunoe TD, Jensen KN (2018) The relation between pre-planning, commissioning and enhanced project performance. Constr Econ Build 18(2):1–14
42. Larsen JK, Ussing LF, Brunø TD (2013) Construction projects focus on evaluation and its benefits by pre-planning. In: Proceedings of 11th international! Postgraduate! Research! Conference (IPGRC13), 1
43. Lee S (2017) Applying system dynamics to strategic decision making in construction. Front Eng Manag 4(1):35–40
44. Leon H, Osman H, Georgy M, Elsaid M (2018) System dynamics approach for forecasting performance of construction projects. J Manag Eng 34(1):4017049
45. Li S, Fang Y, Wu X (2020) A systematic review of lean construction in Mainland China. J Clean Prod 257:120581
46. Li L, Lin J, Ouyang Y, Luo XR (2022) Evaluating the impact of big data analytics usage on the decision-making quality of organizations. Technol Forecast Soc Chang 175:121355
47. Liu G, Ye K, Tan Y, Huang Z, Li X (2022) Factors influencing homeowners' housing renovation decision-making: towards a holistic understanding. Energy Build 254:111568

48. Lorkowski J, Kreinovich V (2018) Bounded rationality in decision making under uncertainty: towards optimal granularity, vol 99. Springer
49. Lorkowski J, Kreinovich V, Lorkowski J, Kreinovich V (2018a) Decision making under uncertainty and restrictions on computation resources: from heuristic to optimal techniques. In: Bounded rationality in decision making under uncertainty: towards optimal granularity, 89–134
50. Lorkowski J, Kreinovich V, Lorkowski J, Kreinovich V (2018b) Towards explaining other aspects of human decision making. In: Bounded rationality in decision making under uncertainty: towards optimal granularity, 25–67
51. Lu H, Jiang S, Song W, Ming X (2018) A rough multi-criteria decision-making approach for sustainable supplier selection under vague environment. Sustainability 10(8):2622
52. Luo O, Shahzad W (2020) Prefabrication and waste minimisation in construction projects: perspectives from New Zealand. In: The 10th international conference on engineering, project, and production management (pp 55–67). Springer Singapore
53. MBIE (2021) Building and construction sector trends: annual report 2021. Ministry of Business, Innovation and Employment, Wellington, New Zealand. Retrieved from. https://www.mbie.govt.nz/dmsdocument/16973-building-and-construction-sector-trends-annual-report-2021-pdf
54. Mahesworo B, Perbangsa AS, Hendarti H (2019) User interface evaluation on government knowledge management portal using Webqual 4.0. In: 2019 International conference on information management and technology (ICIMTech), vol 1, pp 244–249
55. Marwala T (2014) Artificial intelligence techniques for rational decision making. Springer
56. Mintzberg H, Rose J (2003) Strategic management upside down: tracking strategies at McGill University from 1829 to 1980. Can J Adm Sci/Revue Canadienne Des Sciences de l'Administration 20(4):270–290
57. Moher D, Liberati A, Tetzlaff J, Altman DG, Group* P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med 151(4):264–269
58. Moshood TD, Nawanir G, Mahmud F (2021) Sustainability of biodegradable plastics: a review on social, economic, and environmental factors. Crit Rev Biotechnol, 1–21
59. Moshood TD, Rotimi FE, Rotimi JOB (2022a) An integrated paradigm for managing efficient knowledge transfer: towards a more comprehensive philosophy of transferring knowledge in the construction industry. Constr Econ Build 22(3):65–98
60. Moshood TD, Rotimi FE, Rotimi JOB (2022b) Knowledge transfer and management in the construction industry: trends and future challenges. Int J Constr Supply Chain Manag 12(1)
61. Murphy R, Seriki O (2021) The impact of environmental turbulence on the strategic decision-making process in Irish quantity surveying (QS) professional service firms (PSFs). Constr Manag Econ 39(9):739–758
62. Mutale W, Chintu N, Amoroso C, Awoonor-Williams K, Phillips J, Baynes C, Michel C, Taylor A, Sherr K (2013) Improving health information systems for decision making across five sub-Saharan African countries: implementation strategies from the African Health Initiative. BMC Health Serv Res 13(2):1–12
63. NZIC (2021) About the pipeline
64. National Construction Pipeline Report (2022) National construction pipeline report 2022. https://www.mbie.govt.nz/dmsdocument/23241-national-construction-pipeline-report-2022
65. Ng'andu E (2022) An assessment of strategic management practices and performance of selected small and medium scale enterprises in the construction sector in Lusaka district. The University of Zambia
66. Nisar QA, Nasir N, Jamshed S, Naz S, Ali M, Ali S (2021) Big data management and environmental performance: role of big data decision-making capabilities and decision-making quality. J Enterp Inf Manag 34(4):1061–1096
67. Noktehdan M, Shahbazpour M, Wilkinson S (2015) Driving innovative thinking in the New Zealand construction industry. Buildings 5(2):297–309
68. Nyariki BN (2016) Influence of strategy evaluation approaches on performance at KCB bank. University of Nairobi

69. Pacifiecon (2021) Accurate and detailed information on planned construction projects
70. Pamulu MS (2010) Strategic management practices in the construction industry: a study of Indonesian enterprises. Queensland University of Technology
71. Pan W, Dainty ARJ, Gibb AGF (2012) Establishing and weighting decision criteria for building system selection in housing construction. J Constr Eng Manag 138(11):1239–1250
72. Parsamehr M, Perera US, Dodanwala TC, Perera P, Ruparathna R (2023) A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management. Asian J Civ Eng 24(1):353–389
73. Paulus D, de Vries G, Janssen M, Van de Walle B (2023) Reinforcing data bias in crisis information management: The case of the Yemen humanitarian response. Int J Inf Manage 72:102663
74. Payne A, Frow P (2016) Customer relationship management: strategy and implementation. In: The marketing book. Routledge, pp 461–488
75. Peters E, Kliestik T, Musa H, Durana P (2020) Product decision-making information systems, real-time big data analytics, and deep learning-enabled smart process planning in sustainable industry 4.0. J Self-Governance Manag Econ 8(3):16–22
76. Price ADF, Ganiev BV, Newson E (2003) Changing strategic management practice within the UK construction industry. Strateg Chang 12(7):347–366
77. Pushpamali NNC, Agdas D, Rose TM (2020) Strategic decision making in construction supply chains: a comparison of reverse logistics strategies. Front Built Environ 6:593372
78. Robert Baum J, Wally S (2003) Strategic decision speed and firm performance. Strateg Manag J 24(11):1107–1129
79. Safa M, Hill L (2019) Necessity of big data analysis in construction management. Strateg Dir 35(1):3–5
80. Saieg P, Sotelino ED, Nascimento D, Caiado RGG (2018) Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: a systematic review. J Clean Prod 174:788–806
81. Salesa J, Reidy P (2019) Construction sector accord. Retrieved from 12 May 2022
82. Schwendimann BA (2011) Mapping biological ideas: concept maps as knowledge integration tools for evolution education. University of California, Berkeley
83. Scott W (2021) Types of construction projects & why they matter
84. Shamim S, Zeng J, Shariq SM, Khan Z (2019) Role of big data management in enhancing big data decision-making capability and quality among Chinese firms: a dynamic capabilities view. Inf Manag 56(6):103135
85. Silverio-Fernández MA, Renukappa S, Suresh S (2021) Strategic framework for implementing smart devices in the construction industry. Constr Innov 21(2):218–243
86. Simon HA (1991) Bounded rationality and organizational learning. Organ Sci 2(1):125–134
87. Souza MLH, da Costa CA, de Oliveira Ramos G, da Rosa Righi R (2020) A survey on decision-making based on system reliability in the context of Industry 4.0. J Manuf Syst 56:133–156
88. TEC (2021) Construction investment brief for 2022 funding. Retrieved from 13 April 2022
89. Tabish SZS, Jha KN (2011) Identification and evaluation of success factors for public construction projects. Constr Manag Econ 29(8):809–823
90. Tan T, Mills G, Papadonikolaki E, Liu Z (2021) Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): a review. Autom Constr 121:103451
91. Tan Y, Shen L, Langston C (2012) Competition environment, strategy, and performance in the Hong Kong construction industry. J Constr Eng Manag 138(3):352–360
92. The Treasure (2019) New Zealand Infrastructure Commission—Te Waihanga
93. Vicente R, Ferreira TM, Da Silva JARM (2015) Supporting urban regeneration and building refurbishment. Strategies for building appraisal and inspection of old building stock in city centres. J Cult Heritage 16(1):1–14
94. Wolbers J, Boersma K, Groenewegen P (2018) Introducing a fragmentation perspective on coordination in crisis management. Organ Stud 39(11):1521–1546

95. Wollmann D, Steiner MTA (2017) The strategic decision-making as a complex adaptive system: a conceptual scientific model. Complexity, 2017
96. Xia D, Yu Q, Gao Q, Cheng G (2017) Sustainable technology selection decision-making model for enterprise in supply chain: based on a modified strategic balanced scorecard. J Clean Prod 141:1337–1348
97. Yang RJ, Wang Y, Jin X-H (2014) Stakeholders' attributes, behaviors, and decision-making strategies in construction projects: importance and correlations in practice. Proj Manag J 45(3):74–90
98. Yin X, Liu H, Chen Y, Al-Hussein M (2019) Building information modelling for off-site construction: review and future directions. Autom Constr 101:72–91
99. Yu Y, Yazan DM, Junjan V, Iacob M-E (2022) Circular economy in the construction industry: a review of decision support tools based on information & communication technologies. J Clean Prod 131335

# New Zealand Construction Nga Roopu and Preferred Nga Tangata: Towards More Purpose-Fit Selection

**Andries van Heerden, Mikael Boulic, Barry William McDonald, and Gregory Chawynski**

## 1 Introduction

### *1.1 Teams (Nga Roopu) Within the Construction Industry*

Most organisations, especially larger ones, execute their projects through teamwork [11, 16]. This ability to organise employees with different skill sets into teams proved to increase productivity within manufacturing and service sectors [14, 29].

In the construction industry, a significant part of employees' undertakings occurs in teams [4, 32]. Various teams from different organisations are put together as the 'construction project team'. The misaligned fit between individual team members and multiple teams within the overall construction project team can harm productivity and product quality [1]. Teams typically have a few members who share leadership roles, perform interdependent jobs, and accept individual and group accountability and rewards [25]. McShane and Von Glinow [18] state, 'all teams are groups, because they consist of people in a unifying relationship, but not all groups are teams'. In

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construction, the nature of the project will typically determine the size of the teams. Therefore, it will not always be small [13].

Large construction organisations also use virtual groups to ensure international competitiveness and increase the ability to access much-needed skills and resources [16]. The challenge with these virtual project teams (VPTs) is creating early and sustained trust between members throughout the project [22]. According to Jelodar et al. [15], trust is a long-term goal and requires effort and time. According to the 'conflict as an antecedent of relationship quality model' proposed by Jelodar et al. [15], attributes such as teamwork, aligned commitment, performance satisfaction, and trust all influence the relationship quality within teams. As collaboration improves, the level of trust between team members increases [3]. Other research findings reported that the characteristics of team members were the most significant contributing factor to building trust in VPTs [19, 22]. Communication will deteriorate without trust and accountability within these teams [16]. Therefore, effective teams should be able to achieve project goals that would not simply be accomplished individually. According to Steyn [26], an effective team can be defined as 'one that achieves both high levels of task accomplishment and good human resource maintenance or relationships'. That is, they maintain a positive working relationship with one another.

Synergy between teams and their members is required for organisations to be competitive and achieve long-term high performance in the construction industry [13]. From the above it is clear that the construction industry needs high-performance teams to cope with the industry's demands [16].

## *1.2 Personalities (Nga Tangata)*

Construction professionals that previously completed projects will know the significant impact that effective teams can have on the success of a project [6]. It is also pivotal that the right person is added to such a team to reduce the unnecessary disruption of the project and current team members [23]. In the past, researchers such as Guion and Gottier [12] reported that personality instruments should not be used when selecting employees. Barrick and Mount [2] contested this notion much later, who presented that personality measures can be used within a work-related context. Other researchers supported this concept and reported that criterion-related validity increases in a work-related context, improving the value of personality constructs from an organisational perspective [20].

A meta-study that extended over 100 years determined that different methods and combinations have diverse validities for predicting future job performance [24]. For example, a structured interview and a general mental ability (GMA) test increased their prediction. However, their research also concluded that methods such as personal-organisation fit, personal-job fit, and amount of education have insignificant validity. Techniques such as graphology have fundamentally no validity. Their research underlined the importance of using at least two kinds of predictors in recruiting processes. Another meta-study by van Aarde et al. [27] concluded that personality has a certain predictive validity. For example, in South Africa, conscientiousness was the best predictor for task performance. Predictors, such as extraversion, emotional stability, and openness were the best predictors for overall performance.

In a previous study by van Heerden et al. [13], construction managers in South Africa were recruited to participate in an online SAPI personality test. Their results indicated that under the SAPI sub-dimensions, the variables (1) achievement orientation, (2) broad-mindedness, and (3) intellect proved to be the most preferred in the construction industry. Achievement orientation forms part of the SAPI's main dimension, 'conscientiousness'. SAPI defines achievement orientation as 'being motivated, perseverant, ambitious and hard-working towards achieving things in life'. Broad-mindedness and intellect were grouped under the SAPI main dimension 'openness'. Broad-mindedness is defined as 'being imaginative and seeking new experiences and ideas', and intellect as 'being knowledgeable, a quick learner, adaptable, articulate, innovative and perceptive'. Based on the results of these studies, there is a strong indication that the construction industry requires personality traits that present high-task performance individuals (conscientiousness), overall solid performers (extraversion, emotional stability, and openness), and individuals that can positively manage relations with others (positive social-relational disposition).

Within the South African multi-cultural context, the SAPI instrument was developed considering both culturally specific (emic) and universalistic (ethic) approaches [27]. A previous study with a sample size of 654 Victoria University students, including 226 Māori students, was conducted using SAPI. Their results confirmed that the SAPI model is not confined to South African cultures and could be used more extensively. Their study concluded that the indigenous SAPI model could be used across cultures for a more inclusive understanding of personality roles [9].

For New Zealand construction organisations to be competitive, they must select the right person to fit in well with the current high-performance team [32]. During the selection of new employees and promotion within the organisation, psychometric tests can effectively be used [7, 20, 27]. According to van der Merwe [28], screening interviews are four times less effective than psychometric tests. Personality could be defined as '(a) the sum total of all the physical, mental, emotional and social characteristics of an individual; and (b) the organised pattern of behavioural characteristics of the individual' [7].

Psychological tests can be used efficiently during recruitment selection, placement, and even counselling. These tests typically outperform all other kinds of predictors, especially personality in the workplace. Even when test-validity coefficients are not always notably high, it would be irrational to refuse them completely [8, 21, 30].

In light of the above, it is evident that high-performance teams and aligned team members required personalities that could positively contribute to the success of projects within the New Zealand construction industry [17]. This exploratory study compared various NZ construction professions with different selected SAPI personality sub-descriptors to establish which is beneficial or disruptive for team members. The study further aims to determine which professions are task or relationship-orientated.

## 2 Method

This research forms part of a broader research project where data was collected from Site Safe members and their industry partners. Before the industry-wide questionnaire was distributed, various discussions and feedback were received from the Site Safe research team and their vertical industry leaders (VIL). Minor changes were incorporated, after which the Site Safe Marketing and Communication team distributed the questionnaire through various platforms such as social media, newsletters, etc. This cross-sectional study collected data from 30 June to 31 July 2020. The data collection tool was a five-point Likert scale-type questionnaire, and we used the South African Inventory Personality (SAPI) sub-descriptions (variables) for exploratory purposes [10, 13]. According to Bowling [5], Likert scales are appropriate techniques to rate people's attitudes, perceptions, or opinions. A total of 430 questionnaires were received, and for this study, only 300 completed questionnaires were used to explore personalities versus three different professions in the New Zealand construction industry. The professions were divided into (1) Blue-collar, (2) White-collar, and (3) Owner/Director/Manager. How we divided these professions are further explained in Sect. 3.3. Principal Component Analysis (PCA) was used to look for highly correlated variables that seem to cluster around a particular construct [31]. PCA is a standard mathematical technique to construct the minimum number of uncorrelated variables (principal components) that will summarise a large proportion of the variation in the data, in this case the variation in Likert scale responses to the SAPI personality variables. The data analysis was undertaken using Minitab 19 (©2022 Minitab LLC.).

## 3 Results and Discussion

### *3.1 Demographic Information*

From the data received, 78.6% were male and 21.1% female. The males (87%) had completed more than ten projects, compared with the females (71%). The respondents (88%) reported their highest level of qualification between Level 4 (Certificate of Achievement)–Level 7 (bachelor's degree). Our data further showed that our respondents were mostly involved in one sector—residential (9.6%), commercial/ retail (9.3%), infrastructure (7.1%), industrial (4.4%), office (2.8%), and defence (0.31%). When we contemplated more than one sector involvement, 45.5% of the respondents were involved in two to three sectors, 18.6% in four to five sectors, and 2.2% in six to seven sectors.

### *3.2 Exploring the South African Personality Inventory (SAPI) Items*

We used Principal Component Analysis for these selected SAPI personality variables. The Eigen analysis was completed, and the Eigenvalues were used to indicate the importance and the Eigenvectors (represented the direction) as presented in Table 1.

PC1 represents the most variation in the data and PC2 the second most, and PC3 the third most. The first PC had variance equivalent to 4.1 variables, which means there is a relatively large difference in personality between those at the positive and negative ends of the scale (PC). The highlighted personality variables are all positively correlated with PC1, which could be described as various aspects of emotional intelligence. Interestingly the data do not bear out the stereotype that those who are high in 'Intellect' and 'Achievement oriented' are emotionally cold: people with these traits tend to score high in this emotional intelligence PC as well. The second PC had variance equivalent to 2.3 personality variables. This PC is most highly related

**Table 1** Eigenvectors of the correlation matrix bases on the manual selected SAPI personality variables

| SAPI Sub-descriptions (variables) | PC1 | PC2 | PC3 |
|---|---|---|---|
| 1. Broad-mindedness | *0.215* | – 0.059 | 0.170 |
| 2. Investigative | *0.245* | – 0.027 | *0.405* |
| 3. Intellect | *0.206* | 0.055 | *0.266* |
| 4. Achievement-orientated | *0.204* | – 0.032 | *0.531* |
| 5. Being organised & punctual | *0.244* | – 0.021 | *0.308* |
| 6. Respect culture | *0.274* | 0.052 | *– 0.244* |
| 7. Empathy | *0.330* | 0.002 | *– 0.403* |
| 8. Motivating others | *0.312* | – 0.081 | 0.060 |
| 9. Integrity | *0.271* | – 0.225 | – 0.037 |
| 10. Maintaining relationships | *0.295* | – 0.077 | – 0.046 |
| 11. Social intelligence | *0.331* | 0.041 | – 0.069 |
| 12. Warm-heartedness | *0.339* | 0.072 | *– 0.293* |
| 13. Deceitfulness | 0.022 | *0.502* | 0.020 |
| 14. Arrogance | – 0.029 | *0.523* | 0.091 |
| 15. Conflict seeking | – 0.015 | *0.511* | 0.097 |
| 16. Sociability | *0.257* | 0.189 | *– 0.134* |
| 17. Playfulness | 0.125 | *0.311* | – 0.070 |

to arrogance, and people who score high in this trait also tend to score highly in deceitfulness, conflict-seeking and to some extent in playfulness. By contrast they have a negative correlation with integrity. The third PC has variance only equivalent to 1.5 personality variables and so is a weaker effect. To interpret it, we could consider two people with the same overall level of emotional intelligence and suppose these individuals may be contrasted by one being somewhat more methodical and task-oriented (investigative, intellect, achievement-oriented, organised, and punctual) and the other individual being stronger in empathy, warm-heartedness, and social and cultural awareness. Further principal components were looked for but did not explain sufficient variation and did not have any obvious interpretation.

Figure 1 shows that most SAPI variables are positively correlated, but (13) deceitfulness, (14) arrogance, and (15) conflict-seeking are entirely different. Playfulness, which presented variable 17, was an outlier. Playfulness (variable 17) and sociability (variable 16) fall under the SAPI main dimension extraversion. Playfulness was defined as 'being lively, enjoying having fun and making others laugh and having the tendency to see the positive side of life'. Sociability was defined as 'being easy-going and talkative and enjoying having people around oneself'.

Figure 1 illustrates that playfulness mainly lies in the middle, and sociability leans more to the right. Variable 17 (playfulness) could have been put together with either group, but in the construction sector context, it was decided to group variable 17 with 13, 14, & 15. These four variables we labelled as the disruptive variables as these will typically cause tension in teams and hinder the achievement of high-performance

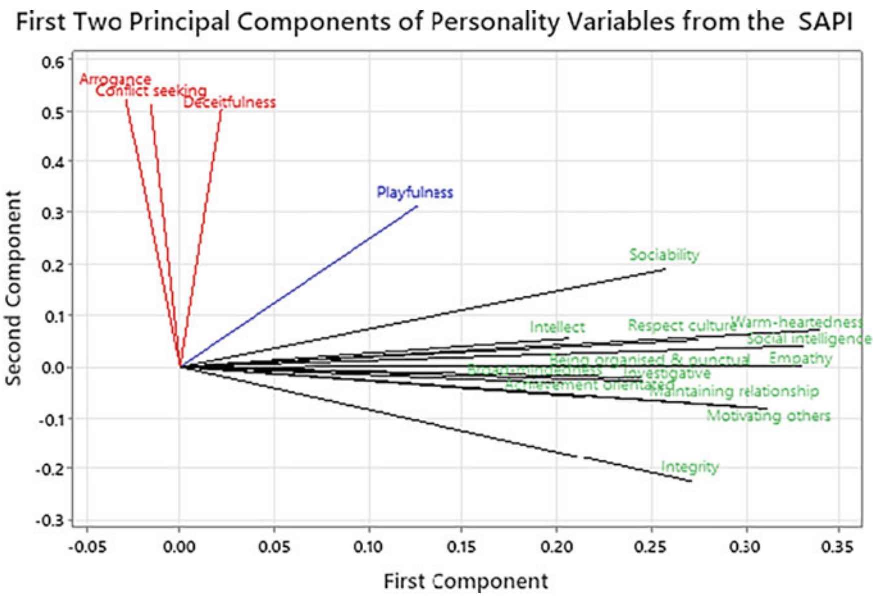


**Fig. 1** Principal components of the selected SAPI correlated variables

teams. SAPI variables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, & 16 were all grouped under the positive characteristics scale.

In Table 1, the PC3 data further illustrated high positive coefficients > 0.2 for SAPI variables 2, 3, 4, and 5. A high negative coefficient for SAPI variables 6, 7, and 12, and to a lesser extent, SAPI variable 16. Based on the perceived contrast scale, we could draw from this information that some respondents scored high in tasks and others high in relationships.

### 3.3 *Current Profession Grouping*

The list received from the respondents the researchers could categorise into three main groupings, i.e. (1) Blue-collar (BC), (2) White-collar (WC), and (3) Owner/Director/Manager (OM). The respondents who reported a specific trade (where they got their boots dirty) were considered blue-collar and represented 21.6% (N = 65). If they reported supervisory roles or managers of a specific task, they were placed into the white-collar group representing 61.6% (N = 185). Owners and directors in the third category, including managers without mentioning a specific task, represented 16.6% (N = 50). Table 2 presents the recorded current professions' means.

Figure 2 clearly illustrates that the white-collar (WC) group are strongly relationship-orientated. The owner/director/manager (OM) group was the opposite of the white-collar group, indicating high-task orientation. The blue-collar (BC) group were more in the middle, leaning more towards the task orientation group.

**Table 2** Current recorded profession means

| Profession | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| Blue-collar | 65 | 5.523 | 2.405 | (4.902, 6.144) |
| White-collar | 185 | 4.789 | 2.576 | (4.421, 5.157) |
| Owner/Director/Manager | 50 | 5.940 | 2.606 | (4.421, 5.157) |
| Pooled StDev = *2.54509* | | | | |

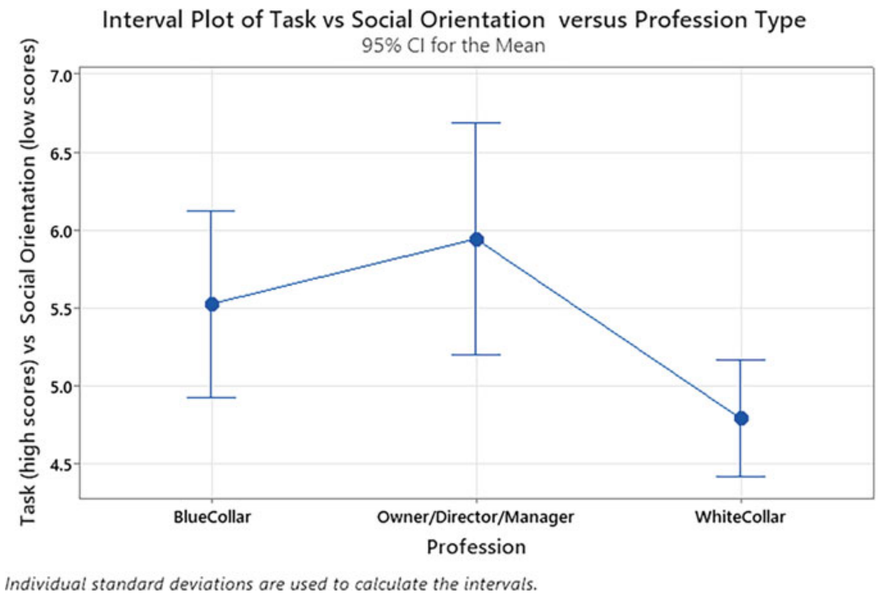


**Fig. 2** Task versus social orientation within the three professions

# 4 Conclusion

Our exploratory study investigated the importance of selecting the right member for project teams, especially high-performance ones. This exploratory study compared various NZ construction professions with different selected SAPI personality sub-descriptors to establish which are beneficial or disruptive for team members. The study further aimed to determine which professions were task or relationship-orientated. From the results we concluded that the NZ construction industry could benefit to do pre-screening psychological testing combined with other tools, such as general mental ability (GMA) tests, to improve the probability of selecting a more purpose-fit team member. This additional resource capability could reduce the possible impact of disruption to current team members, the project, and ultimately the organisation. The SAPI-selected manual variables showed that some characteristics are more desirable in a construction industry context than others. We proposed two main groups to be considered when thinking of best-fit team dynamics, viz. positive and disruptive personality scales.

As part of our conclusion, we also noted that different professions have different orientations, which can further cause conflict in teams. White-collar workers were found to be much more concerned with relationships, whereas blue-collar and owner/director/manager groups focused more on tasks. Practically, the NZ construction industry needs to understand the value it will add to project teams, organisations, and the industry by employing the right candidate for their career, not just a job.

Organisations should also be reluctant to employ team members just to fill a position. The research confirmed that selecting the right individual for a team should be carefully considered, focusing on a positive long-term relationship that could build adaptable capacity for future construction projects. Strategies to promote teamwork among collaborators in a project could include mandatory courses for construction professionals on team communication, leadership attributes, or teamwork.

Future research might focus on conducting the online SAPI personality test within the three identified professions and concentrate on how personalities impact on task and relationship orientation.

## 5 Ethics Statement

This exploratory study forms part of a broader research project and was approved by the Massey University Human Ethics Committee: Human Ethics Northern Committee Ethics Notification—NOR 19/47.

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**Author Contributions** Hennie van Heerden contributes to conceptualisation, methodology, investigation, data collection, draft preparation, manuscript editing, visualisation, supervision, and project administration. Mikael Boulic contributes to conceptualisation, methodology, investigation, draft preparation, and visualisation. Barry McDonald contributes to conceptualisation, methodology, validation, analysis, and visualisation. Gregory Chawynski contributes to conceptualisation, investigation, data collection, and manuscript editing.

## References

1. Baiden BK, Price AD, Dainty AR (2006) The extent of team integration within construction projects. Int J Project Manage 24(1):13–23
2. Barrick MR, Mount MK (1991) The big five personality dimensions and job performance: a meta-analysis. Person Psychol 44:1–26
3. Bond-Barnard TJ, Fletcher L, Steyn H (2018) Linking trust and collaboration in project teams to project management success. Int J Manag Proj Bus 11(2):432–457. https://doi.org/10.1108/IJMPB-06-2017-0068
4. Boshoff D, Krugell C, van Heerden H (2017) Characteristics of the safety climate in teams with world-class safety performance on construction projects in South Africa. Acta Structilia 24(1):99–127. https://doi.org/10.18820/24150487/as24i1.5
5. Bowling A (1997) Research methods in health. Open University Press, Buckingham
6. Burma ZA (2014) Human-resource management and its importance for today's organisations. Int J Educ Soc Sci 1(2):85–94

7. Cilliers C, Meiring D (2014) Determining the best factorial fit for the South African personality inventory: comparison of block-and random-item formations (Master's thesis). Retrieved from http://hdl.handle.net/2263/45929. 30 June 2023
8. Fetvadjiev VH, Meiring D, Nel JA, van der Vijver FJR, Hill C (2015) The South African Personality Inventory (SAPI): a culture-informed instrument for the country's main Ethnocultural Groups. Am Psychol Assoc 27(3):827–837
9. Fetvadjiev V, Neha T, Van de Vijver F, Mcmanus M, Meiring D (2020) The cross-cultural relevance of indigenous measures: the South African personality Inventory (SAPI), family orientation, and well-being in New Zealand. J Cross Cult Psychol. https://doi.org/10.1177/0022022120969979
10. George T (2023) Exploratory research | definition, guide, & examples. Scribbr. Retrieved 12 April 2023, from https://www.scribbr.com/methodology/exploratory-research/
11. Georgiadis G (2015) Projects and team dynamics. Rev Econ Stud 82(1):187–218. https://doi.org/10.1093/restud/rdu031
12. Guion RM, Gottier RF (1965) Validity of personality measures in personnel selection. Pers Psychol 18:135–164
13. van Heerden AHG, Burger M, Zulch B (2018) The road to purpose-fit selection of the construction manager. University of Pretoria, Pretoria, South Africa
14. Ichniowski C, Shaw K (2003) Beyond incentive pay: insiders' estimates of the value of complementary human resource management practices. J Econ Perspect 17:155–180
15. Jelodar MB, van Heerden A, Chawynski G (2020) An interdisciplinary perspective of conflict and relationships in construction procurement and logistics. Int J Constr Supply Chain Manag 10(1):30–45. https://doi.org/10.14424/ijcscm100120-30-45
16. Kreitner R, Kinicki A (2001) Organisation behaviour, 5th edn. The McGraw-Hill Companies Inc., New York
17. Kwofie TE, Alhassan A, Botchway E, Afranie I (2015) Factors contributing towards the effectiveness of construction project teams. Int J Constr Manag 15(2):170–178. https://doi.org/10.1080/15623599.2015.1033818
18. McShane SL, Van Glinow MA (2008) Organizational behavior: emerging realities for the workplace revolution. (4th edn.). McGraw-Hill/Irwin
19. Meng X (2010) Assessment framework for construction supply chain relationships: development and evaluation. Int J Project Manage 28(7):695–707. https://doi.org/10.1016/j.ijproman.2009.12.006
20. Mouton S (2017) An investigation into the first- and second-order factor structure of the South African Personality Inventory (SAPI) on a relatively large South African sample. Master of Commerce (Industrial Psychology), Stellenbosch, University of Stellenbosch
21. Muchinsky PM, Kriek HJ, Schreuder AMG (1998) Personnel psychology. International Thomson Publishing Southern Africa (Pty) Ltd.
22. Sagar SK, Oladinrin OT, Arif M, Rana MQ (2023) Interpretive structural model of trust factors in construction virtual project teams. Constr Innov 23(1):248–264. https://doi.org/10.1108/CI-09-2021-0179
23. Sanders BA (2008) Using personality traits to predict police officer performance. Polic Int J 31(1):129–147. https://doi.org/10.1108/13639510810852611
24. Schmidt FL, Hunter JE (1998) The validity and utility of selection methods in personnel psychology: practical and theoretical implications of 85 years of research findings. Psychol Bull 124:262–274
25. Smit PJ, de Cronje GJ (2001) Management principles: a contemporary edition for Africa. 2nd ed. Cape Town. Juta & Co (Ltd.)
26. Steyn H (ed) (2012) Project management: a multi-disciplinary approach, 3rd, rev. FPM Publishing, Pretoria
27. van Aarde N, Meiring D, Wiernik BM (2017) The validity of the big five personality traits for job performance: meta-analysis of South African studies. Int J Select Assess 25(3):223–239. https://doi.org/10.1111/ijsa.12175

28. Van der Merwe RP (2002) Psychometric testing and human resource management. SA J Ind Psychol 28(2):77–86
29. van Heerden AHG (2018) Soft skills and the construction site manager: the Chameleon Professional. In: Goossens R (eds) Advances in social & occupational ergonomics. AHFE 2017. Advances in Intelligent Systems and Computing, 605. Springer, Cham. https://doi.org/10.1007/978-3-319-60828-0_21
30. van Heerden A, Burger M, Zulch B (2020) The construction manager's mask: a more purpose-fit selection for South Africa. In: Karwowski W, Ahram T, Nazir S (eds) Advances in human factors in training, education, and learning sciences. AHFE 2019. Advances in Intelligent Systems and Computing, 963. Springer, Cham. https://doi.org/10.1007/978-3-030-20135-7_23
31. van Heerden A, Jelodar MB, Chawynski G, Ellison S (2023) A study of the soft skills possessed and required in the construction sector. Buildings 13(2):522. MDPI AG. https://doi.org/10.3390/buildings13020522
32. Walker A (2011) Organizational behaviour in construction. Blackwell, London

# Quantity Surveyors' Perspective on Knowledge Areas for Sustainable Construction

**Vimlesh Prabhu Desai and Lysette D'souza**

## 1 Introduction

Construction industry is dynamic in nature. Some of the most recent developments in the industry include the increased use of automation as a result of labour shortage [14], Building Information Modelling (BIM) as a result of globalization [19], sustainable building practises [42], and the implementation of big data techniques [10]. Sustainability is an ideology that seeks to modify consumption and production patterns that are severely taxing the planet's ecological reserves at present [44]. The construction industry is without a doubt a significant contributor to climate change, as it accounts for nearly half of the world's greenhouse gas emissions and consumes forty percent of the materials entering the global economy [7]. The term 'sustainable construction' encompasses all phases of a building's life cycle, from initial conception to final dismantling, and includes not only the building itself but also its planning, design, construction, operation, maintenance, renovation and demolition. Tackling sustainability requires a holistic approach that addresses the three principles of sustainable development—social, environmental and economic. Sustainability as a concept is been widely discussed around the world as a viable alternative to the traditional 'purchase, consume and dispose' economic model and a potential answer to the problems of inefficient resource usage and pollution [4]. Sustainable design and construction attempt to minimize energy and material use while creating a comfortable, safe and productive built environment. Construction professionals are expected to take on multiple tasks in order to keep up with the ever-changing demands of the business brought on by technological progress, intense competition and the sector's inherent

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fluidity. Olanrewaju and Anahve [31] identified architects, structural engineers, civil engineers, service engineers and quantity surveyors as construction project leaders. Government of India plan to build 12 million affordable houses in urban areas by year 2024 [35]. To keep up with the demand and meet the target, sustainable construction has never been so important. To ensure sustainability in the built environment, experts from various disciplines and stakeholders in the construction sector, including QSs, must collaborate to develop holistic and informed strategies.

Quantity surveying is often thought of as a job that only deals with building costs, but it can actually help a project succeed in terms of time, money and quality as a whole. QSs are tasked with overseeing budgets and advising clients and architects on how to save costs without sacrificing quality throughout the whole building process. Asset financial management, feasibility studies, contract administration and cost planning are all areas in which quantity surveyors are involved. QSs are expected to be well-rounded professionals with a wide breadth of knowledge, skills and ability to use their expertise in a variety of settings. Quantity surveying's ability to satisfy the objectives of sustainable construction may be gauged by looking at how the industry has adapted in terms of services offered, level of employee involvement and approach to problem solving. According to Chamikara et al. [11], a Quantity Surveyor is a specialist who works in the building business to promote a more sustainable approach. In the new age of sustainable construction, the role of quantity surveyors is changing, this means new skills and abilities for the field need to be studied. The paradigm shift towards sustainability means that traditional quantity surveying practises will no longer be adequate for businesses to thrive [55]. This new trend gives QSs more opportunities to apply the latest innovations. According to Adekinle et al. [3], there is a discrepancy between construction professionals' understanding of sustainability and how their perceptions of it translate into practise, necessitating the identification of the competencies required of a quantity surveyor engaged in sustainable construction. Competencies are a set of intertwined knowledge, skills, abilities, values and qualities that a person possesses in order to perform efficiently and effectively in a certain role or environment [54]. Oke et al. [30] found that professional QSs are profoundly rooted in the core skills and competencies of their traditional roles, as opposed to the skills and competencies required for novel and emergent roles. The majority of graduating QSs in Sri Lanka lack the necessary skills, according to research by Yogeshwaran et al. [55]. In order for quantity surveyors to function effectively in the growing domain of sustainability, it is crucial that they comprehend the requirements of sustainable construction and identify the necessary skills. Given the complexities of the sector and growing demand for sustainability, the job of the QS is likely to evolve significantly in the near future, necessitating a wide range of new talents. It is thus important to evaluate the knowledge areas QSs should familiarize for advocating sustainable construction. The objective of this study is to investigate the pertinent knowledge domains that are of importance to QSs in order to augment their understanding and proficiency in the context of sustainable construction.

## 2 Literature Review

### 2.1 Sustainability

Construction and destruction are connected; due to the environmental effect of building waste and demolitions, [28] recommend that the construction sector optimize its resource use. Wasted building materials and components accelerate ecosystem damage, raise environmental costs and deplete resources. According to The Building Economist [47], the building industry's high energy use poses a serious threat to human survival. To combat the rising tide of greenhouse gas emission, diminishing freshwater systems and other natural resource depletion caused by human overexploitation, the concept of sustainability was developed [32]. Sustainability has the potential to improve user health and comfort, reduce energy consumption, maximize resource use and reduce environmental wastes and social disturbances [17]. Sustainability concepts are increasingly used to address the technical process that defines a building or construction project's performance. This new function creates significant challenges for construction or building projects throughout their lifespan [46]. Building sustainably calls for an expansive and long-term perspective [18]. The perceived high costs, especially in design and construction, have stymied recent advancements in sustainability. Green experts with sufficient knowledge of sustainable building may eliminate these misunderstandings once and for all. Rapid change has occurred in the construction sector, with the industry shifting from the conventional design and construction approach to new delivery systems more suited to environmentally responsible building. It's not sufficient to just care about the environment anymore, professionals must prioritize sustainable practises. Practitioners in the construction sector must be quick to respond to the shifting landscape. Because of the expanding sustainability industry, many specialists in related fields, such as architecture, engineering, surveying, planning and design, now have a chance to offer sustainability advisory services. Professional builders all around the world are now catching on to the sustainability movement and seeing the benefits of sustainable development. According to Abidin [1], all construction industry players, including quantity surveyors, contribute to sustainable building in Malaysia.

### 2.2 Quantity Surveyors' Role in Construction Industry

QSs combine construction, engineering and economics while to be competent they use their knowledge, skills and talents to complete a task effectively and efficiently. A quantity surveyor is brought in at the beginning of a building project to create a schedule of all the items that will be utilised. According to Shafiei and Said [41], Quantity Surveyor's primary areas of expertise are construction cost estimation, quantification, contract writing (including tendering papers and cost planning documents), contract management and the creation of final accounts. In addition to their standard responsibilities, quantity surveyors are frequently called upon to serve as cost experts for building projects. QSs who understand technology and innovation, are vital advisors throughout a project's lifecycle [5, 11]. QSs assist customers to get the most from their money spent in the building business by balancing the roles of economist and cost accountant. Their involvement across pre and post construction stages of projects add value in the financial and contractual management of projects.

To keep up with the ever-changing demands of the modern construction business, experts in the field are expected to take on a variety of jobs. QSs role has seen a sea change since it first emerged as a profession in 1800s [52]. QSs initially provided only financial management services for construction projects and cost consultancy services to clients, but as technology and environmental concerns developed in the construction industry, their role changed. QSs' work has expanded beyond costing alternative design solutions to pro-actively advising on how to bring value to the building sector. Stakeholder needs affected by sustainable designs and construction will greatly affect a project's ultimate cost due to their complexity. Thus, the quantity surveyor is the most crucial construction expert who must perform such difficult tasks to optimize a project's cost. A quantity surveyor is a crucial member of any company's team, and as such, he or she must constantly adapt to new challenges and new ways of doing business. According to Reed and Wilkinson [37] and Ashworth et al. [6], QSs play an important role in reducing greenhouse gases and making buildings energy efficient. Similarly to achieve sustainability, QSs can rely on BIM, as the best decisions for environmentally friendly layouts can be made during the planning and design phases with the use of BIM [8]. QSs may expand their responsibilities and learn new skills to meet the industry's evolving needs thanks to this development. QSs, if they want to keep their jobs in the future, will have to adapt by incorporating sustainability ideas into their work. It has been acknowledged by Mishiyi et al. [25] that professional QSs' use of antiquated company structures and operational methods will not meet the complex demands of today's customers.

## *2.3 Changing Demand on Quantity Surveying Profession*

Technology advancement, environmental concerns, social awareness, sustainability adaptation and strict legislative requirements have revolutionized quantity surveying by opening up new job paths for QSs. As a result of the construction industry's fast transformation, QSs are now expected to perform a far wider range of duties than in the past. Risk management, quality management and project management are just a few examples of how QSs' responsibilities have expanded into the realm of management; cost management is another important facet of the profession, and it encompasses value management, life cycle cost analysis, cost–benefit analysis, investment appraisal, cost engineering services, feasibilities studies and cost modelling [13]. Several writers have pointed out that in today's rapidly evolving global environment, QSs are involved in a wide range of fields, including business administration, economics, law, management, accountancy, sustainable construction management, supply chain management, quality assurance co-ordination, facilities management and technology (including BIM and CostX) [55]. The diversified expectation will require the QSs to possess several competencies. Due to the multifaceted nature of a QS's work and the breadth of their expertise, defining their specific set of competencies is challenging [41]. Professional bodies such as Royal Institution of Chartered Surveyors (RICS), Australian Institute of QSs (AIQS), Pacific Association of QSs (PAQS) and Indian Institute of Quantity Surveyors (IIQS) have defined guidelines and requirements to ensure quantity surveyors remain competent and practise highest standards of professionalism in the profession of quantity surveying. Despite being listed by the professional bodies, the level of competencies to be achieved by QSs has thus far not been defined [55]. QSs play a crucial role in promoting sustainable practices by minimizing waste, planning with as little waste as possible, using pre-assembly whenever possible, minimizing over-specification, using the natural environment, preserving biodiversity and reducing energy use during building, especially by avoiding energy-intensive materials like cement and aluminium [26]. In order to improve the construction industry's approach to sustainability, it is necessary to define knowledge areas that are pivotal.

## 3 Research Design

A mixed research approach, qualitative and quantitative, was adopted for this study. A triangulated research methodology consisting of literature review, pilot study and questionnaire survey was used to gather the data. IBM SPPS software was used to analyse the data.

The first objective of the study was to identify the knowledge areas for sustainable construction. A systematic literature review followed by semi-structured interviews was used to fulfil this objective. Published literature such as research papers, news/trade magazine articles, and dissertation reports, published documents of professional bodies, such as RICS, AIQS, PAQS and IIQS provided an initial list of knowledge areas. The review also helped to gain an understanding of sustainable construction and changing role of QSs. Semi-structured interviews with nine QSs, identified through purposive sampling, having more than 25 years' experience were then conducted to refine the list; any new items not covered by secondary data got included in the list at this stage. The experts were asked open ended questions as 'What knowledge areas pertinent to sustainable construction practices are applicable to quantity surveying profession?' and 'Are the following knowledge areas applicable to QSs in terms of sustainable construction?' Thereafter a draft questionnaire consisting of these knowledge areas was pilot tested for refinement, and congeniality of collecting responses for the questions asked. The result of literature review, semi-structured interviews and pilot study was used to prepare a final questionnaire for subsequent questionnaire survey. Table 1 shows a list of knowledge areas pertaining to sustainable construction.

The second objective was to evaluate the knowledge areas and find which are perceived more important and which are perceived less important. For this, the

**Table 1** Knowledge areas pertaining to sustainable construction

| Code | Knowledge areas |
|---|---|
| KA01 | Environmental science and climate change |
| KA02 | Systems thinking |
| KA03 | Computer literacy on latest s/w packages such as BIM, CostX |
| KA04 | Sustainability analysis |
| KA05 | Green costing |
| KA06 | Cost management |
| KA07 | Sustainable construction technology |
| KA08 | Value engineering |
| KA09 | Stakeholder engagement |
| KA10 | Change management |
| KA11 | Energy modelling and analysis |
| KA12 | Environmental legislations and regulations |
| KA13 | Problem solving |
| KA14 | Forward thinking |
| KA15 | Leadership and strategic management |
| KA16 | Life cycle cost analysis |
| KA17 | Carbon credit calculation |
| KA18 | Estimation & financial control |
| KA19 | Communication & negotiation |
| KA20 | Innovation and critical thinking |
| KA21 | Green certification |
| KA22 | Contract administration |
| KA23 | Waste management |
| KA24 | Measurement/quantification |
| KA25 | Lean construction management |
| KA26 | Risk management |
| KA27 | Procurement and tendering |

data was collected through a questionnaire survey administered among QSs having minimum five years' experience. The respondents were asked to rate the knowledge areas in purview of sustainable construction on a five point Likert scale. 5–very important, 4–important, 3–average, 2–less important, 1–not important.

# 4 Data Analysis

A total of 268 questionnaires were floated among quantity surveying professionals with more than 5 years total experience. Among the 103 filled responses received, 96 were found to be valid for analysis. The response rate was 35.82%. The details of the respondents is shown in Table 2.

## *4.1 Reliability Test*

To determine internal consistency of the factors used in the questionnaire, the data was subjected to reliability analysis test. The widely used reliability test is Cronbach's Alpha. If the test delivers a Cronbach's Alpha coefficient of above 0.7, the data is considered to be reliable [16]. For the present study Cronbach's alpha coefficient was 0.896.

## *4.2 Relative Importance Index (RII)*

RII was used to convert the numerical scores of individual knowledge areas into relative ranking. According to [22] and [12] when evaluating the ranks of each

**Table 2** Details of the respondents

| Respondents information | Groups | Number | Percent (%) |
|---|---|---|---|
| Gender | Male | 74 | 77.08 |
| | Female | 22 | 22.92 |
| Highest level of education | Graduate | 44 | 45.83 |
| | Post graduate | 48 | 50.00 |
| | Doctorate (Ph.D.) | 4 | 4.17 |
| Total industry experience (years) | > 20 | 15 | 15.63 |
| | > 15 & ≤ 20 | 25 | 26.04 |
| | > 10 & ≤ 15 | 33 | 34.37 |
| | > 5 & ≤ 10 | 23 | 23.96 |
| Experience in sustainable construction projects (nos.) | > 10 | 38 | 39.58 |
| | > 7 & ≤ 10 | 25 | 26.04 |
| | > 4 & ≤ 7 | 16 | 16.67 |
| | > 1 & ≤ 4 | 11 | 11.46 |
| | 1 | 6 | 6.25 |

factor, mean and standard deviations are insufficient since they fail to account for the relationships among different factors.

RII has been widely used to determine relative significance; [11] used RII to rank competencies of QSs in Sri Lanka. Equation 1 was used to calculate RII,

$$\text{RII}(\text{RelativeImportanceIndex}) = \frac{\Sigma W}{(N \text{x} A)} \tag{1}$$

$W$—Ratings given by respondents to each knowledge areas on a scale of '1 to 5'. $A$—The highest rank on the scale which in this case is '5', and $N$—number of total respondents.

Table 3 gives the relative importance of knowledge areas.

## 5 Discussion

The knowledge areas identified from literature review, validated by semi-structured interviews and evaluated by questionnaire survey were ranked using RII method. The top fifteen knowledge areas are discussed below.

'Environmental science and Climate change' with an RII of 0.877 was judged as the top knowledge area QSs must familiarize within the context of sustainable construction. The UN Intergovernmental Panel on Climate Change warned in its most recent special report that we have just few years to prevent a climate change disaster by keeping global warming below 1.5 °C [20]. Sustainable construction is important because it helps combat climate change and has a favourable correlation with energy efficiency [36]. To meet the sustainability issues and develop new paradigms that can bring about global sustainability, individuals, consumers, professions, communities and society at large need to develop new competencies [48].

'Systems thinking' featured as second most important knowledge area. Sustainability challenges are immensely complex and complicated; it requires systems thinking to understand the conditions that generate and propagate these challenges. Businesses benefit greatly from the use of system thinking in navigating the complexities of sustainability challenges [27]. Systems thinking is a process for understanding the interrelationships among the key components of a system. Sustainable development as a system in intertwined among social, economic, environmental and political factors. Taking a systems approach to addressing the sustainability challenges has been gaining traction with academics and industry alike [51].

'Computer literacy on latest s/w packages such as BIM, CostX' ranked third. The RICS Assessment of Professional Competence (APC) Guide (2017, August) lists Building Information Modelling (BIM) as a required technical competency [38]. By adopting BIM, crucial decisions concerning environmentally friendly layouts can be made early on during the planning and design phases [8]. BIM adoption in the construction industry has increased but is still hindered by poor awareness, high implementation costs, inadequate technical know-how, low technology adoption,

**Table 3** Relative importance ranking of the knowledge areas pertinent to QSs in terms of sustainable construction

| Code | RII | Rank |
|---|---|---|
| KA01 | 0.877 | 1 |
| KA02 | 0.865 | 2 |
| KA03 | 0.863 | 3 |
| KA04 | 0.842 | 4 |
| KA05 | 0.838 | 5 |
| KA06 | 0.829 | 6 |
| KA07 | 0.817 | 7 |
| KA08 | 0.815 | 8 |
| KA09 | 0.806 | 9 |
| KA10 | 0.779 | 10 |
| KA11 | 0.777 | 11 |
| KA12 | 0.775 | 12 |
| KA13 | 0.773 | 13 |
| KA14 | 0.767 | 14 |
| KA15 | 0.767 | 14 |
| KA16 | 0.756 | 15 |
| KA17 | 0.754 | 16 |
| KA18 | 0.748 | 17 |
| KA19 | 0.713 | 18 |
| KA20 | 0.713 | 18 |
| KA21 | 0.710 | 19 |
| KA22 | 0.710 | 19 |
| KA23 | 0.700 | 20 |
| KA24 | 0.696 | 21 |
| KA25 | 0.677 | 22 |
| KA26 | 0.665 | 23 |
| KA27 | 0.623 | 24 |

legal disputes and uncertainties in policies, and data confidentiality concerns [23, 39]. Using CostX or any BIM-based cost estimating tool can automate, streamline and refine the cost estimation process.

'Sustainability analysis' plays a key role in industry; firms realize that what is good for society and environment can also be good for business. Energy, efficiency, environment and society are four pillars of sustainability analysis [21]. QSs need to gain knowledge, skills and aptitude in these areas to develop competency in sustainability analysis.

'Green costing' pertains to the extra cost incurred by the client for green building. Since green building ratings are becoming increasingly common, it is important for the Quantity Surveyor to be up-to-date on the latest technologies and innovations in sustainable construction [33]. Quantity surveyors' expertise will lie in adjusting high-level cost models at the feasibility stage to match the budget while still informing the design consultants on the parameters of efficiency, design factors, concepts and controlled quantity factors and rates [40].

'Cost management' is an important knowledge area for QSs, whereby they utilize cost-effective means to make construction projects more feasible while increasing the value of the end product [11]. Cost management highly impacts reduction of construction waste and materials thereby contributing to sustainability. Stakeholder needs shaped by sustainable design and construction will greatly affect a project's cost. Thus, the quantity surveyor is the construction industry's most important specialist who must perform the difficult task of optimizing a project's cost [53].

'Sustainable construction technology' deals with construction processes, building materials, design principles, drawings and specifications and designing and installing services [13]. Low running expenses, cheaper utility prices, improved productivity due to cleaner air and quality of life aspects, and higher social standing are only some of the advantages of green construction technologies [26]. Using renewable and recyclable resources and materials is the cornerstone of sustainable construction. Sustainable construction technology places a premium on reducing waste and other negative impacts on the environment, keeping energy and material usage at a minimum, and maximizing the project's safety and efficiency throughout the life cycle.

'Value Engineering (VE)' is a powerful tool for cost saving and quality improvement. In addition to minimizing time, enhancing quality, reliability, maintainability and performance, the primary objective of value engineering (VE) is to increase value. VE can be applied during any stage of construction project. VE uses multi-disciplinary teams to analyse project design and construction approach. VE aids to identify critical parameters that play a substantial role in cost of the project [43].

'Stakeholder engagement' is the ability to identify and proactively interact with relevant stakeholders. Being rooted in your local community and familiar with your stakeholders is important, as is connecting with others in social networks and fostering relationships in the real world [50]. Start locally and work upwards. As stakeholder engagement increases, so does the complexity of social interaction patterns between actors, necessitating mutual trust as a governance mechanism [49]. Any stakeholder engagement strategy that aims to accomplish sustainability-related goals should emphasize the need of identifying and understanding the various sustainability agendas of stakeholders and monitoring their success using key performance indicators [9].

'Change Management' needs to be a part of organizational culture to get the most from sustainability. Change management is the extent to which a company's mindset supports its ability to allocate resources to handle strategic change in a business environment that is always changing. Firms' economic, political, social and cultural ecosystems have a significant impact on the complexity of change management in sustainable construction [2]. The behaviours of business actors, managers and employees shape QSs capacity to allocate resources to manage change in a dynamic business environment [34].

'Energy modelling and analysis' refers to the process of analysing a building's energy consumption and energy-generating systems using computer simulation software. In order to achieve the goal of a green construction revolution, building codes for both homes and businesses have become increasingly stringent in terms of energy efficiency requirements. Energy optimization in buildings is a highly sought-after expertise; experts may find ways to reduce energy use and foster a green revolution.

'Environmental legislations and regulations' are pushing construction professionals to prepare for sustainable practices. Effective enforcement of environmental laws will undoubtedly encourage the practise of sustainable construction [29]. Government laws and legislations are one of the most important drivers of sustainable construction [24], but lack of knowledge about applicable rules and policies is one of the greatest obstacles or challenges to attaining absolute sustainability in the construction industry.

'Problem solving' demands the use of meta-cognitive skills such as planning, monitoring and evaluating [15]. In a world where sustainability is becoming increasingly crucial, those professionals who are able to find answers and offer creative solutions to new and complicated issues will be in high demand. Companies often fail to make the transition to sustainable practises because they fail to think outside the box and lack the courage to attempt something new. Firm's having a culture that encourages employees to speak their minds are able to make strides towards sustainability.

'Forward thinking' professionals anticipate shifts in the market and seize chances for sustained growth. Having a firm grasp of sustainability's best practises is important, but so is keeping an eye on the horizon in case any unexpected developments happen. It takes foresight and planning to create a business strategy that includes your commitment to sustainability. Organizations can develop the flexibility to adapt to changing environmental and construction industry conditions.

'Leadership and strategic management' entails ability to transfer responsibility, encourage others to step up, effectively communicate organizational change, and keep one's team grounded in reality. Dealing with rapid, complex and often discontinuous change requires effective leadership. In sustainable construction development, a leader's leadership style and the manner in which he or she manages the project, as well as the subordinates, can convert the project towards sustainability and improve productivity [45].

## 6 Conclusion

The aim of this study was to examine the impact of sustainable construction on the knowledge domains relevant to quantity surveying professionals. The study began with a literature review, semi-structured interviews and pilot study which helped define the knowledge areas pertinent to QSs in the area of sustainability. Thereafter a questionnaire survey was employed to gather inputs from the industry on the importance of these areas. Analysis of the data acquired allowed the study to reach its intended conclusion.

Among the findings advanced by this study, 'Environmental science and Climate change', 'Systems thinking', 'Computer literacy on latest s/w packages such as BIM, CostX', 'Sustainability analysis', 'Green Costing', 'Cost Management', 'Sustainable construction technology', 'Value Engineering', 'Stakeholder engagement', 'Change management', 'Energy modelling and analysis', 'Environmental legislations and regulations', 'Problem solving', 'Forward thinking' and 'Leadership and strategic management' appear to be top fifteen knowledge areas relevant to QSs in the evolving business environment of sustainable construction. In the light of recent developments in the construction sector, this research contributes theoretically by expanding the knowledge areas in which competencies of QSs need to be given consideration.

Organizations will benefit from a better understanding of sustainability competencies as they work to create new recruiting strategies, selection procedures and training programmes. It can help HR professionals reevaluate their methods and make adjustments as necessary. Associations of quantity surveying professionals can provide training programmes, improve certification systems, and facilitate member-to-member sharing of information and expertise in these areas. Furthermore, the research will help academic institutions enhance their quantity surveying courses. The QSs profession is evolving, and with it comes a greater need for QSs to acquire and hone a wider range of skills and competences. It secures QSs' continued existence and opportunities for career advancement in the face of intense competition.

The scope of this research has its limits. To begin, all of the participants in this study are from quantity surveying profession. Secondly, adopting additional methods such as case study approach, Delphi technique can enrich the findings. Although this study has certain flaws, the results are more trustworthy than those from a library search alone since they were gathered using a fieldwork technique that had respondents share their actual experiences. Further research could study other professionals in different sectors in the purview of sustainability. A valid comparison between the two results will throw additional light in the knowledge area.

## 7 Ethics Statement

Not applicable.

**Author Contributions** Vimlesh contributed to conceptualization, methodology, validation, draft preparation, manuscript editing, visualization, supervision and project administration. Lysette contributed to conceptualization, methodology, data collection, manuscript editing and visualization. The authors have read and agreed with the manuscript before its submission and publication.

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## References


1. Abidin NZ (2010) Investigating the awareness and application of sustainable construction concept by Malaysian developers. Habitat Int 34(4):421–426. https://doi.org/10.1016/j.habitatint.2009.11.011
2. Acs ZJ, Stam E, Audretsch DB, O'Connor A (2017) The lineages of the entrepreneurial ecosystem approach. Small Bus Econ 49:1–10
3. Adekunle SA, John I, Aigbavboa C (2019) Quantity surveying education for sustainable development: industry perception. In: Proceedings of West Africa Built Environment Research (WABER) conference. Accra, Ghana: Ghana Academy of Arts and Sciences, pp 864–875
4. Adi WTJ, Wibowo P (2020) Application of circular economy in the Indonesia construction industry. Proc IOP Conf Ser: Mater Sci Eng 849(1):1–8
5. Ahmed AM, Sayed W, Asran A, Nosier I (2023) Identifying barriers to the implementation and development of sustainable construction. Int J Constr Manag 23(8):1277–1288. https://doi.org/10.1080/15623599.2021.1967577
6. Ashworth A, Hogg K, Higgs C (2013) Willis's practice and procedure for the quantity surveyor. John Wiley & Sons
7. Asif M, Muneer T, Kelley R (2007) Life cycle assessment: a case study of a dwelling home in Scotland. Build Environ 42(3):1391–1394. https://doi.org/10.1016/j.buildenv.2005.11.023
8. Azhar S, Brown J (2009) BIM for sustainability analyses. Int J Constr Educ Res 5(4):276–292. https://doi.org/10.1080/15578770903355657
9. Bal M, Bryde D, Fearon D, Ochieng E (2013) Stakeholder engagement: achieving sustainability in the construction sector. Sustainability 5(2):695–710. https://doi.org/10.3390/su5020695
10. Bilal M, Oyedele LO, Qadir J, Munir K, Ajayi SO, Akinade OO, Owolabi HA, Alaka HA, Pasha M (2016) Big Data in the construction industry: a review of present status, opportunities, and future trends. Adv Eng Inform 30(3):500–521. https://doi.org/10.1016/j.aei.2016.07.001
11. Chamikara PBS, Perera BS, Rodrigo MN (2020) Competencies of the quantity surveyor in performing for sustainable construction. Int J Constr Manag 20(3):237–251. https://doi.org/10.1080/15623599.2018.1484848
12. Chan DW, Kumaraswamy MM (1997) A comparative study of causes of time overruns in Hong Kong construction projects. Int J Project Manage 15(1):55–63. https://doi.org/10.1016/S0263-7863(96)00039-7
13. Chandramohan A, Perera BAKS, Dewagoda KG (2022) Diversification of professional quantity surveyors' roles in the construction industry: the skills and competencies required. Int J Constr Manag 22(7):1374–1381. https://doi.org/10.1080/15623599.2020.1720058
14. Chen Q, de Soto BG, Adey BT (2018) Construction automation: research areas, industry concerns and suggestions for advancement. Autom Constr 94:22–38. https://doi.org/10.1016/j.autcon.2018.05.028
15. Cho KL, Kim SY (2006) The Effects of cognitive styles and metacognition on illstructured problem solving and argumentation in an individual problem solving situation. J Educ Inf Media 12(3):5–32
16. Cronbach LJ (1951) Coefficient alpha and the internal structure of tests. Psychometrika 16:297–334
17. Darko A, Chan AP (2016) Critical analysis of green building research trend in construction journals. Habitat Int 57:53–63. https://doi.org/10.1016/j.habitatint.2016.07.001
18. Dobson DW, Sourani A, Sertyesilisik B, Tunstall A (2013) Sustainable construction: analysis of its costs and benefits. Am J Civ Eng Archit 1(2):32–38. https://doi.org/10.12691/ajcea-1-2-2
19. Doumbouya L, Gao G, Guan C (2016) Adoption of the Building Information Modeling (BIM) for construction project effectiveness: the review of BIM benefits. Am J Civ Eng Archit 4(3):74–79. https://doi.org/10.12691/ajcea-4-3-1
20. IPCC (2018) Global warming of 1.5 °C. In: An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,

sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland
21. Jiang Y, Bhattacharyya D (2016) Sustainable engineering economic and profitability analysis. In: Sustainability in the design, synthesis and analysis of chemical engineering processes. Butterworth-Heinemann, pp 141–167. https://doi.org/10.1016/B978-0-12-802032-6.00006-2
22. Kometa ST, Olomolaiye PO, Harris FC (1994) Attributes of UK construction clients influencing project consultants' performance. Constr Manag Econ 12(5):433–443. https://doi.org/10.1080/01446199400000053
23. Li P, Zheng S, Si H, Xu K (2019) Critical challenges for BIM adoption in small and medium-sized enterprises: evidence from China. Adv Civ Eng 2019:1–14. https://doi.org/10.1155/2019/9482350
24. Maqbool R, Amaechi IE (2022) A systematic managerial perspective on the environmentally sustainable construction practices of UK. Environ Sci Pollut Res 29(42):64132–64149
25. Mishiyi H, Cumberlege R, Buys F (2019) Challenges facing newly established quantity surveying firms to secure tenders in South Africa. Acta Structilia 26(1):42–60. https://doi.org/10.18820/24150487/as26i1.2
26. Muthoga M, Githaiga J (2022) Quantity Surveyors' readiness in implementation of sustainable building construction in Kenya: a case study of Nairobi City County. Int J Sci Res 11(9):580–585
27. Negru M (2021) System Thinking for sustainability from a business perspective. 2030 Builders. Retrieved from https://2030.builders/system-thinking/. 23 June 2023
28. Nuñez-Cacho P, Górecki J, Molina-Moreno V, Corpas-Iglesias FA (2018) What gets measured, gets done: development of a circular economy measurement scale for building industry. Sustainability 10(7):2340. https://doi.org/10.3390/su10072340
29. Nwokoro I, Onukwube H (2011) Sustainable or green construction in Lagos, Nigeria: principles, attributes and framework. In: Proceedings of the West Africa Built Environment Research (WABER) conference, pp 883–895
30. Oke AE, Ogunsemi DR, Adeyelu M (2019) Quadrant and gap analysis of required and exhibited quantity surveyors' competencies. J Eng, Des Technol 17(6):1161–1173. https://doi.org/10.1108/JEDT-01-2019-0029
31. Olanrewaju A, Anahve PJ (2015) Duties and responsibilities of quantity surveyors in the procurement of building services engineering. Procedia Eng 123:352–360. https://doi.org/10.1016/j.proeng.2015.10.046
32. Olubunmi OA, Xia PB, Skitmore M (2016) Green building incentives: a review. Renew Sustain Energy Rev 59:1611–1621. https://doi.org/10.1016/j.rser.2016.01.028
33. Omotayo T, Tan SW, Ekundayo D (2022) Sustainable construction and the versatility of the quantity surveying profession in Singapore. Smart Sustain Built Environ (ahead-of-print). https://doi.org/10.1108/SASBE-07-2021-0125
34. Peter MK, Kraft C, Lindeque J (2020) Strategic action fields of digital transformation: an exploration of the strategic action fields of Swiss SMEs and large enterprises. J Strateg Manag 13(1):160–180. https://doi.org/10.1108/JSMA-05-2019-0070
35. Press Information Bureau [PIB] (2023) Year round review 2022: Ministry of Housing and Urban Affairs. Press Information Bureau, Delhi. Retrieved from https://www.pib.gov.in/PressReleasePage.aspx?PRID=1889773. 1 July 2023
36. Ramesh T, Prakash R, Shukla KK (2010) Life cycle energy analysis of buildings: An overview. Energy and Buildings 42(10):1592–1600. https://doi.org/10.1016/j.enbuild.2010.05.007
37. Reed RG, Wilkinson SJ (2005) The increasing importance of sustainability for building ownership. J Corp Real Estate 7(4):339–350. https://doi.org/10.1108/14630010510700831
38. Royal Institution of Charted Surveyors [RICS] (2017) Assessment of professional competence. Royal Institute of Chartered Surveyors, London. Retrieved from http://www.rics.org/lk/search-results/?sq¼AssessmentþofþProfessionalþCompetence&so¼Relevance-Aug-2017-WEB.pdf. 1 July 2023
39. Saka AB, Chan DW, Siu FM (2020) Drivers of sustainable adoption of building information modelling (BIM) in the Nigerian construction small and medium-sized enterprises (SMEs). Sustainability 12(9):3710. https://doi.org/10.3390/su12093710

40. Seah E (2009) Sustainable construction and the impact on the Quantity surveyor. In: 13th Pacific Association of quantity surveyors congress, pp 36–48
41. Shafiei MM, Said I (2008) The competency requirements for quantity surveyors: enhancing continuous professional development. Sri Lankan J Hum Resour Manag 1(2)
42. Sharma M (2018) Development of a 'green building sustainability model' for green buildings in India. J Clean Prod 190:538–551. https://doi.org/10.1016/j.jclepro.2018.04.154
43. Shelote K, Agrawal R, Gupta S, Ralegaonkar R (2018) Application of value engineering for sustainable construction: a study. In: Proceedings of the international conference on urban sustainability: emerging trends, themes, concepts & practices (ICUS)
44. Spreafico C, Landi D (2022) Using product design strategies to implement circular economy: differences between students and professional designers. Sustainability 14(3):1122. https://doi.org/10.3390/su14031122
45. Tabassi AA, Roufechaei KM, Ramli M, Bakar AHA, Ismail R, Pakir AHK (2016) Leadership competences of sustainable construction project managers. J Clean Prod 124:339–349. https://doi.org/10.1016/j.jclepro.2016.02.076
46. Tan A, Udeaja C, Babatunde SO, Ekundayo D (2017) Sustainable development in a construction related curriculum–quantity surveying students' perspective. Int J Strateg Prop Manag 21(1):101–113. https://doi.org/10.3846/1648715X.2016.1246387
47. The Building Economist (2014) The quest for sustainable energy: when will it happen? The Building Economist (The pink issue), 12–17. Retreived from http://issuu.com/aiqs_be/docs/aiqs_buildingeconomist_june2014. 20 June 2023
48. United Nations Educational, Scientific and Cultural Organization [UNESCO] (2014) Roadmap for implementing the global action programme on education for sustainable development, UNESCO
49. Venn R, Berg N (2014) The gatekeeping function of trust in cross-sector social partnerships. Bus Soc Rev 119(3):385–416. https://doi.org/10.1111/basr.12038
50. Venn R, Perez P, Vandenbussche V (2022) Competencies of sustainability professionals: an empirical study on key competencies for sustainability. Sustainability 14(9):4916. https://doi.org/10.3390/su14094916
51. Voulvoulis N, Giakoumis T, Hunt C, Kioupi V, Petrou N, Souliotis I, Vaghela CJGEC (2022) Systems thinking as a paradigm shift for sustainability transformation. Glob Environ Chang 75:102544. https://doi.org/10.1016/j.gloenvcha.2022.102544
52. Wao JO (2015) Predicting the future of quantity surveying profession in the construction industry. J Constr Proj Manag Innov 5(2):1211–1223. https://hdl.handle.net/10520/EJC183324
53. Wao JO, Flood I (2016) The role of quantity surveyors in the international construction arena. Int J Constr Manag 16(2):126–137. https://doi.org/10.1080/15623599.2016.1142251
54. Wesselink R, De Jong C, Biemans HJ (2010) Aspects of competence-based education as footholds to improve the connectivity between learning in school and in the workplace. Vocat Learn 3:19–38
55. Yogeshwaran G, Perera BAKS, Ariyachandra MMF (2018) Competencies expected of graduate quantity surveyors working in developing countries. J Financ Manag Prop Constr 23(2):202–220. https://doi.org/10.1108/JFMPC-06-2017-0019

# Scientometric Review of Research Trends on Construction Project Variations

**Muhammad Aliyu Yamusa, Yahaya Makarfi Ibrahim, Muhammad Abdullahi, Hassan Adaviriku Ahmadu, and Mu'awiya Abubakar**

## 1 Introduction

The constant variations problems that arise in construction projects have been the subject of numerous study efforts [5, 6, 23, 24, 30, 41]. These initiatives offer solutions that help with variation management from the design stage all the way through construction. These initiatives, however, merely lessen the effect of variations.

Since variations in construction projects are unavoidable, it is especially important to address them and keep them to the barest minimum [25]. These variations, if not properly managed, can lead to overruns in cost and time, reduced productivity, and even rework [11, 12, 16, 21, 22, 31] in addition to causing payment-related issues [38].

Despite the numerous research existing on variations in construction projects, attempts to compile large literature on the subject is in its preliminaries, which according to Zhang et al. [42] presents a major risk of overlooking or neglecting essential areas and questions. These include but are not limited to, the latest topics and trends, explored and unexplored areas, opportunities, and under-researched themes for research and practice improvement. Previous efforts (for example Mohammad and Hamzah [20] and Wan et al. [40]) are only addressing a fraction of variations

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management. This study, therefore, aims to conduct a holistic review of variations management research efforts.

## 2 Research Methodology

This study used a systematic approach to analyse the large body of construction variations studies. Similar methodology was used in the construction domain by Osei-Kyei et al. [27], Wuni et al. [34], and Song et al. [32]. The analysis includes investigations done between 1982 and 2023. The systematic review procedure is depicted in Fig. 1. The sections that follow cover the stages of the methodology.

### 2.1 Software Tools Selection

The right scientific software must be used in order to perform a proper scientometric analysis. With the help of various scientific software and recent technical advancements, a vast volume of literature can be mapped [39]. Several tools have been created, each with a distinct scope, advantages, and disadvantages. VOSviever, CitNetExplorer, BibExcel, VintagePoint, CiteSpace, and Gephi are a few of these tools. For this investigation, an open access piece of scientific software called the VOSviewer (version 1.6.9) was used. This tool was chosen because it can scientifically connect books and visualise bibliometric networks using a variety of criteria.

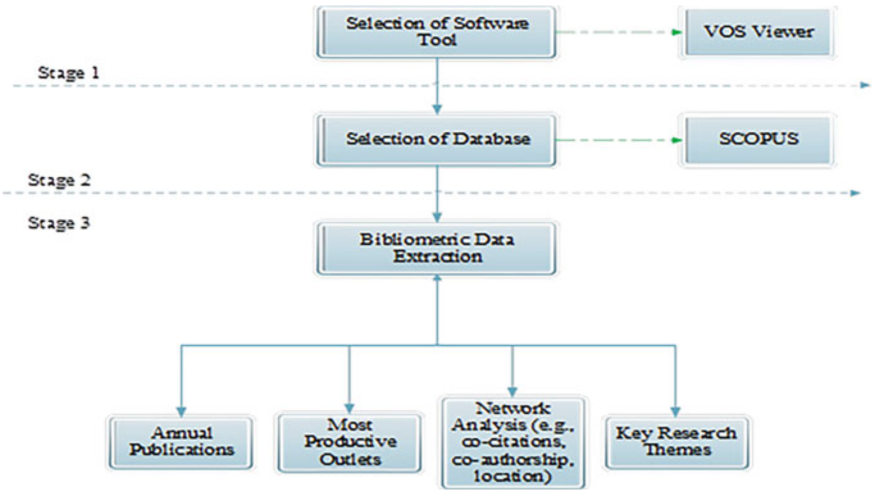


**Fig. 1** A flowchart of the research methodology. *Sources* Osei-Kyei et al. [27], Wuni et al. [34], Song et al. [32], Osei-Kyei and Chan [26]

The widespread use of VOSviewer in recent studies is a further argument in favour of adoption [27, 34].

## 2.2 Database Selection

When conducting a literature search, indexed databases are more trustworthy. Web of Science and Scopus are two of the most prominent ones [26]. This is due to the extensive coverage they give to conferences and scholarly journals. Due to its larger coverage and ability to include recent studies, Scopus was deemed a better choice for the study [26]. Additionally, VOSviewer (version 1.6.9) is more compatible with the Scopus file format, according to Wuni et al. [34].

## 2.3 Bibliometric Data Extraction and Journals Selection

The last step of the methodology is the database's bibliometric data extraction, followed by analysis. Keywords like causes, risk, uncertainty, model, and prediction were taken from Scopus and expanded to include variations management research.

The full code used for the literature search is:

*(TITLE-ABS-KEY ( ( variation OR "variation order" OR "change order" OR contingency ) ) AND TITLE-ABS-KEY ( ( factors OR management OR causes OR risks OR uncertainty OR types OR sources OR model OR prediction OR valuing ) ) AND TITLE-ABS-KEY ( ( construction OR "construction projects" OR building OR "construction industry" ) ) ) AND ( LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( LIMIT-TO ( SUBJAREA , "BUSI" ) )*

897 publications were listed in the variations management search results. The results of the search included articles from several prestigious journals, including Architectural Engineering and Design Management, Construction Management and Economics, Eastern-European Journal of Enterprise Technologies, Engineering, Construction and Architectural Management, and International Journal of Construction Management.

The bibliometric data was obtained as a "Comma-Separated Values (CSV)" file and entered into VOSviewer for the purpose of scientifically linking the corpus of literature on variations management. The analysis used mappings in the form of networks and tables to properly visualise and evaluate the most pertinent variations management research. Citations, authorship, country productivity, and outstanding themes in the variations management study were noted. The findings presentation and discussion are covered in the following parts.

## 3 Results and Discussion

### *3.1 Annual Publication Trends of Variations Management*

The publication trend of studies on variations management is from 1982 to 2023. It is clear that since the early 2000s, variations management research has grown significantly. This is due to the quick global adoption of variations management in the 2000s. This sparked the interest of numerous academic and professional researchers who wanted to explore and develop the idea. Nevertheless, the abundance of studies on variations management is a sign of future research that may be carried out in this area. This might be the result of increased awareness and efforts on the part of various nations, particularly developing nations that haven't fully adopted variations management. Researchers have therefore started to look into and analyse how variations management is being used in underdeveloped nations.

### *3.2 Prominent Research Outlets of Variations Management*

It is impossible to overstate the value of scholarly publications or other research outlets in communicating research findings. Academics all around the world are eager to have a significant impact on normative literature through the publication of their research findings in prestigious journals or research outlets [17, 18]. This illustrates the importance of rigorous investigation of variations management-related research published in reputable academic journals or high-ranking research outlets. This enlightens academics and researchers on the platforms the outlets they should take into account while publishing their findings related to the research's theme. Leading variations management studies journals and research outlets' scientific mapping was examined. The connection points and mappings between the well-known journals and outlets are shown in Fig. 2.

The detailed numerical statistics of the renowned research journals/outlets are shown in Table 1. An outlet is required to have at least five publications and at least 20 citations in order to be taken into account for mapping. 20 journals/outlets are the top sources of variations management research during the past 40 years, as indicated in Fig. 2 and Table 1. The most well-known sources of research findings in variations management are the outlets with large nodes. Additionally, as shown in Fig. 2, there are significant publications in the Journal of Construction Engineering and Management, Journal of Cleaner Production, Construction Management and Economics, Journal of Management in Engineering, and Journal of Operations Management. Citations show that there is a strong link.

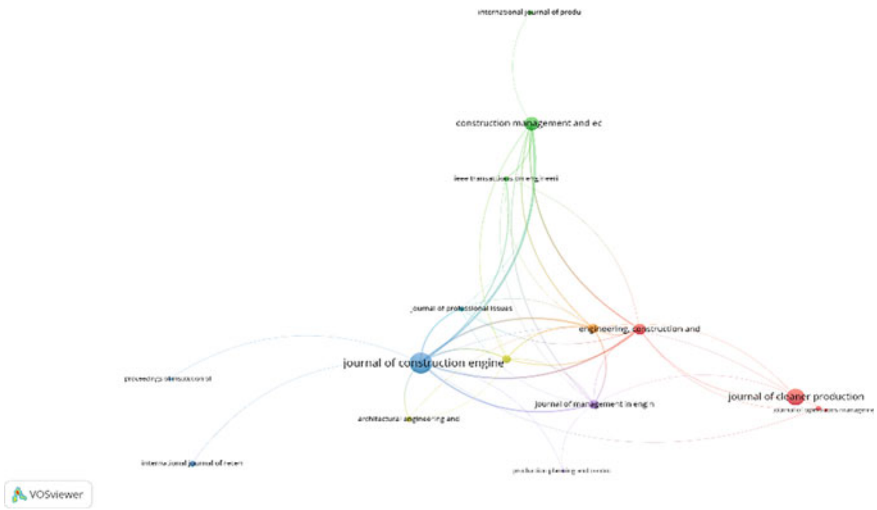


**Fig. 2** Prominent journals/outlets in variations management research studies

### *3.3 Co-occurrence Network of Keywords*

In order to extract the primary themes of research articles and index publications in research databases, keywords are essential [8]. Therefore, the choice of keywords for research articles should be made with the utmost care based on an analysis of the keywords for the research topic. In the light of this, the important keywords from the variations management research were extracted, and a careful analysis was done. This is depicted in Fig. 3, and Table 2 contains the precise numerical statistics.

There were numerous keywords detected in the variations management research articles. A keyword has to appear at least 10 times to be taken into account for mapping, producing a list of 23 keywords. The terms with big nodes in Fig. 4 are those that are often used in variations management research. Electronic commerce, supply chain management, public procurement, e-government, purchasing, and the Internet are a few of them. The network analysis's various colours depict the groups of connected and often occurring keywords in variations management research. For instance, the terms "project management," "construction management," "risk management," "contingency," "change order," and “construction industry” commonly co-occur. Researchers should use keywords with large nodes, as illustrated in Fig. 3, to increase the visibility of their research in databases, increasing the number of times their papers are cited as a result.

**Table 1** Numerical analysis of prominent research outlets of variations management

| Journal | No. of articles | Total citations | Av. citations | Total link strength |
|---|---|---|---|---|
| Journal of Construction Engineering and Management | 199 | 8419 | 42 | 167 |
| Journal of Cleaner Production | 124 | 3784 | 31 | 5 |
| Construction Management and Economics | 84 | 2369 | 28 | 78 |
| Journal of Management in Engineering | 41 | 1363 | 33 | 50 |
| Journal of Operations Management | 7 | 1348 | 193 | 1 |
| Engineering, Construction and Architectural Management | 55 | 759 | 14 | 65 |
| International Journal of Production Economics | 11 | 605 | 55 | 5 |
| Journal of Civil Engineering and Management | 30 | 576 | 19 | 40 |
| International Journal of Construction Management | 37 | 530 | 14 | 67 |
| IEEE Transactions on Engineering Management | 11 | 314 | 29 | 15 |
| Architectural Engineering and Design Management | 15 | 300 | 20 | 8 |
| International Journal of Production Research | 13 | 234 | 18 | 1 |
| Journal of Professional Issues In Engineering Education and Practice | 11 | 227 | 21 | 24 |
| Journal of Risk Research | 7 | 165 | 24 | 0 |
| Eastern-European Journal of Enterprise Technologies | 12 | 77 | 6 | 0 |
| International Journal of Recent Technology and Engineering | 19 | 35 | 2 | 1 |
| Proceedings of Institution of Civil Engineers: Management, Procurement and Law | 6 | 33 | 6 | 1 |
| Production Planning and Control | 6 | 33 | 6 | 2 |
| Lecture Notes in Business Information Processing | 5 | 29 | 6 | 0 |
| International Journal for Housing Science and Its Applications | 6 | 27 | 5 | 0 |

### *3.4 Co-authorship Network Analysis*

The idea-fertilisation that results from collaboration between academics from different universities has a significant impact on knowledge sharing and research expertise [34]. This facilitates obtaining significant grants and funding for cutting-edge research. Therefore, it is crucial to carefully examine how top academics in the field of variations management research collaborate. This is crucial for finding renowned, accomplished academics who are available for collaboration. Figure 4 lists

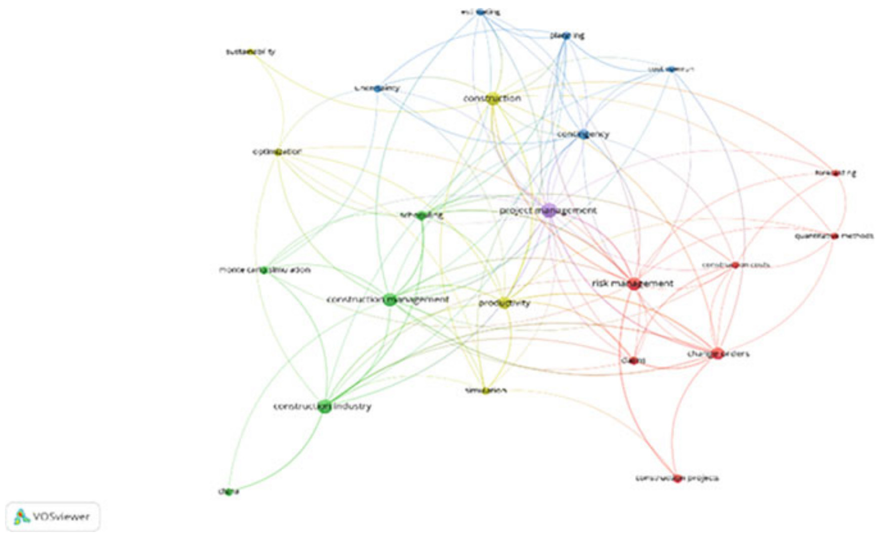


**Fig. 3** Network analysis of keywords

the top researchers in the field of variations management along with the connections between them. Table 3 contains a breakdown of their precise numerical statistics. A researcher needs at least five published articles and at least 20 citations to further improve the results. This is critical as the total number of researchers/authors captured in the database are over 1000. This threshold was employed by similar studies in the past [27, 34]. Only 27 authors met the adopted threshold.

The bigger nodes in Fig. 4 that represent the well-known researchers include Hanna A.S., Adeli H., Chan A.P.C., Arditi D., Liu M., and Li H. This shows that these academics worked along with a number of other researchers to publish variations management research. Leading academics in the field of variations management studies collaborate in clusters that are represented by various colours in the network analysis. For instance, Liu M., Hanna A.S., Chan A.P.C, and Adeli H. have more than 300 citations, according to the numerical figures.

### *3.5 Article Citation Analysis (High-Impact Articles)*

The basis for calculating an article's impact is the number of citations it receives [32]. An evaluation of the impact of variations management articles is therefore necessary. This will make it easier to recognise the value of earlier studies. The outcome will empower next researchers, particularly postgraduate students interested in online acquisition of important references to take into consideration for their research. The top three research studies found to be most impactful in variations management are Causes of Delay In Large Construction Projects by Assaf and Al-Hejji [7], Causes of

**Table 2** Numerical analysis of keywords of variations management articles

| Keyword | Occurrences | Total link strength |
|---|---|---|
| Project management | 44 | 47 |
| Construction | 37 | 39 |
| Productivity | 28 | 36 |
| Change orders | 29 | 35 |
| Construction management | 35 | 34 |
| Risk management | 31 | 34 |
| Construction industry | 38 | 28 |
| Scheduling | 19 | 26 |
| Planning | 15 | 19 |
| Contingency | 21 | 18 |
| Claims | 14 | 17 |
| Estimating | 10 | 14 |
| Simulation | 12 | 14 |
| Optimization | 13 | 12 |
| Cost overrun | 10 | 11 |
| Uncertainty | 12 | 11 |
| Construction costs | 11 | 10 |
| Monte Carlo simulation | 15 | 8 |
| Construction projects | 17 | 7 |
| Forecasting | 10 | 6 |
| Quantitative methods | 10 | 6 |
| China | 13 | 5 |
| Sustainability | 10 | 3 |

Delay and Cost Overruns in Construction of Groundwater Projects in a Developing Countries by Frimpong et al. [10]; and Conflicts, Claims and Disputes In Construction by Kumaraswamy [15] (Table 4).

# 4 Major Variations Management Research Areas

## *4.1 Causes of Variations*

Construction projects frequently experience variations [3, 4]. Variations in a building project cannot be entirely avoided, even though they can be handled [11, 16, 21, 22, 25, 26]. If these variations are not adequately controlled, they can result in cost and time overruns, decreased productivity, and even rework. Effective variations management in construction projects has therefore been a significant source of worry.

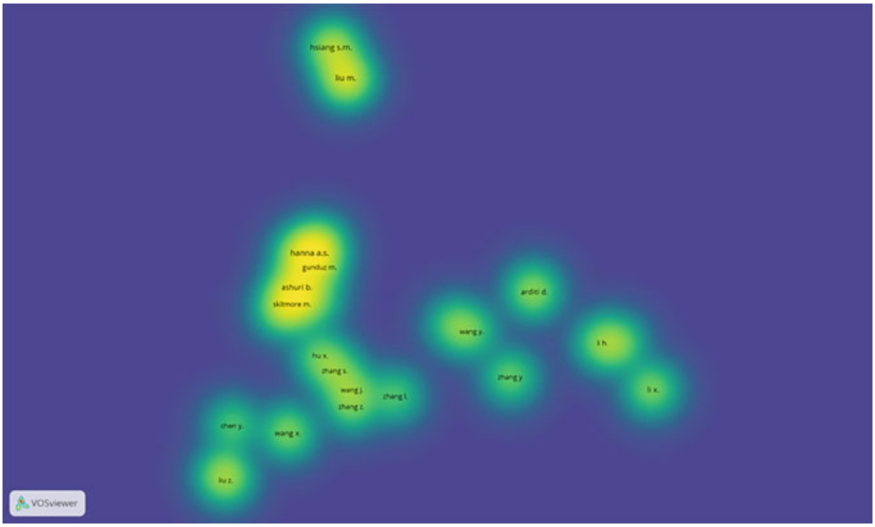


**Fig. 4** Density map of co-authorship network

It is impossible to overstate the importance of having a thorough understanding of the causes of variations. Numerous initiatives have been conducted over the years to investigate the reasons of variations. Poor preliminary research, insufficient information, inexperienced/incompetent designers, and/or poor coordination between design teams are a few of these. Others include insufficient knowledge of the project at the preliminary stages, insufficient examination of the contract conditions relating to variations [11], poor initial research, insufficient data, inexperienced or incapable designers, and/or poor coordination between design teams [13, 14], insufficient stakeholder communication [19], insufficient variation management systems in place [11, 12], unclear roles and responsibilities of parties involved in the variations [31]. To manage differences in construction projects, these reasons have been used as the foundation.

## *4.2 Management of Variations*

Over the years, a number of attempts have been undertaken to regulate variations by research. The project's overall viability is supported by the variations management process, which aims to forecast, identify, analyse, minimise, control, document, and learn from previous variations. In order to manage variations, various researchers have created models that handle one or more of the aforementioned functions. Arain and Pheng [6] created a theoretical framework for controlling variations in the assessment and taking proactive measures to counteract their unfavourable consequences. More recently, Shabani and Nik-Bakht [30] used a social network analysis (SNA)

**Table 3** Numerical statistics of most collaborative researchers

| Author | Documents | Citations | Total link strength |
|---|---|---|---|
| Liu M. | 13 | 330 | 786 |
| Hsiang S.M. | 10 | 211 | 751 |
| Wang Z. | 6 | 67 | 705 |
| Arditi D. | 8 | 391 | 674 |
| Li H. | 6 | 363 | 667 |
| Zhang Y. | 6 | 74 | 313 |
| Wang X. | 7 | 167 | 296 |
| Wang S. | 5 | 73 | 296 |
| Liu Z. | 5 | 97 | 292 |
| Zhang Z. | 5 | 35 | 238 |
| Zhang L. | 5 | 20 | 235 |
| Wang J. | 5 | 66 | 221 |
| Chen Y. | 5 | 92 | 218 |
| Hu X. | 5 | 85 | 186 |
| Zhang S. | 6 | 207 | 161 |
| Wang Y. | 5 | 170 | 138 |
| Liu C. | 5 | 105 | 118 |
| Li X. | 7 | 70 | 114 |
| Chan A.P.C. | 6 | 441 | 111 |
| Hanna A.S. | 12 | 460 | 105 |
| El-Adaway I.H. | 5 | 144 | 73 |
| Ashuri B. | 8 | 334 | 70 |
| Wilkinson S. | 5 | 42 | 65 |
| Gunduz M. | 5 | 56 | 64 |
| Skitmore M. | 6 | 52 | 38 |
| Zhang J. | 5 | 107 | 21 |
| Adeli H. | 5 | 611 | 4 |

to pinpoint the main players in charge of handling invoice processing and variation requests. They also evaluated how the kind of contract affected the behaviour and characteristics of the project's key players. Using a system dynamics technique, Al-Kofahi et al. [3] estimated the impact of fluctuations on labourers' productivity. The analysis made it possible to identify the key factors that affect labour productivity variations in a certain project type. Using multidimensional performance criteria, Naji et al. [24] suggested an operational and systematic variations framework to improve the overall project success. In a different study, Naji et al. [23] also identified a broad range of multidimensional performance factors that affect variations management in order to create an adaptive neuro-fuzzy inference system (ANFIS)

**Table 4** High impact articles on variations management research studies

| Reference | Article | Citations | Total link strength |
|---|---|---|---|
| Assaf and Al-Hejji [7] | Causes of Delay in Large Construction Projects | 7 | 20 |
| Frimpong et al. [10] | Causes of Delay and Cost Overruns in Construction of Groundwater Projects in a Developing Countries | 7 | 6 |
| Kumaraswamy [15] | Conflicts, Claims and Disputes in Construction | 5 | 20 |
| Hanna et al. (1999) | Impact of Change Orders on Labour Efficiency for Mechanical Construction | 5 | 7 |
| Akintoye and Macleod (1997) | Risk Analysis and Management in Construction | 5 | 5 |
| Touran (2003) | Calculation of Contingency in Construction | 5 | 4 |
| Kazaz et al. (2012) | Causes of Delays in Construction Projects in Turkey | 4 | 11 |
| Mpofu et al. (2017) | Profiling Causative Factors Leading to Construction Project Delays in the United Arab Emirates | 4 | 10 |
| Thomas and Napolitan (1995) | Quantitative effects of Construction Changes on Labour Productivity | 4 | 6 |
| Eisenhardt (1989) | Building Theories from Case Study Research | 4 | 4 |
| Akinci and Fischer (1998) | Factors Affecting Contractors' Risk of Cost Overburden | 4 | 1 |
| Ibbs et al. (2012) | Construction Change: Likelihood, Severity, and Impact on Productivity | 4 | 0 |
| Mak and Picken (2000) | Mak, S., Picken, D., Using Risk Analysis to Determine Construction Project Contingencies | 4 | 0 |

for modelling the factors quantitatively and assessing the success of variations management implementation in the construction sector.

### 4.3 Emerging Technologies in Variations Management

The acceptance and application of artificial intelligence (AI) is growing quickly, and it has been found that this is crucial for the development and success of variations management. Variations management has been found to depend on data, as decisions on how best to manage variations depend on prior knowledge and experience. As a result, the ability of AI to make use of data in enhancing decision-making and improving the efficiency of business processes can improve variations management generally by reducing human involvement, time and errors, as well as improving transparency, efficiency and automation [1, 2, 35–37]. Also, the advent of smart contract systems based on blockchain technology has been established to reduce costs and improve cash flow [29], increase transparency [33], create an audit trail [9], and produce better-quality schedule and cost data [28]. These can be leveraged to improve the variations management process and extend it to payment of those variations seamlessly.

## 5 Knowledge Gaps and Future Research Consideration

The research on variants management has received praiseworthy efforts. However, because variations remain persistent in construction projects, there is still considerable work to be done. Some of the elements that future research should take into account have been highlighted by this study. First and foremost, there is a potential for using AI to improve the variations management process generally. The study recommends a careful analysis of the variations management process to establish suitable AI tools like machine learning, deep learning and natural language processing to develop self-learning tools that can improve the management of variations in construction projects. Previous similar efforts in managing construction projects can be used as a basis.

In view of the development and benefits of Big Data and digitalization, future research should take into account fusing variations management with cutting-edge technologies like BIM, AI, IoT, Blockchain, and Smart Contracts. According to the literature, the fifth industrial revolution is currently underway. Therefore, variations can use digital management methods at this point.

## 6 Conclusion

The relevance and immersive benefits of variations management has made variations management a vital research discourse. This paper, therefore, analysed the variations management research trend using a scientometric review. The paper adopted bibliometric data of 897 publications from 1982 and 2023. Key outcomes from this review include:

- The documents analysis by year shows that variations management research saw a stable growth from the year 2000. The leading five (5) research outlets in variations management publications with the most citations include the Journal of Construction Engineering and Management, Journal of Cleaner Production, Construction Management and Economics, Journal of Management in Engineering, and Journal of Operations Management.
- The most relevant keywords used by authors in terms of total link strength and frequency of co-occurrence from the analysis are "project management," "construction management," "risk management," "contingency," "change order," and "construction industry".
- Hanna A.S., Adeli H., Chan A.P.C., Arditi D., Liu M., and Li H. were found to be the prominent authors after the co-authorship analysis in variations management research.
- Lastly, the top three research studies found to be most impactful in variations management are Causes of Delay In Large Construction Projects by Assaf and Al-Hejji [7]; Causes of Delay and Cost Overruns In Construction of Groundwater Projects in a Developing Countries by Frimpong et al. [10]; and Conflicts, Claims and Disputes in Construction by Kumaraswamy [15].

This document provides graduate students, researchers, the government, industry, stakeholders, journals, and funding organisations with comprehensive contextual information on variations management research. The findings inform variations management researchers on the current factors taken into account in variations management studies. Additionally, it provides upcoming scholars with information on the top authors in the field. This will facilitate the formation of partnerships with experts. Finally, the findings identify the most important variations management research topics that should receive funding and government support.

Future academics should also think about how developing digital components can enhance variations management, particularly in areas like data management and automation. This is important since the building sector is transitioning into a stage of the fifth industrial revolution.

Like any review study, this one includes some limitations that might make it harder to generalise the results. First off, the study was not limited to just academic articles. Conference articles were also examined in the study. Second, for this study, the authors solely examined critical papers. This is because we were unable to read all 897 of the articles that were extracted for this investigation. However, proper diligence was used, and the important materials were carefully read. Therefore, it was not a mistake if any important items were left out of the qualitative discussion. Last but not least, the study's use of too many terms left out several themes.

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**Author Contributions** Muhammad Aliyu Yamusa contributes to conceptualization, methodology, software, validation, analysis, investigation, data collection, and draft preparation. Yahaya Makarfi Ibrahim, Muhammad Abdullahi, Hassan Adaviriku Ahmadu and Mu'awiya Abubakar contribute to conceptualization, draft preparation, manuscript editing, and supervision. All authors have read and agreed with the manuscript before its submission and publication.

## References

1. Abdullahi B, Ibrahim YM, Ibrahim Y, Ibrahim AD, Bala K, Yamusa MA (2023) Development of machine learning models for classification of tenders based on UNSPSC standard procurement taxonomy. Int J Procurement Manage, In press. https://doi.org/10.1504/IJPM.2023.10056755
2. Abdullahi B, Ibrahim YM, Ibrahim Y, Ibrahim AD, Bala K, Yamusa MA (2024) Development of machine learning models for categorisation of Nigerian Government's procurement spending to UNSPSC procurement taxonomy. Int J Procurement Manag 19(1):106–121. https://doi.org/10.1504/IJPM.2022.10057133
3. Al-Kofahi ZG, Mahdavian A, Oloufa A (2020) System dynamics modeling approach to quantify change orders impact on labor productivity 1: principles and model development comparative study. Int J Construct Manage, 1–12. https://doi.org/10.1080/15623599.2020.1711494
4. Alleman D, Antoine ALC, Stanford MS, Molenaar KR (2020) Project delivery methods' change-order types and magnitudes experienced in highway construction. J Leg Aff Dispute Resolut Eng Constr 12(2):04520006. https://doi.org/10.1061/(ASCE)LA.1943-4170.0000380
5. Alsuliman J, Bowles G, Chen Z (2012) Current practice of variation order management in the Saudi construction industry. In: Smith SD (ed) 28th Annual ARCOM Conference, 3–5 September. Association of Researchers in Construction Management, Edinburgh, UK, pp 1003-1012
6. Arain F, Pheng L (2007) Modeling for management of variations in building projects. Eng, Const Architect Manage 14(5):420–433
7. Assaf SA, Al-Hejji S (2006) Causes of delay in large construction projects. Int J Project Manage 24(4):349–357. https://doi.org/10.1016/j.ijproman.2005.11.010
8. Chen J, Su Y, Si H, Chen J (2018) Managerial areas of construction and demolition waste: a scientometric review. IJERPH. 15(11):2350
9. Demirkan S, Demirkan I, McKee A (2020) Blockchain technology in the future of business cyber security and accounting. J Manage Anal 7(2):189–208. https://doi.org/10.1080/23270012.2020.1731721
10. Frimpong Y, Oluwoye J, Crawford L (2003) Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. Int J Project Manage 21(5):321–326. https://doi.org/10.1016/s0263-7863(02)00055-8
11. Gündüz M, Nielsen Y, Özdemir M (2013) Quantification of delay factors using the relative importance index method for construction projects in Turkey. J Manage Eng 29(2):133–139. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000129
12. Gunduz M, Tehemar S (2020) Assessment of delay factors in construction of sport facilities through multi criteria decision making. Prod Plann Control 31(15):1291–1302. https://doi.org/10.1080/09537287.2019.1704903

13. Ibrahim MW, Hanna A, Kievet D (2020) Quantitative comparison of project performance between project delivery systems. J Manage Eng 36(6):04020082. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000837
14. Khoshgoftar M, Bakar AHA, Osman O (2010) Causes of delays in Iranian construction projects. Int J Construct Manage 10(2):53–69. https://doi.org/10.1080/15623599.2010.10773144
15. Kumaraswamy MM (1997) Conflicts, claims and disputes in construction. Eng, Const Architect Manage 4(2):95–111. https://doi.org/10.1108/eb021042
16. Larsen J, Shen G, Lindhard S and Brunoe T (2016) Factors affecting schedule delay, cost overrun, and quality level in public construction projects. J Manage Eng 32(1):04015032. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000391
17. Lecheler S, Kruikemeier S (2016) Re-evaluating journalistic routines in a digital age: a review of research on the use of online sources. New Media Soc 18(1):156–171
18. Lewis S (2015) Qualitative inquiry and research design: choosing among five approaches. Health Promot Pract 16(4):473–475
19. Love PE, Matthews J, Fang W (2020) Rework in construction: a focus on error and violation. J Constr Eng Manage 146(9):06020001. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001901
20. Mohammad N, Hamzah Z (2019) A review of causes of variation order in the construction of terrace housing projects in Malaysia. In: MATEC Web of Conferences, Vol 277, p 03013. EDP Sciences
21. Moselhi O, Assem I, El-Rayes K (2005) Change orders impact on labor productivity. J Constr Eng Manage 131(3):354–359. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:3(354)
22. Msallam M, Abojaradeh M, Jrew B, Zak I (2015) Controlling of variation orders in highway projects in Jordan. J Eng Archit 3(2):95–104. https://doi.org/10.15640/jea.v3n2a11
23. Naji KK, Gunduz M, Naser AF (2022b) The effect of change-order management factors on construction project success: a structural equation modeling approach. J Construct Eng Manag 148(9). Available at: https://doi.org/10.1061/(asce)co.1943-7862.0002350
24. Naji KK, Gunduz M, Naser AF (2022a) An adaptive Neurofuzzy inference system for the assessment of change order management performance in construction. J Manag Eng 38(2). Available at: https://doi.org/10.1061/(asce)me.1943-5479.0001017
25. Noruwa BI, Arewa AO, Merschbrock C (2020) Effects of emerging technologies in minimising variations in construction projects in the UK. Int J Const Manage 22(11):2199–2206. https://doi.org/10.1080/15623599.2020.1772530
26. Osei-Kyei R, Chan AP (2015) Review of studies on the critical success factors for public–private partnership (PPP) projects from 1990 to 2013. Int J Project Manage 33(6):1335–1346
27. Osei-Kyei R, Jin X, Nnaji C, Akomea-Frimpong I, Wuni IY (2022) Review of risk management studies in public-private partnerships: a scientometric analysis. Int J Const Manage. https://doi.org/10.1080/15623599.2022.2063013
28. Penzes B, Kirkup A, Gage C, Dravai T, Colmer M (2018) Blockchain technology in the construction industry: digital transformation for high productivity
29. Qian X, Papadonikolaki E (2020) Shifting trust in construction supply chains through blockchain technology. Eng, Construct Architect Manage 28(2):584–602. https://doi.org/10.1108/ECAM-12-2019-0676
30. Shabani AS, Nik-Bakht M (2021) Functional evaluation of change order and invoice management processes under different procurement strategies: social network analysis approach. J Constr Eng Manage 147(1):04020155. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001974
31. Shrestha K, Shrestha P (2019) Change orders on road maintenance contracts: causes and preventive measures. J Leg Aff Dispute Resolut Eng Constr 11(3):04519009 https://doi.org/10.1061/(ASCE)LA.1943-4170.0000299
32. Song J, Zhang H, Dong W (2016) A review of emerging trends in global PPP research: analysis and visualization. Scientometrics. 107(3):1111–1147
33. Tezel A, Febrero P, Papadonikolaki E, Yitmen I (2021) Insights into blockchain implementation in construction: models for supply chain management. J Manage Eng 37(4). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000939

34. Wuni IY, Shen GQ, Osei-Kyei R (2019) Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. Energy Build 190:69–85
35. Yamusa MA, Ibrahim YM, Abdullahi M, Ahmadu HA, Abdullahi B, Ibrahim AD, Bala K (2023) Developing a machine learning integrated e-procurement system for Nigerian public procuring entities. Int J Procure Manage. https://doi.org/10.1504/IJPM.2023.10055600
36. Yamusa MA, Ibrahim YM, Abdullahi M, Ahmadu HA, Abdullahi B, Ibrahim AD, Bala K, Aminu A (2023) Developing requirement model for a web-based e-procurement system in Nigeria. Int J Elect Govern 15(3):234–254. https://doi.org/10.1504/IJEG.2023.133573
37. Yamusa MA, Ibrahim YM, Ibrahim AD, Bala K, Abdullahi B, Abdullahi M, Ahmadu HA, Aminu A (2020) A conceptual framework for developing machine learning models for procurement processes. In: Proceedings of the 5th Research Conference of the NIQS (RECON 5), pp 273–285
38. Ye KM, Rahman HA (2010) Risk of late payment in the Malaysian construction industry. Int J Mech Indust Eng 4(5):503–511
39. Yildiz AE, Dikmen I, Birgonul MT (2014) Using expert opinion for risk assessment: a case study of a construction project utilizing a risk mapping tool. Proced 119:519–528
40. Zawawi NAWA, Azman NFIN, Kamar MSS (2010) Sustainable construction practice: a review of Change Orders (CO) in Construction Projects
41. Zhang D, Haas C, Goodrum P, Caldas C, Granger R (2012) Construction small-projects rework reduction for capital facilities. J Constr Eng Manage 138(12):1377–1385. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000552
42. Zhang L, Yuan J, Xia N, Bouferguene A, Al-Hussein M (2020) Improving information sharing in major construction projects through OC and POC: RDT perspective. J Construct Eng Manag 146(7):04020068

# COVID-19 and the Changes It Made to Construction Demand in New Zealand

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## 1 Introduction

Investigating the impacts of COVID-19 on the construction industry in the world provides us with ideas on the causes, outcomes, and how the world dealt with the pandemic. The COVID-19 pandemic has caused significant disruptions to global supply chains due to restrictions on business operations and international movement, revealing the vulnerabilities of freight networks [18, 33]. Supply chain issues have particularly impacted the building and construction sector, which decrease construction demands. The pandemic has caused a demand shock, a supply shock, and a financial shock to the global economy [36]. Most economists believe that the pandemic encompasses features of both supply and demand shocks. A supply shock entails any factor that diminishes the economy's ability to manufacture goods and services.

In contrast, a demand shock decreases consumers' capacity or inclination to buy goods and services at particular prices [5]. The construction industry has been negatively affected by reduced operational surpluses and revenues, credit and liquidity issues, poor business sentiment, and uncertainty, which have led to decreased demand for construction projects [9, 18, Kim et al. 2022]. Ling et al. [20], in a study, identified one of the critical effects of the pandemic on the construction industry in Singapore was a decline in construction demand, which was driven by various factors, including travel restrictions and quarantine measures. Additionally, the pandemic led to a general slowdown in economic activity, which reduced the demand for new construction projects. As a result of the decline in construction demand, many construction firms experienced financial difficulties during the pandemic. King et al. [17], in a paper, explain that the construction demand declined as it has disrupted the supply chain and suggest adopting digital technologies to overcome the situation and

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continue to operate. Del Rio-Chanona et al. [9] note that the pandemic has significantly reduced demand for construction projects due to the economic slowdown, restrictions on mobility and social distancing measures, and uncertainty about the future.

On the other hand, the pandemic has also significantly impacted households globally, with remote work eliminating the need for commuting to work and increasing the demand for home offices. The lockdown restrictions as part of the New Zealand governments response plan to COVID-19 [24, 25] and remote work culture reduced the demand for office buildings, while the demand for residential building construction has remained stable due to the need for home renovation (Boesel et al. 2021; Kim et al. 2022).

As such, it is essential to accurately diagnose and quantify the pandemic's impacts on the construction industry's demand movements for the success of construction projects and businesses. Understanding post-COVID-19 fluctuations in demand for various architectural services can enhance project plans, investment strategies, and decision-making for project planners, architects, construction engineers, and real estate investors (Kaklauskas et al. 2021).

Accurately diagnosing and quantifying the pandemic's impacts on the construction industry's demand movements is essential for the success of construction projects and businesses. Therefore, understanding post-COVID-19 fluctuations in demand for various architectural services is crucial for project planners, architects, construction engineers, and real estate investors.

According to Ivanov [13], a pandemic such as COVID-19 can reveal unforeseen risks in the supply chain due to prolonged disruptions. These disruptions coincide with the epidemic's spread among the population and affect supply, demand, and logistics. According to Allen-Coghlan and McQuinn [2], the pandemic has caused an economic slowdown that has reduced income levels, job losses, and decreased demand for housing. The construction industry has been particularly affected due to the significant decline in market demand for goods and services resulting from total or partial lockdowns in many countries. This has led to a reduction in the number of construction projects being undertaken and a decrease in revenue for construction companies. Ivanov [13] notes that COVID-19 has caused detrimental swings in supply and demand, making it one of the most significant challenges faced by the industry.

The current level of uncertainty, poor business sentiment, reduced operational surpluses and revenues, diversion of funds for COVID-19 management, and credit and liquidity issues are expected to have a significant impact on the construction industry, and the demand for construction projects has already decreased [30].

When COVID-19 was declared a pandemic and many restrictions for social distancing and international border control were implemented, a supply shock began to occur [29]. Border restrictions created intense competition for logistic services, and many businesses failed to obtain them on time. This unplanned breach of contract led to a severe scarcity of goods or raw materials at various demand nodes [12].

However, Dasaklis et al. [7] argued to manage and afford the expense of maintaining such a large inventory, businesses should develop plans and policies for managing alternative suppliers and the size of stock to address demand surges.

Due to the lockdown, building materials couldn't arrive at the construction site from outside, preventing progress on the project. These materials are sourced from various domestic or overseas factories which were not accessible for construction activities. Moreover, the unavailability of vehicles has prevented the delivery of necessary materials, adding to the causes of work delays. The firms that produce all these supplies also lost a lot of money due to the significant losses in the construction industry and the livelihoods of individuals transporting products [21].

Local effects can be investigated by knowing the general impacts of the COVID-19 pandemic on a global scale. In 2020, New Zealand experienced a Lockdown period due to the COVID-19 pandemic, which led to changes in workplace and lifestyle, resulting in changes in residential demands and building specifications for businesses and workers, such as shrinking office spaces. A survey conducted by the Ministry of Business, Innovation, and Employment (MBIE) in 2021 quantified these changes and found that businesses were seeing specifications for offices and commercial space becoming smaller, while home offices and more flexible residential design options were becoming more commonly specified. In addition, there was an increase in homes designed for multi-generational users/extended families, and multi-level buildings were becoming more common [22].

These changes in building specifications were mainly driven by the increasing trend of working from home, which became more popular during the pandemic. As a result of spending more time at home, many homeowners in New Zealand decided to spend their leisure time planning and executing renovation projects. This led to a record high in home improvement work nationwide, with the value of consents for total alterations and additions to existing homes being $1.8 billion over the nine months ending September 2020 [4, 31]. The high demand for residential housing in New Zealand is driven by a shortage of affordable housing, increasing house prices and rents [26].

Due to lockdown restrictions and travel bans, people could not spend money on overseas holidays or other leisure activities. As a result, many redirected their funds towards home renovation, repairs, or new property purchases. This increased demand led to a surge in building consent and a higher need for construction professionals. However, the increased demand also caused a shortage of resources, including materials and labour. Some materials were imported, but disruptions in global supply chains and factory closures in Auckland led to even more significant shortages. The limited supply of resources caused prices to rise, and the industry faced delays in delivery times. In summary, the lockdowns and travel restrictions led to a shift in consumer spending towards home-related expenses, which caused a surge in demand for building and construction services. However, the shortage of resources caused by global disruptions and local factory closures resulted in increased prices and delivery delays [24, 25].

Despite the challenges posed by the COVID-19 pandemic, the building construction sector in New Zealand continued to grow, with a record number of new dwelling consents granted in September 2022 year. The strong demand for residential housing resulted in the granting of 50,736 consents for new homes in the 12 months ending in June 2022, up 14.4 percent from the year ended June 2021 [35]. The North Island's growing population has had a notable impact on home construction in Auckland. In recent years, the Auckland region has experienced a consistent rise in newly built houses due to robust demand for residential properties, and it is home to more than 75% of New Zealand's businesses. The COVID-19 pandemic caused a slight reduction in building work in Auckland in 2020 [34].

The supply chain disruptions and the challenges in meeting market demand have also impacted the construction sector, with suppliers struggling to meet the sector's needs [32]. The continued high demand for residential building activity has put the industry in good stead to recover from the impacts of the COVID-19 pandemic [23]. However, the complexity of global supply chain issues means that the full effects may still be felt for some time [23].

The COVID-19 pandemic has also impacted the demand outlook for construction in New Zealand. Deloitte [10] predicts that the demand outlook for horizontal construction will increase over the next five years, while the demand outlook for vertical construction has been impacted more severely by COVID-19. They expect a dramatic drop-in activity before a recovery. Stimulus initiatives will support vertical construction but are unlikely to make up for the shortfall in demand associated with the cancellation of private sector developments.

## 2 Method

This study aimed to investigate the impact of COVID-19 on the demand change in the construction industry in New Zealand. A qualitative methodology was used to achieve this goal, which involved conducting expert interviews followed by content analysis of responses. The qualitative approach was appropriate for this study, allowing the researcher to obtain in-depth viewpoints and experiences from expert respondents concerning the phenomenon under investigation [3]. Qualitative content analysis and thematic analysis were used to analyse textual data to reveal themes [11]. Content analysis involves systematically studying a body of text, visuals, and symbolic material [14, 19].

Eighteen experts involved in the construction industry during COVID-19 were interviewed using a snowball sampling technique. The interviewees were selected among construction companies' general managers, quantity surveyors, planners, site engineers, site managers, operation managers, and other informed construction workers (Table 1). A careful selection and classified sample are required to ensure that all potential viewpoints and opinions can be conveyed [8]. To ensure the quality of responses, the interviewees were chosen from the high managerial levels with at least five years of experience in the construction industry. A semi-structured interview was conducted for 40 min to 1 h. The interview questions aimed to explore how

**Table 1** Profile of interviewees

| Construction role | Number of respondents | Interviewee code |
|---|---|---|
| General manager | 5 | R7, R14, R15, R16, R17 |
| Project manager | 3 | R1, R2, R3, |
| Quantity surveyor | 3 | R4, R6, R13 |
| Site engineer | 2 | R8, R12 |
| Operation manager | 2 | R9, R11 |
| Planner | 2 | R5, R10 |
| Business manager | 1 | R18 |

the supply chain has been challenged and changed during the pandemic and influenced by it, as well as to reveal the processes and responses given to the challenges by those involved in the construction work in New Zealand.

Interviews continued until theoretical saturation was achieved [16]. Saturation can be viewed as the researchers having collected all the needed data and not adding anything else to the databank [1]. What matters is whether the results represent the subject of the investigation, not the research population.

The data gathered from the respondents were transcribed and uploaded into the NVivo software, which was used for data management and analysis. NVivo was developed to make it simpler to analyse the large amounts of text used in qualitative research since it allows for deeper analysis and has more advanced tools for data visualisation [28]. After categorising and coding the textual data, the main subjects were revealed based on the transcribed interviews. In addition to document reviews and observations, additional supporting data is also considered. The analysed data from the interviews and the existing literature and New Zealand reports shaped this paper.

## 3 Results

Unlike other parts of the world, New Zealand experienced a surge in construction demand for all building products [27]. R16 described the demand surge: "The industry is very, very busy." Some construction companies, builders, and architects in New Zealand have reported high demand, particularly with renovations, which have spiked due to people spending more time at home during the lockdown and not spending their money on overseas holidays [6]. According to R5 and R7, "demand was high. Prices were going up" and "there's a higher, much higher demand at the moment, we do a lot of work in the housing market. So, it's the demanders moment.“

The increased demand in the housing sector drives more demand for the materials. According to R13, "Timber was a bit of a problem even before COVID, but that made it worse because of the demand." Moreover, underestimating the construction demands led to more shortages. R5 explained: “The supplier underestimated the demand, and we don’t have alternatives.”

The increase in demand has a direct effect on price escalation. R14 confirmed it: “All this, of course, goes into the next problem escalation. Supply drives demand. Demand drives costs.” It is like a continuous chain escalating the problem. The rise in demand and lack of supply leads to price escalation. The New Zealand market can’t respond to huge demand. According to R12, R14, and R15, the New Zealand construction market is small, and “it is not like going to a supermarket and buying from the shelf.”

When COVID-19 hit and borders closed, the material flow to the country stopped. R17 explained the lack of material: “We struggled to keep up with demand, and product outages were a regular occurrence, particularly for mesh.”

The idea of manufacturing, shipping, and using material on a short-term basis reduces the number of products in inventories and the storage cost; however, with the COVID-19 occurrence, the companies found out that they can’t continue work with low stocks. At that moment, when companies shut down, there was not a massive amount of material in the warehouses to distribute. R1 explained, “The supply chain has gone to this idea to make things on time and almost per order to save storage space and reduce the price.” On the other hand, the shipping issues and shutting down the factories globally restricted companies from securing materials for their project. According to R3, “They cancelled all orders across New Zealand, and then you have to reorder every month.” The uncertainty around the time of border reopening made the suppliers, distributors, manufacturing owners, and contractors buy their needed material and store it somewhere. According to R12, “People started buying up massively, even though they didn’t need it, which would further restrain material.” They bought the material and couldn’t find and afford warehouses. The response was to stock the material on the construction site. According to R2, “We didn’t have enough storage for that material, so we started stocking the site.” However, the material was on the commuting pathways or working spaces, and they were at risk of damage because of being exposed. Some other respondents leased the warehouses as they couldn’t move and stock a lot of material on-site. According to R6, “We are restricted in the industry as storage is not something you generally have. Building sites need open spaces for everyone to work, so you can’t just fill up.” The lack of storage makes the construction industry think about building more warehouses. According to R17: “Demand for warehouse space and large distribution centres continues to be strong partly as a result of COVID impacts on global supply chains,” and R18 confirmed: “The big impact on our market is a huge demand for industrial property. The supply chain disruption necessitates having more stock on hand which means more demand for warehouse space.”

Shifting demands from residential to industrial makes more workers available in the industrial sector. R18: “Last year there was a major labour shortage but now there’s partly because other sectors of the construction industry are quiet.”

## 4 Discussion

The COVID-19 pandemic has significantly impacted industries globally, and the construction industry is no exception. In New Zealand, the construction industry has experienced a surge in demand for building products, unlike the global situation, mainly due to increased demand for housing renovations and new dwellings. As a result, there has been a shortage of building materials and increased prices, creating challenges for the construction industry in New Zealand.

The COVID-19 pandemic has also led to changes in work arrangements, with many companies implementing work-from-home policies. This has led to reduced demand for office space.

With many people spending more time at home due to COVID-19 restrictions, there has been an increased demand for residential buildings. Additionally, with more people working from home, there is a higher demand for home offices and other amenities. Before the pandemic, many companies had adopted a strategy of manufacturing, shipping, and using materials on a short-term basis. This strategy helped to reduce the number of products held in inventories and lowered storage costs. However, with the COVID-19 pandemic, companies could not continue to work with low stocks. The global shutdown of factories and shipping issues have restricted companies from securing materials for their projects. This has led to the cancellation of orders across New Zealand, leading to more uncertainty in the supply chain.

The uncertainty around the time of border reopening has led suppliers, distributors, manufacturing owners, and contractors to buy and store the needed materials somewhere. However, this has led to a shortage of storage space, making it challenging to stock the materials. Some interview respondents have leased warehouses as they could not move and store many materials on-site. However, the lack of storage space has made the construction industry consider building more warehouses to keep the materials.

The shortage of building materials has led to some large companies buying up materials in bulk, even if they do not need them, which strains needy small companies. This has led to some companies leasing warehouses immediately and procuring essential project materials. The logic behind this idea is not only procuring material but also if they could get offshore material into New Zealand, they could assemble some parts in a warehouse. The traditional procurement models definitely and the priority and selection of suppliers and subcontractors and how sustainable these practices are was under scrutiny [15].

The shortage of building materials has worsened because the country's borders were closed, leading to a halt in the flow of materials. Some interview respondents reported that product outages were regular. The shortage of building materials has led to a shift in demand from residential to industrial construction. This shift in demand has made more workers available in the industrial sector. This has helped alleviate the labour shortage in the construction industry in New Zealand.

This study provides an opportunity for decision-makers to have a better understanding of the impacts of the pandemic on the material supply chain in New Zealand, including the sudden increase of the material demand, the possibility of shifting demand as it happened during the pandemic by moving from the residential to industrial construction, to empower them to predict the changes and altering needs and prepare strategies to mitigate them. The study highlights the need to improve supply chain management by reviewing the supply chain models and exploring alternatives to bring more flexibility and resilience into the industry.

The study highlights the need to consider the importance of diversifying the suppliers by including more regional and local suppliers, investment in local manufacturing capabilities, investment in warehousing and storage for at least essential construction materials, innovation in building construction with a focus on designs and materials that are less dependent on overseas supplies, and move towards the modern methods of the adapting flexible construction such as modular or prefabricated as they allow work to continue even when the material is unavailable.

The experience of the pandemic can push the construction industry towards emerging new business models that are more resilient to disruptions and uncertainties.

## 5 Conclusion

In conclusion, the COVID-19 pandemic has had a significant impact on the construction industry in New Zealand, posing challenges to the construction industry. Unlike the global trends, New Zealand experienced a surge in construction demand from residential to industrial construction due to an increased interest in the housing sector. The increased demand led to a shortage of building materials and a corresponding price increase. These challenges were exacerbated by the global shutdown of factories and supply chain disruptions caused by COVID-19, restricting the building materials availability in New Zealand. The situation exposed the shortcomings of the industry's method of keeping low stock for immediate use, designed to save cost and storage space.

With the border closure and the ongoing uncertainty, despite the lack of adequate storage, companies attempted to secure future-needed materials by purchasing in bulk and storing them. This action increased demand for warehouse space and made the companies keep the materials on-site. This strategy strained smaller companies that struggled to secure essential materials as bulk buying of their larger counterparts.

The study contributes to knowledge by providing insights into the impacts of a global pandemic on a specific industry in New Zealand as a geographically isolated country and how the country responds to that disruption. It expands understanding of the complexities and vulnerabilities of the construction material supply chain during COVID-19. It highlights the importance of adaptability, flexibility, and forward-thinking in business strategies such as localising supply chains, diversifying sourcing, and empowering local manufacturers to mitigate risks. The insights from this study could be used in future studies about supply chain management and construction industry resilience in the face of global disruptions.

## 6 Ethics Statement

This paper is part of a Ph.D. thesis and has been assessed as Low Risk in the Annual Report of the Massey University Human Ethics Committee with the Ethics Notification Number: 4000023852.

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## References

1. Alam MK (2020) A systematic qualitative case study: questions, data collection, NVivo analysis and saturation. Qual Res Organ Manage: An Int J
2. Allen-Coghlan M, McQuinn K (2020) Property prices and COVID-19 related administrative closures: what are the implications? https://www.esri.ie/system/files/publications/WP661_0.pdf
3. Amoah C, Simpeh F (2021) Implementation challenges of COVID-19 safety measures at construction sites in South Africa. J Facil Manag 19(1):111–128. https://doi.org/10.1108/JFM-08-2020-0061
4. Bell M (2022) It's been the biggest renovation boom in decades, but it's winding down. Stuff. https://www.stuff.co.nz/life-style/homed/renovations/127835851/its-been-the-biggest-renovation-boom-in-decades-but-its-winding-down
5. Brinca P, Duarte JB, Faria-e-Castro M (2020) Is the COVID-19 pandemic a supply or a demand shock? Available at SSRN 3612307
6. Brunsdon N (2021) Southland Region post COVID scenario analysis for Great South February 2021. Economics put simply—Infometrics. https://greatsouth.nz/storage/app/media/Publications/post_COVID_analysis_report_southland.pdf
7. Dasaklis TK, Rachaniotis N, Pappis C (2017) Emergency supply chain management for controlling a smallpox outbreak: the case for regional mass vaccination. Int J Syst Sci: Operations Logis 4(1):27–40
8. De Ruyter K, Scholl N (1998) Positioning qualitative market research: reflections from theory and practice. J Cetacean Res Manag 1(1):7–14. https://doi.org/10.1108/13522759810197550
9. Del Rio-Chanona RM, Mealy P, Pichler A, Lafond F, Farmer JD (2020) Supply and demand shocks in the COVID-19 pandemic: an industry and occupation perspective. Oxford Rev Economic Pol 36(Supplement_1):S94-S137

10. Deloitte (2021) A better way forward building the road to recovery together. Construction Sector COVID-19 Recovery Study. https://www.tewaihanga.govt.nz/assets/Uploads/Construction-Sector-Covid-19-Recovery-Study.pdf
11. Forman JDL (2008) Empirical methods for bioethics: a primer. Adv Bioeth, USA: Elsevier 11:39–62
12. Gray J (2020) Covid-linked supply-chain woes hit Metroglass. New Zealand Herald
13. Ivanov D (2021) Supply chain viability and the COVID-19 pandemic: A conceptual and formal generalisation of four major adaptation strategies. Int J Product Res 1–18
14. Jelodar MB, Yiu TW (2012) Evaluation of relationship quality in construction cases using a process model of conflict and disputes in project management. In: The 8th International Project Management Conference (IPMC2012), Tehran-Iran
15. Jelodar MB, Yiu TW, Wilkinson S (2013) Stirring sustainable procurement by conceptualizing relationship quality in construction World Building Congress 2013, Brisbane Convention & Exhibition Centre, Queensland, Australia
16. Jelodar MB, Yiu TW, Wilkinson S (2016) A conceptualisation of relationship quality in construction procurement. Int J Project Manage 34(6):997–1011
17. King SS, Rahman RA, Fauzi MA, Haron AT (2022) Critical analysis of pandemic impact on AEC organizations: the COVID-19 case. J Eng, Design Tech 20(1):358–383. https://doi.org/10.1108/JEDT-04-2021-0225
18. KPMG (2022) Six key trends impacting global supply chains in 2022: from logistics disruption, to workforce and labour. Retrieved 16/04/2023 from https://kpmg.com/sg/en/home/insights/2022/03/six-key-trends-impacting-global-supply-chains-in-2022.html
19. Krippendorff K (2018) Content analysis: an introduction to its methodology. Sage publications
20. Ling FY, Zhang Z, Yew AY (2022) Impact of COVID-19 pandemic on demand, output, and outcomes of construction projects in Singapore. J Manag Eng 38(2):04021097
21. Majumder S, Biswas D (2021) COVID-19 impacts construction industry: now, then and future. In: COVID-19: prediction, decision-making, and its impacts. Springer, pp 115–125
22. MBIE (2021) National construction pipeline report 2021, a forecast of building and construction activity
23. MBIE (2022) Building and construction sector trends—annual report 2022. https://www.mbie.govt.nz/dmsdocument/25439-building-construction-sector-trends-annual-report-2022
24. Mirhosseini SF, Wilkinson S, Babaeian Jelodar M (2022) New Zealand's response to the COVID-19 pandemic and the effects of its governance on the construction industry. IOP Conf Series: Earth Environ Sci 1101(3):032037. https://doi.org/10.1088/1755-1315/1101/3/032037
25. Mirhosseini SF, Wilkinson S, Jelodar MB (2022) A review of the impacts of COVID-19 on the construction industry in Auckland, New Zealand. In: 7th New Zealand built environment research symposium,
26. MSD (2023) Housing quarterly report. Retrieved 22/04/2023 from https://www.msd.govt.nz/about-msd-and-our-work/publications-resources/statistics/housing/housing-quarterly-report.html
27. Newsroom (2022) More supply chain pain for construction
28. Patton MQ (2002) Qualitative research & evaluation methods. Sage
29. Raišienė AG, Rapuano V, Varkulevičiūtė K, Stachová K (2020) Working from home—who is happy? a survey of Lithuania's employees during the COVID-19 quarantine period. Sustainability 12(13):5332
30. Rani HA, Farouk AM, Anandh K, Almutairi S, Rahman RA (2022) Impact of COVID-19 on construction projects: the case of India. Buildings 12(6):762
31. Renovations (2020) Home renovation after COVID lockdown. Retrieved 22/04/2023 from https://www.renovations.nz/our-blog/home-renovation-after-covid-lockdown/
32. Sachdeva S (2021) Years more supply chain pain for construction. Newsroom
33. Shih WC (2020) Global supply chains in a post-pandemic world. Harv Bus Rev 98(5):82–89
34. Statista (2021) Construction industry in New Zealand—statistics & facts. Retrieved 14-11-2021 from https://www.statista.com/topics/5725/construction-industry-in-new-zealand/#dossierKeyfigures

35. StatisticsNewZealand (2022) Annual inflation at 7.3 percent, 32-year high. Retrieved 16/04/2022 from https://www.stats.govt.nz/news/annual-inflation-at-7-3-percent-32-year-high/
36. Triggs A, Kharas H (2020) The triple economic shock of COVID-19 and priorities for an emergency G-20 leaders meeting. Brookings Institution

# Health & Safety and Wellbeing Issues Confronting New Zealand Building Council Staff Involved in Compliance Issues

**Zhimei Chen, Gregory Chawynski, Claire Flemmer, and Andries van Heerden**

## 1 Introduction

Occupational health and safety encompass the illnesses and risks arising from the work environment [10]. According to the World Health Organization (WHO), these include physical health, mental health and social wellbeing [45]. Globally, the construction industry is recognized as one of the most hazardous job sectors, particularly for those working on construction sites and exposed to extreme weather, heights and heavy machinery [4, 18, 21]. Consequently, most studies on health & safety and wellbeing in the construction sector focus on the physical health risks of onsite labour. Comparatively little is known about the health & safety and wellbeing of the building professionals employed in the public sector who are responsible for checking compliance with government regulations during the design, construction, and maintenance stages of building projects. In New Zealand, the government collects annual injury data for the construction industry but does not survey occupational health and safety, chronic diseases and mental health for public sector employees [40]. This research aims to address this gap by investigating the types of health & safety and wellbeing issues faced by New Zealand building professionals in a council office, looking at the

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support mechanisms that are provided and assessing what can be done to improve the situation for this group.

A joint International Labour Organization/World Health Organization (ILO/WHO) Committee on occupational health recognized that health & safety and well-being need to be considered for all workers in all workplaces [15]. In the public sector Nasios [29] notes that productivity increases when occupational health issues are addressed. Most public sector jobs are office-based with long periods of sitting and the common health issues are work-related stress and musculoskeletal disorders. These can result in sleeping difficulties, depression, anxiety, muscular tension, headaches and heart problems [5, 19, 20, 23]. Several studies show that reducing sedentary behaviour and increasing both leisure time and physical activity can improve worker's physical and mental health and improve productivity [9, 20, 28, 32, 34, 42]. Personal factors such as age, gender and work status may affect the extent of adverse health issues [35]. The relationship between work and stress is complex [13]. George et al. [11] found that occupational stress has no relation with the worker's age. Increased workload and increased working hours are both associated with increased occupational stress, increased physical and mental health issues, decreasing productivity and worsening job satisfaction [17, 27, 30, 33, 46]. Research into reducing occupational stress show that organizational policies reducing sedentary behaviour, ethical leadership and good communication between managers and subordinates are effective and increase job satisfaction [12, 24, 26, 38, 39, 43]. Despite this, many employers view health and safety issues as additional, unwelcome costs and there is a downward trend in public spending on occupational health and safety inspections [29].

In New Zealand, the Health and Safety at Work (HSAW) Act 2015 notes that any "Person Conducting a Business or Undertaking" (PCBU) has a primary duty of care for their workers and must reduce work-related physical and mental health risks [14]. HSAW stipulates that organization must provide the appropriate training and information to ensure worker safety. Many employers provide additional employee assistance programmes (EAPs), which give free counselling to support the employee's wellbeing [8]. The three largest building councils in New Zealand are the Auckland Council, the Christchurch City Council and the Wellington City Council. Of these three, only Wellington City Council includes limited information about the employee's health & safety and wellbeing in their annual report [1, 7, 44].

In summary, little is known about the health & safety and wellbeing of public sector professionals responsible for managing and inspecting building compliance issues and this research aims to address that gap. It uses a survey of Christchurch City Council (CCC) building professionals to determine the common health & safety and wellbeing problems. It then investigates the support mechanisms that are currently provided by the CCC and looks into additional ways to improve health & safety and wellbeing for building professionals.

**Table 1** Research method and justification

| Research design | Choice | Justification |
|---|---|---|
| Philosophy | Interpretivist | Qualitative data will be interpreted to gauge demographics, extent of health & safety and wellbeing and support offered by CCC |
| Approach | Inductive | Use the data to generate a model of the health & safety and wellbeing of building professionals and compare this with current models |
| Strategy | Action | Participants in a case study environment are actively engaged in order to achieve the research objectives |
| Methods | Mono | Qualitative data on the opinions of a sample population |
| Tools | Interview | Cross-sectional survey of at least 50 building professionals in CCC building consent unit |

## 2 Method

The CCC Building Consenting Unit was selected as the case study organization for the research and "in person" interviews were chosen as the research tool. The justification for the method, based on Saunders et al. [36], is summarized in Table 1.

There were three parts to the questions used in the survey: Part One collected demographic information, Part Two collected information about the individual experiences of health & safety and wellbeing and Part Three collected open-ended opinions on the support being offered by the organization and recommendations for additional support. Surveys were conducted at the premises in September 2022 and resulted in 63 valid responses, representing approximately 25% of the council employees. A more detailed description of the methodology is given in Chen [6].

## 3 Results

More detailed results from the research are available in Chen [6]. These include the effect of age, gender and role on the number of hours spent on work and on leisure activities each week.

### *3.1 Demographic Information*

Table 2 summarizes the demographics of the sixty-three building professionals working at the CCC Building Consent Unit who participated in this research. 76% were aged from 31 to 60 years, and there were slightly more males (54%) than females (46%). 9.5% of the participants had management roles, while 57% and 33% were in technical and supporting roles, respectively. The small percentage of those

**Table 2** Demographics of the 63 survey respondents

| Characteristic | | Number | Percentage (%) |
|---|---|---|---|
| Age (years) | 18–30 | 8 | 12.7 |
| | 31–40 | 13 | 20.6 |
| | 41–50 | 16 | 25.4 |
| | 51–60 | 19 | 30.2 |
| | Over 60 | 7 | 11.1 |
| Gender | Male | 34 | 54.0 |
| | Female | 29 | 46.0 |
| Role | Technical | 36 | 57.1 |
| | Management | 6 | 9.52 |
| | Supporting | 21 | 33.3 |

in management is a limitation of the study that will bias the findings towards the opinions of the technical and supporting staff.

### 3.2 *Health & Safety and Wellbeing Issues*

Figure 1 shows the physical and mental health issues experienced by the participants. Of the 63 participants, 75% have mental health issues, either as their only issue (37%) or in addition to physical health issues (38%). The latter added to the 10% who have only physical issues show that 48% of the participants have physical health issues. 16% have no health issues.

The effect of age, gender and role on the participant's health is shown in Figs. 2, 3, and 4, respectively.

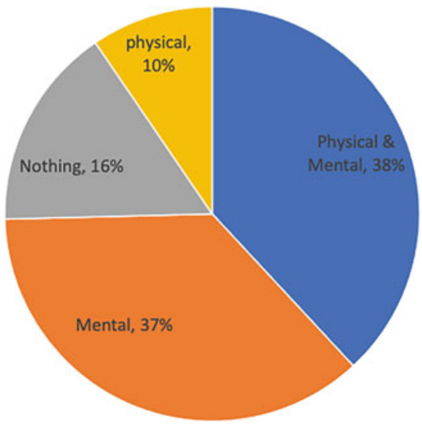


**Fig. 1** Participant health issues

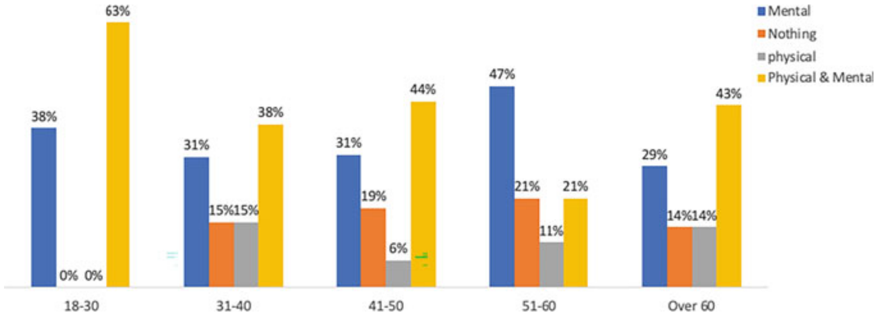


**Fig. 2** Building professional health issues by age

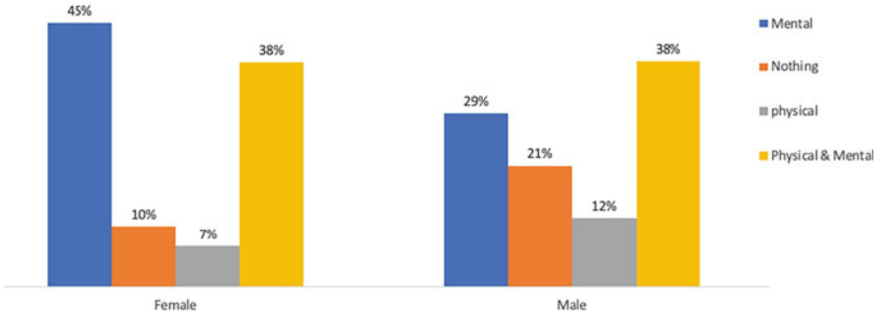


**Fig. 3** Building professional health issues by gender

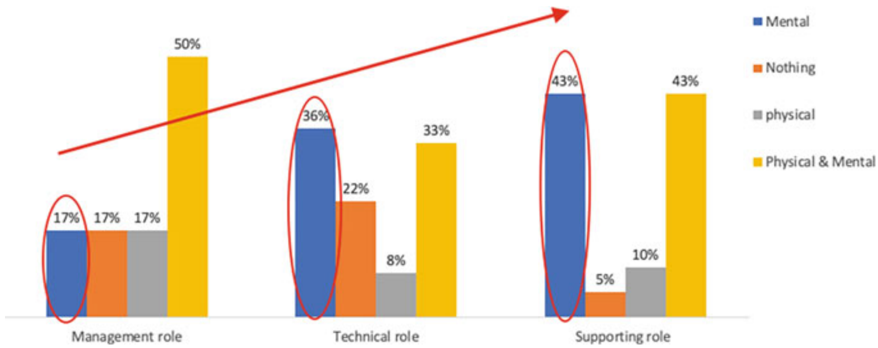


**Fig. 4** Building professional health issues by role

All eight participants in the youngest age group (18–30) experienced mental health issues and 63% also experienced physical health issues (Fig. 2). The 51–60-year age group had the highest percentage of mental health issues, with just under half of the participants experiencing this problem. The literature reports mixed findings on the effect of age on mental and physical wellbeing, with considerable variation amongst different countries and cultures [37].

Figure 3 shows that 45% of females report having mental issues and this is considerably higher than the 29% of males with mental issues. Both genders have the same proportion (38%) of combined physical and mental issues but slightly more males (12%) report physical health issues than women (7%). This might indicate that females are more comfortable than males about reporting mental health issues. This is supported in the literature which reports that females are more aware of their mental health issues and that males find it more difficult to communicate mental health issues [22, 25].

Figure 4 shows the effect of the building professional role on the reported health issues. It is apparent that those in management roles experience much lower mental health issues (17%), than those in technical roles (36%) and those in supporting roles (43%). Since managers earn higher salaries than technical workers and technical workers earn more than those in supporting roles, the results show that the lowest income group have the highest percentage of mental issues, and this agrees with findings reported by Thomson et al. [41].

The participants were asked what symptoms they experienced at the end of a full day of work how frequently they exhibited symptoms. The responses are shown in Figs. 5 and 6.

Almost half of the participants (46%) suffered from muscular tension and about a third experienced headaches, anxiety, sleeping difficulties and work or private life distractions (Fig. 5). Only 21% of the participants reported none of the listed symptoms. A quarter of the participants experienced health symptoms often and 35% experienced the symptoms sometimes (Fig. 6). The findings agree with other studies showing that musculoskeletal problems are common in office workers and

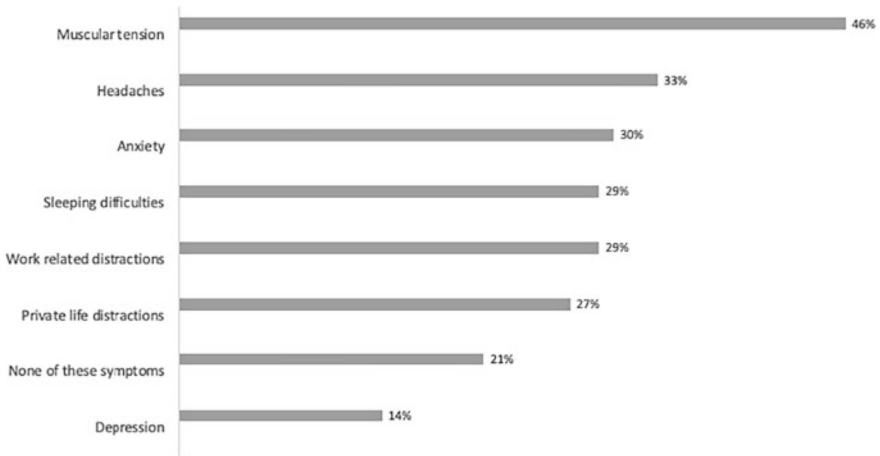


**Fig. 5** Participant symptoms

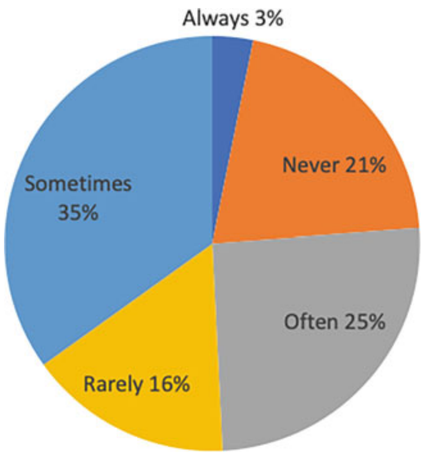


**Fig. 6** Frequency of symptoms

that addressing them through ergonomic furniture and exercise reduces the problem [31].

### 3.3 *Health & Safety and Wellbeing Support*

62% of the participants agreed that the organization provided adequate health & safety and wellbeing support. The effect of age, gender and role on this support are shown in Figs. 7, 8 and 9.

The 41–50 age group participants were the most satisfied with the health & safety and wellness support provided to them (Fig. 7). Males were more satisfied than females (Fig. 8) and those in management roles were completely satisfied compared with those in technical and supporting roles (Fig. 9).

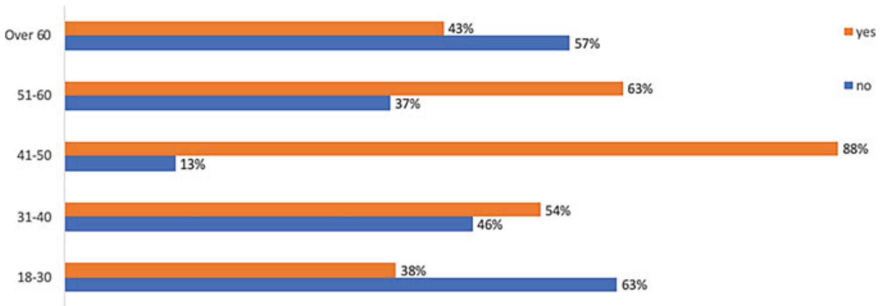


**Fig. 7** Adequacy of provided support by age group

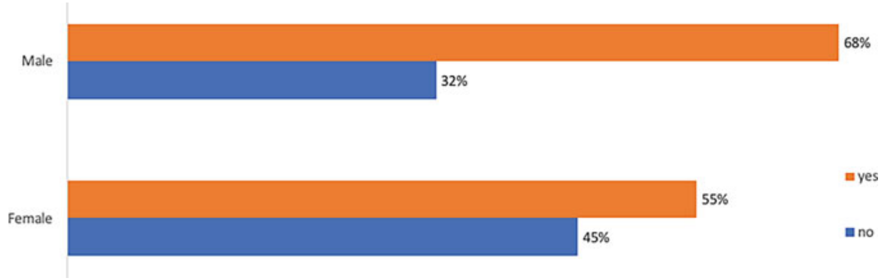


**Fig. 8** Adequacy of provided support by gender

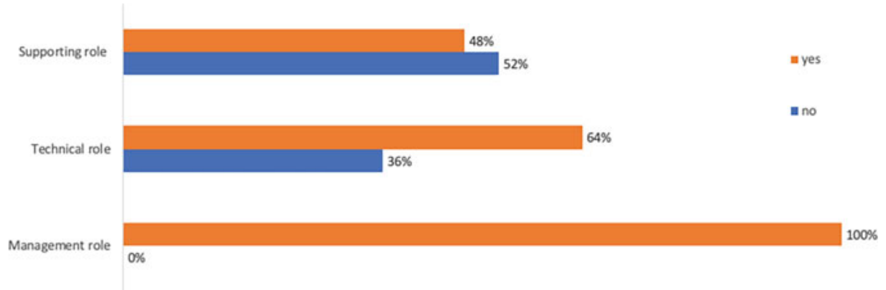


**Fig. 9** Adequacy of provided support by role

An open-ended question on recommendations for improved support was answered by 51 participants (93% of the women and 71% of the men) and led to the results shown in Fig. 10.

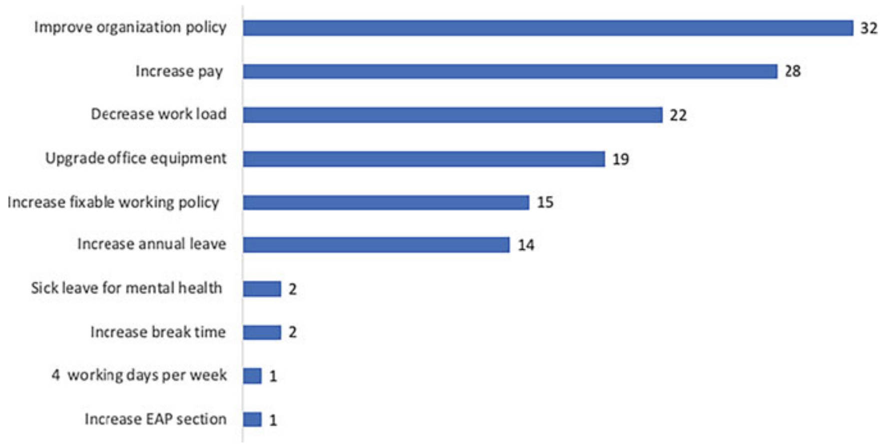


**Fig. 10** Recommendations for improving health & safety and wellbeing support

32 of the participants (63%) felt that the organization's policy on health & safety and wellbeing support could be improved. Over half were in favour of increased pay and other common recommendations were reduced workloads, better office equipment, more flexible working hours and more annual leave. The literature shows that good health & safety and wellbeing support policies, including flexible working hours, improve employee performance, productivity and customer service delivery in organizations [2, 3].

## 4 Discussion

The aim of the research was to investigate the health & safety and wellbeing issues faced by building professionals involved in the administration of compliance matters. The results were based on a survey of 63 employees in the Christchurch City Council Building Consenting Unit. 75% of the participants have mental health issues such as anxiety, sleeping difficulty and depression. A higher proportion of females (45%) reported mental health issues than males (29%), confirming previous studies that found males were less likely to communicate mental health issues. Those in management roles had a considerably lower proportion of mental health issues (17%), than those in technical roles (36%) and those in supporting roles (43%). This agrees with the findings in the literature that the lowest income group have the highest percentage of mental issues. 48% of the participants have physical health issues such as muscular tension and headaches. These are common problems for office workers and result in lower productivity, and financial loss to the employer. Workplace interventions such as providing ergonomic workstations, promoting neck and back exercises, providing access to physiotherapy and counselling services have been shown to increase productivity [6, 31].

Most of the participants agreed that the organization provided adequate health & safety and wellbeing support. Participants in management roles were completely satisfied, while those in technical roles and supporting roles were less satisfied, possibly indicating unequal access to support. Improving the organization's policy on wellness was the main recommendation. This was followed by recommendations for increased salary, decreased workload, better office equipment and more flexible working hours. All of these have been found to improve employee productivity [2, 3, 16]. Interestingly, almost all the female participants (93%) provided suggestions for improving health & safety and wellbeing support, compared with just 71% of the males, which may be another indication that males are less willing to ask for support.

A limitation of the study is the small number of participants and the single case study organization. In addition, only 10% of the participants had management roles, so the findings are likely to be skewed towards the opinions from those in the technical and supporting roles.

## 5 Conclusion

This research contributes information on the health & safety and wellbeing of building professionals working in management, technical and supporting roles at the Christchurch City Council Building Consent Unit. It shows that although most of the participants felt that the existing wellbeing support was adequate, three quarters experienced work-related stress and almost half had physical health issues from sitting for long periods. The findings may be useful to both employers and employees. Employers should consider improving the wellbeing support by providing counselling, physiotherapy, flexible working hours, ergonomic workstations and additional resources to lessen workloads. They should have a clear health & safety and wellbeing policy and ensure that all employees know how to access support. Building professionals should improve their awareness of wellbeing issues and use strategies such as talking through problems, seeking help, taking breaks and exercising. Male employees, in particular, need to understand the importance of using the organization's wellbeing support systems. The financial cost of providing additional wellbeing support is likely to be offset by the increased productivity from employees who have better mental and physical health. Finally, the government should consider revising the current Health and Safety at Work Act to address mental and physical issues, with standards on healthier office working environments and on mental health policy.

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## References

1. Auckland Council (2022) Summary annual report 2021/2022, pp 1–33. Retrieved from Summary of the Auckland Council Group Annual Report 2020/2021 on June 16, 2023
2. Badul S, Subban M (2022) Employee health and wellness programmes: Critical considerations for supervisors. Administratio Publica 30(1):116–140
3. Bjärntoft S, Hallman DM, Mathiassen SE, Larsson J, Jahncke H (2020) Occupational and individual determinants of work-life balance among office workers with flexible work arrangements. Int J Environ Res Public Health 17(4):1418–1433

4. Boshoff D, Krugell C, van Heerden H (2017) Characteristics of the safety climate in teams with world-class safety performance on construction projects in South Africa. Acta Structilia 24(1):99–127. https://doi.org/10.18820/24150487/as24i1.5
5. Chauntry AJ, Bishop NC, Hamer M, Kingsnorth AP, Chen Y-L, Paine NJ (2022) Sedentary behaviour is associated with heightened cardiovascular, inflammatory and cortisol reactivity to acute psychological stress. Psychoneuroendocrinol 141(105756):1–11
6. Chen ZC (2022) What health and safety and wellbeing issues currently confront professionals working in the building industry that undertake roles in certifying projects. Thesis for the degree of Master of Construction in Construction Law, School of Built Environment, Massey University, New Zealand, 1–52
7. Christchurch City Council Annual report (2023) ISBN: 978-1-99-101702-4, 1–304. Retrieved from 2022-Annual-Report.pdf (ccc.govt.nz) on June 9, 2023
8. Employment New Zealand (2023). Health and safety at work. Retrieved from https://www.employment.govt.nz/workplace-policies/health-and-safety-at-work/# on June 9, 2023
9. Faghy MA, Duncan MJ, Pringle A, Meharry JB, Roscoe CMP (2022) UK university staff experience high levels of sedentary behaviour during work and leisure time. Int J Occup Saf Ergon 28(2):1104–1111
10. Gardiner K, Rees D, Adisesh A, Zalk D, Harrington JM (2022) Occupational health—pocket consultant, 6th edn. John Wiley and Sons, pp 1–480. ISBN 1119718619
11. George S, Al Saffar EM, Almohammedsaleh Z (2021) The impact of occupational stress and burnout among employees of different age groups on job satisfaction: evidence from Saudi Arabia and Bahrain. In: International Conference on Sustainable Islamic Business and Finance, IEEE, pp 159–162
12. van Heerden A, Jelodar MB, Chawynski G, Ellison S (2023) A study of the soft skills possessed and required in the construction sector. Buildings 13(2):522. https://doi.org/10.3390/buildings13020522
13. van Heerden AH, Chawynski G, Bartolo-Doblas J (2021) Building resilience among construction professionals in New Zealand: a study of major stressors and stress reduction strategies. Int J Const Supply Chain Manage 11(2):107–120
14. HSAW (2021) Health and safety at work Act 2015 No. 70 (2021), Public Act 3 purpose—New Zealand legislation. Retrieved from https://www.legislation.govt.nz/act/public/2015/0070/latest/DLM5976667.html on June 9, 2023
15. ILO/WHO Committee on Occupational Health (1953) Joint ILO/WHO committee on occupational health: second report of a meeting held in Geneva from 6 to 12 October 1952, pp 1–32. Retrieved from https://apps.who.int/iris/handle/10665/40212 on June 9, 2023
16. Jelodar MB, van Heerden A, Chawynski G (2020) An interdisciplinary perspective of conflict and relationships in construction procurement and logistics. Int J Const Supply Chain Manage 10(1):30–45
17. Kamaluddin I, Elmi F, Rimawan E (2021) The influence of occupational health, occupational safety, and job stress, on work productivity of air traffic controllers at AirNav Indonesia (case study of JATSC branch) Surabaya Branch, Sentani Branch). Rev Int Geograp Educ Online 11(7):1000–1009
18. Karthick S, Kermanshachi S, Ramaji I (2022) Health and safety of construction field workforce active in extreme weather conditions. In: Proceedings of the Construction Research Congress 2022, Virginia, USA, pp 737–747
19. Kett AR, Sichting F (2020) Sedentary behaviour at work increases muscle stiffness of the back: why roller massage has potential as an active break intervention. Appl Ergon 82(102947):1–6
20. Leitzmann MF, Jochem C, Schmid D (2018) Sedentary behaviour epidemiology. Springer, Switzerland. ISBN 9783319615523
21. Leung M-Y, Liang Q, Olomolaiye P (2016) Impact of job stressors and stress on the safety behavior and accidents of construction workers. J Manag Eng 32(1):1–10
22. Li T (2022) The impact of advertising exposure on the gendered perceptions of men with mental health concerns. J Consum Mark 39(6):610–620

23. Ma Y, Wang Y-J, Chen B-R, Shi H-J, Wang H, Khurwolah MR, Li Y-F, Xie Z-Y, Yang Y, Wang L-S (2017) Study on association of working hours and occupational physical activity with the occurrence of coronary heart disease in a Chinese population. PLoS ONE 12(10):1–14
24. Maartje CBR, Roosmarijn MCS, Irene LDH, Noortje MW, Paulien MB (2020) Decreasing employees' work stress by a participatory, organisational level work stress prevention approach: a multiple-case study in primary education. BMC Public Heal 20(1):1–16
25. Mackett RL (2022) Gender, mental health and travel. Transportation 49(6):1891–1920
26. Maphong R, Nakhonket K, Sukhonthasab S (2022) The effectiveness of two levels of active office interventions to reduce sedentary behavior in office workers: a mixed-method approach. Arch Environ Occup Health 77(6):504–513
27. Marcatto F, Colautti L, Larese Filon F, Luis O, Di Blas L, Cavallero C, Ferrante D (2016) Work-related stress risk factors and health outcomes in public sector employees. Saf Sci 89:274–278
28. Marques A, Peralta M, Gouveia ÉR, Martins J, Sarmento H, Gomez-Baya D (2020) Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status. Eur J Sport Sci 20(9):1268–1276
29. Nasios G (2021) Occupational health and safety: challenges and prospects in the Greek public sector. J Public Admin, Fin & Law 22:56–72
30. Pachito DV, Pega F, Bakusic J, Boonen E, Clays E, Descatha A, Delvaux E, De Bacquer D, Koskenvuo K, Kröger H, Lambrechts M-C, Latorraca COC, Li J, Martimbianco C, Riera AL, Rugulies R, Sembajwe R, Siegrist G, Sillanmäki J, Sumanen L, Suominen M, Ujita S, Vandersmissen Y, Godderis L (2021) The effect of exposure to long working hours on alcohol consumption, risky drinking and alcohol use disorder: a systematic review and meta-analysis from the WHO/ILO joint estimates of the work-related burden of disease and injury. Environ Int 146:106205
31. Pereira M, Comans T, Sjøgaard G, Straker L, Melloh M, O'Leary S, Chen X, Johnston V (2019) The impact of workplace ergonomics and neck-specific exercise versus ergonomics and health promotion interventions on office worker productivity: a cluster-randomized trial. Scand J Work Environ Health 45(1):42–52
32. Prince SA, Rasmussen CL, Biswas A, Holtermann A, Aulakh T, Merucci K, Coenen P (2021) The effect of leisure time physical activity and sedentary behaviour on the health of workers with different occupational physical activity demands: a systematic review. Int J Behav Nutr Phys Act 18(1):1–17
33. Qiu D, Li Y, Li R, He J, Ouyang F, Luo D, Xiao S (2022) Long working hours, work-related stressors and sleep disturbances among Chinese government employees: a large population-based follow-up study. Sleep Med 96:79–86
34. Rollo S, Prapavessis H (2021) A combined health action process approach and mHealth intervention to reduce workplace sitting time in office-working adults: a secondary analysis examining health-related quality of life and work performance outcomes. Psychol Health 36(10):1200–1216
35. Sakellaris IA, Saraga DE, Dimitroulopoulou S, Bartzis JG, Mandin C, Roda C, Bluyssen PM, Fossati S, Carrer P, De Kluizenaar Y, Mihucz VG, Szigeti T, Hänninen O, De Oliveira Fernandes E (2016) Perceived indoor environment and occupants' comfort in European "Modern" office buildings: The OFFICAIR Study. Int J Environ Res Public Health 13(5):444–459
36. Saunders M, Lewis P, Thornhill A (2009) Research methods for business students. Pearson, New York
37. Schönfeld P, Brailovskaia J, Margraf J (2017) Positive and negative mental health across the lifespan: a cross-cultural comparison. Int J Clin Heal Psychol 17(3):197–206
38. Schwepker CH Jr, Valentine SR, Giacalone RA, Promislo M (2021) Good barrels yield healthy apples: Organisational ethics as a mechanism for mitigating work-related stress and promoting employee well-Being. J Bus Ethics 174(1):143–159
39. Smeltzer LR (1987) The relationship of communication to work stress. J Bus Commun 24(2):47–58
40. Stats NZ (2022). Injury statistics—work-related claims: 2021, Statistics New Zealand. ISSN 1179-125X. Retrieved from Injury statistics–work-related claims: 2021 | Stats NZ on June 16, 2023

41. Thomson RM, Igelström E, Purba AK, Shimonovich M, Thomson H, McCartney G, Reeves A, Leyland A, Pearce A, Katikireddi SV (2022) How do income changes impact on mental health and wellbeing for working-age adults? a systematic review and meta-analysis. The Lancet. Public heal 7(6):e515–e528
42. Vandelanotte C, Short C, Rockloff M, Di Millia L, Ronan K, Happell B, Duncan MJ (2015) How do different occupational factors influence total, occupational, and leisure-time physical activity? J Phys Act Health 12(2):200–207
43. Wang W, Li Y, Sakata K, Komiya A (2020) What makes employees' work so stressful? effects of vertical leadership and horizontal management on employees' stress. Front Psychol 11(340):1–12
44. Wellington City Council (2022) Annual report 2020/2021, 1–174. Retrieved from Annual Report 2020/2021—Volume 1 (wellington.govt.nz) on June 16, 2023
45. WHO (2019). World Health Organisation, September 17. Occupational health. Retrieved from https://www.who.int/health-topics/occupational-health on June 9,2023
46. Zhang Y, Xue P, Zhou L, Wei F, Fang X, Zou H (2022) Research progress on health effects associated with exposure to long working hours. J Environ Occup Med 39(8):937–941

# Assessing Health and Safety Practices in the Nigerian Construction Industry in the Era of the Fourth Industrial Revolution: Issues and Challenges

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## 1 Introduction

The construction industry plays a vital role in an economy's economic growth and gross domestic product (GDP) in terms of its contribution [56, 57]. The construction industry is viewed to be prone to accidents. The study of Zhou et al. [61] showed that Health and Safety practices in the construction industry reiterate the negative H&S achievement on construction sites as a global phenomenon. It has been noted that negative H&S practices among employees significantly contribute to the failure of H&S performances related to construction research [13, 24, 45]. Sánchez et al. [56] stated that the number of accidents in the construction industry is unacceptable, which results in poor H&S practices on employees, organisations, society, and nations. Safety management primarily focuses on non-site safety-related procedures, roles, and responsibilities [30]. The Council for Scientific and Industrial Research (CSIR) [59] noted that the rapid development and convergence of emerging technologies is what is driving the Fourth Industrial Revolution (4IR), also known as Industry 4.0. The World economic forum (WEF) [60] argues that businesses will increase productivity, streamline projects and procedure management, improve quality, and improve H&S by implementing innovations like 3D printing and scanning, advanced building materials, augmented reality, autonomous equipment, and drones.

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In South Africa, the most recent legislative Acts pertaining to H&S practices in the construction industry include the Regulations and Amendments Act, No. 181 of the 1993 Labour Relations Act (2003), and the amended Health and Safety Act (2010) introduced by the Department of Labour. The primary objective of these Acts is to establish an advisory council on occupational H&S and protect individuals from H&S hazards arising from workplace activities (Department of Labour, amended Health and Safety Act 2010). However, it has been consistently observed that H&S practices performance in the construction industry remains inadequate [38]. The industry struggles with the insufficient implementation of H&S measures and a consistent failure to apply appropriate H&S controls [32]. Like many other countries, South Africa is also impacted by the global issue of poor H&S standards [37].

Consequently, it is crucial to prioritize H&S practices in the Nigeria construction industry more than ever. Harnessing technologies from the fourth industrial revolution (4IR) can aid in managing H&S in construction [12]. These technologies can be employed early in projects to facilitate safety management, identify potential risks and hazards, and provide real-time monitoring of people and vehicle movement on construction sites [12, 42]. They can also help detect hazardous zones resulting from ongoing activities and issue alerts when individuals enter these zones.

Despite the evident significance of the construction industry, the adoption of technological advancements in building environments in developing countries has been minimal [41]. Gaspar et al. [22] indicated that this reluctance may be attributed to job security concerns. The risk of job losses in the construction industry is also acknowledged [11]. Moreover, illiteracy and limited wireless Internet connectivity have been identified as factors that reduce the likelihood of embracing these technologies. However, it is recognised that individuals with the requisite expertise and skills will be better equipped to adapt to the changing landscape [11]. According to Meltzer [34], the country experiences an alarming rate of over 100 yearly fatalities. This can be attributed to the absence of an integrated digital tool that effectively identifies safety hazards. Currently, construction sites rely on conventional 2D/3D drawings, manual data entry, and standardised H&S plans replicated across projects [34]. In a study by Johansen and Walter [26] conducted in the United Kingdom, lean methods were described as a systematic approach involving the application of various tools and techniques at different stages of construction projects within the industry.

However, in the context of assessing H&S practices in the Nigerian construction industry in the Era of the fourth industrial revolution, it is crucial to acknowledge the challenges posed by the illiteracy of many workers, particularly in developing countries. This illiteracy hinders effective communication regarding H&S matters and prioritises wages over other aspects of employment conditions. Hence, the focus on H&S issues becomes secondary for illiterate workers [27]. This situation has further contributed to the construction industry's negative reputation in terms of its poor H&S record, as the employment of unskilled labour has been a common practice. Cooper and Cotton [15] argue that the lack of skills and education among construction operatives is a significant factor contributing to accidents on construction sites.

Moreover, inadequate training on H&S matters exacerbates the problem [20]. In the light of these challenges, Darko and Lowe [16] and Frimpong et al. [19] advocate for implementing training programmes targeting construction artisans in Ghana. Such initiatives would equip them with the necessary skills for enhancing efficiency and safety performance at construction sites.

These issues and challenges, as highlighted in Table 1, have deprived H&S professionals within the developing countries in the construction industry of meeting the demand for H&S practices in project flow, budgeting execution, and delivery of the project [7, 44, 46]. This study considers issues and challenges faced in the construction industry in the Era of 4IR as they affect the construction operation and process in developing countries using the Nigerian construction industry as a case study.

**Table 1** Issues and challenges facing H&S practices in the era of the 4IR

| S.no. | Issues and challenges facing health and safety practices in the Era of the 4IR | Authors |
|---|---|---|
| 1 | A working at high elevation | [23, 58] |
| 2 | Manual handling of objects | [23, 28] |
| 3 | Lack of implementation of safety regulations | [23, 28, 58] |
| 4 | Lack of implementation of regulations and amendments to safety laws | [11, 17, 52] |
| 5 | Inadequate H&S controls | [6, 39] |
| 6 | lack of skilled workers in the use of technologies | [2, 10, 11] |
| 7 | Risk of job losses due to digitalisation | [22, 35] |
| 8 | Lack of literacy workers | [11, 31, 36] |
| 9 | Lack of wireless internet connectivity | [21, 40] |
| 10 | High cost of digital tools | [35, 57] |
| 11 | Fear of job losses | [43, 57] |
| 12 | Unavailability of digital tools specialists | [43, 57] |
| 13 | Lack of adequate information on digitalisation | [8] |
| 14 | Lack of adequate knowledge on digitalisation | [8, 34] |
| 15 | Inadequate infrastructure | [8, 53] |
| 16 | Lack of education on digitalisation | [1, 18] |
| 17 | Poor safety culture | [9, 47] |
| 18 | Size of projects | [4, 18, 25] |
| 19 | Insufficient electricity | [55] |
| 20 | High costs of construction materials | [25, 43, 53] |
| 21 | High-interest rates | [7, 44] |
| 22 | Lack of access to wireless broadband | [3, 25, 29] |
| 23 | Lack of productivity | [48, 51] |
| 24 | Skilled labour shortages | [46, 49] |

## 2 Methodology

This research was conducted within the confines of Lagos state, Nigeria, focusing on construction professionals engaged in projects within the construction industry. The selection of respondents was based on their active involvement and expertise in the Health and Safety (H&S) processes within construction projects. Lagos state was specifically chosen due to its abundance of ongoing construction endeavours, encompassing both government and private projects, each having established H&S units in their construction processes. Employing the systematic random sampling method, we distributed 100 questionnaires to the respondents, successfully retrieving 87 of them. The choice of this sampling method was driven by its simplicity, directness, and the elimination of clustering concerns compared to the cluster method [54]. Additionally, it ensures an even coverage of all elements [44]. The questionnaire, structured on a 5-point Likert scale, achieved an 87% response rate, with responses ranging from Strongly Disagreeing = 1, Disagreeing = 2, Neutral = 3, Agreeing = 4, to Strongly Agree = 5. Prior to analysis, the collected data underwent thorough screening and cleaning. The respondents were queried about their gender, years of experience, profession, and the specific mode of operations they were engaged in within the construction industry. Furthermore, the questionnaire delved into twenty-four issues and challenges related to H&S practices in the construction industry during the Fourth Industrial Revolution, as identified in the literature.

The research also performed a descriptive analysis, encompassing percentage, frequency, mean item score (MIS), and standard deviation. Utilising the mean item score (MIS) for descriptive analysis, the Likert scale responses in the research questionnaire were examined. Following computation, the issues and challenges related to Health and Safety (H&S) practices were arranged in descending order based on their mean item score (MIS). The computation of MIS involved weighing the responses from survey participants for each question and aligning them with collectively agreed-upon scores by respondents, serving as indicators of comparative significance. This approach facilitated the evaluation of issues and challenges impacting H&S practices in the context of the Fourth Industrial Revolution (4IR) in the construction industry. The study employed descriptive statistical tools, particularly MIS, to analyse participant ratings for various questions in the survey questionnaire. As highlighted by Pallant [50], means play a crucial role in descriptive research by indicating the average scores of participants on a given measure. The standard deviation, another descriptive statistic, elucidates the spread of numbers around the mean [50]. The descriptive analysis encompassed percentage, frequency, and standard deviation.

## 3 Results

Table 2 presents the details of the respondents involved in the survey. The details include their years of experience, profession, and type of construction projects.

**Table 2** Analysis of demographic variables

| Variable | Characteristics | Frequency | Percentage (%) |
|---|---|---|---|
| Years of experience | 1–2 | 7 | 7.5 |
| | 3–5 | 20 | 22.5 |
| | 6–10 | 18 | 20.9 |
| | 11–15 | 19 | 21.9 |
| | 16–20 | 14 | 17.6 |
| | 21–25 | 6 | 6.4 |
| | Above 25 years | 3 | 3.2 |
| | Total | 87 | 100 |
| Profession | Quantity surveyor | 14 | 16.6 |
| | Mechanical engineer | 2 | 2.7 |
| | Architects | 13 | 15.5 |
| | Civil engineers | 20 | 22.5 |
| | Builders | 21 | 24.1 |
| | Construction managers | 8 | 9.6 |
| | Electrical engineers | 5 | 4.8 |
| | Town Planners | 4 | 4.3 |
| | Total | 87 | 100 |
| Type of construction projects | Contracting firms | 46 | 52.9 |
| | Consulting firms | 12 | 13.9 |
| | Government ministries | 21 | 25.1 |
| | Professional institutions | 8 | 8.6 |
| | Total | 87 | 100 |

The respondents' years of experience in H&S practices within the construction industry. The result illustrates that 7.5% (7) of the respondents have 1–2 years of experience in construction operations. 22.5% (20) of the respondents have 3–5 years of experience, while 20.9% (18) have 6–10 years of working experience in the construction industry. Similarly, 21.9% (19) have between 11–15 years of working experience. This is followed by 17.6% (15) with 16–20 years of working experience in the construction industry. The results also revealed that only 6.4% (6) have 21–25 years of working experience, while only 3.2% (3) have over 25 years of working experience in the construction industry. As shown in Table 2, 16.6% (14) of the respondents are Quantity Surveyors, 2.7% (2) of the respondents are Mechanical Engineers, 15.5% (13) are Architects, 22.5% (20) are Civil Engineers, 24.1% (21) are Builders, 9.6% (8) are Construction Managers, 4.8% (5) are Electrical Engineers, and 4.3% (4) are Town Planners. The type of construction projects where respondents carried out their H&S practices within the construction industry. The outcomes revealed that 52.9% (46) of the respondents are contracting firms, 13.9% (12) are consulting firms, 25.1% (21) are government ministries, and 8.6% (8) are professional institutions.

Table 3 illustrates the respondent ranking of issues and challenges facing the construction industry in adopting H&S practices in the Nigerian construction industry in the Era of the 4IR. The outcomes show the top and low-ranked issues and challenges facing the construction industry in adopting H&S practices in the Nigerian construction industry in the Era of the 4IR using the mean score ($\overline{x}$) and standard deviation ($\sigma X$) within the construction industry and they include; working at high elevation ranked first with the $\overline{x} = 4.11$; $\sigma X = 0.799$, ranked second was the size of the project $\overline{x} = 4.09$; $\sigma X = 0.894$, while the risk of job losses due to digitalisation was ranked third with the $\overline{x} = 4.06$; $\sigma X = 0.896$. The lack of implementation of safety regulations was ranked fourth with $\overline{x} = 3.99$; $\sigma X = 0.907$, while constant amendments to safety laws with the $\overline{x} = 3.98$; $\sigma X = 0.907$, and lack of skills in the use of technologies with $\overline{x} = 3.98$; $\sigma X = 0.898$ were ranked fifth. Ranked seventh was manual handling of objects with $\overline{x} = 3.9$; $\sigma X = 0.845$, inadequate infrastructure with $\overline{x} = 3.98$; $\sigma X = 0.829$, and unavailability of digital tools specialists with $\overline{x} = 3.98$; $\sigma X = 0.827$. Inadequate H&S controls with $\overline{x} = 3.93$; $\sigma X = 0.769$ and high costs of construction materials with $\overline{x} = 3.93$; $\sigma X = 0.877$ were ranked tenth. The three factors ranked twelfth are lack of literacy workers with $\overline{x} = 3.89$; $\sigma X = 0.898$, poor safety culture with $\overline{x} = 3.89$; $\sigma X = 0.898$ and lack of education on digitalisation with $\overline{x} = 3.89$; $\sigma X = 0.789$. While high-interest rates was ranked fifteen with $\overline{x} = 3.88$; $\sigma X = 0.868$, lack of access to wireless broadband was ranked sixteenth with $\overline{x} = 3.75$; $\sigma X = 1.806$, lack of wireless internet connectivity was ranked seventeenth with $\overline{x} = 3.66$; $\sigma X = 1.053$. In addition, ranked eighteenth and nineteenth are insufficient electricity with $\overline{x} = 3.64$; $\sigma X = 1.120$, lack of productivity with $\overline{x} = 3.64$; $\sigma X = 1.139$. while the high cost of digital tools with $\overline{x} = 3.57$; $\sigma X = 1.062$ and lack of adequate knowledge of digitalisation with $\overline{x} = 3.57$; $\sigma X = 1.026$ ranked twentieth; twenty second ranked was lack of adequate information on digitalisation with $\overline{x} = 3.57$; $\sigma X = 1.155$, skilled labour shortages ranked twenty third with $\overline{x} = 3.48$; $\sigma X = 1.059$, and fear of job losses ranked lastly with $\overline{x} = 3.43$; $\sigma X = 1.062$.

## 4 Discussion of Findings

The study assessed the issues and challenges in H&S practices in the construction industry in the Era of 4IR using the Nigerian construction industry. The result of the study indicated manual handling of objects, inadequate H&S controls, risk of job losses due to digitalisation, lack of literacy workers, working at high elevation, lack of skills in the use of technologies, constant amendments to safety laws, and lack of implementation of safety regulations are issues and challenges facing the H&S practices in the Era of the 4IR. The findings align with the submission of Greguric [23], who identified the following H&S challenges working at high elevation and manual handling of objects, an occurrence of slips. In addition, Pringle and Frost [52], Dorji and Hadikusumo [17], and Birkel et al. [11] noted that the implementation of H&S digitalisation practice requires enabling regulations and laws.

**Table 3** Ranking of issues and challenges facing the construction industry in adopting health and safety practices in the Nigerian construction industry in the Era of the 4IR by respondents

| Issues and challenges facing the construction industry in adopting health and safety practices | $\overline{x}$ | $\sigma X$ | $R$ |
|---|---|---|---|
| Working at high elevation | 4.11 | 0.799 | 1 |
| Risk of job losses due to digitalisation | 4.06 | 0.896 | 2 |
| Size of the project | 4.09 | 0.894 | 3 |
| Lack of implementation of safety regulations | 3.99 | 0.907 | 4 |
| Constant amendments to safety laws | 3.98 | 0.898 | 5 |
| Lack of skills in the use of technologies | 3.98 | 0.842 | 5 |
| Manual handling of objects | 3.97 | 0.845 | 7 |
| Inadequate infrastructure | 3.97 | 0.829 | 7 |
| Unavailability of digital tools specialists | 3.97 | 0.927 | 7 |
| Inadequate health and safety controls | 3.93 | 0.769 | 10 |
| High costs of construction materials | 3.93 | 0.877 | 10 |
| Lack of literacy workers | 3.89 | 0.898 | 12 |
| Poor safety culture | 3.89 | 0.898 | 12 |
| Lack of education on digitalisation | 3.89 | 0.789 | 12 |
| High-interest rates | 3.88 | 0.868 | 15 |
| Lack of access to wireless broadband | 3.75 | 1.086 | 16 |
| Lack of wireless internet connectivity | 3.66 | 1.053 | 17 |
| Insufficient electricity | 3.64 | 1.120 | 18 |
| Lack of productivity | 3.59 | 1.139 | 19 |
| High cost of digital tools | 3.57 | 1.062 | 20 |
| Lack of adequate knowledge of digitalisation | 3.57 | 1.026 | 20 |
| Lack of adequate information on digitalisation | 3.56 | 1.155 | 22 |
| Skilled labour shortages | 3.48 | 1.059 | 23 |
| Fear of job losses | 3.43 | 1.062 | 24 |

Mean of the values = $\overline{x}$; standard deviation (SD) = $\sigma X$; Rank = $R$

The findings also showed that the high cost of digital tools, fear of job losses, lack of wireless Internet connectivity, and lack of adequate information on digitalisation are issues and challenges facing the H&S practices in the Era of the 4IR. The findings align with opinions that the risk of loss of jobs due to the digitalisation of H&S practices [11, 22, 35]. In the same vein, Birkel et al. [11], Gamil et al. [21], and Newman et al. [40] attributed the challenges of H&S digitalisation to a lack of wireless internet connectivity. Employees' lack of literacy also affects the H&S digitalisation practices [11, 31, 36].

The findings also showed that issues and challenges facing the H&S practices in the Era of the 4IR are lack of access to wireless broadband, lack of productivity, skilled labour shortages, insufficient electricity, and lack of adequate knowledge of digitalisation. This aligns with the assertion that mismatches between available skills and required skills affect H&S digitalisation [4, 5, 14, 33]. Hence, H&S practices digitalisation require upgrading employees' technical skills to use digitalisation tools in managing H&S in the Nigerian construction industry.

The findings indicated that the unavailability of digital tools specialists, the size of the project, and the lack of education on digitalisation are issues and challenges facing the H&S practices in the Era of the 4IR. Meno [35] attributed the challenges of digitalisation to a lack of adequate skills, unavailability of training capabilities, prefer traditional methods, and unavailability of funds from a client. Furthermore, the findings indicated that poor safety culture, high-interest rates, inadequate infrastructure, and high costs of construction materials are issues and challenges facing the H&S practices in the Era of the 4IR. According to Meno [35], the high cost of digital tools, fear of job losses, lack of cost to adopt, lack of adequate skills, and unavailability of training capabilities affect digitalisation. Similarly, Aghimien et al. [3] added that the unravelling risk of construction digitalisation is due to fear of change, unavailability of financial resources, unskilled technical support, lack of innovation, and client insistence.

The study findings imply that providing useful information on the issues and challenges facing the H&S practices in the Era of the 4IR in the Nigerian construction industry. The paradigm shifts in the construction H&S practices of the Era of the fourth industrial revolution brought about changes in the traditional practices of H&S. These changes require construction organisations to acquire knowledge to overcome the high cost of digital tools, fear of job losses, lack of wireless internet connectivity, lack of adequate information on digitalisation, lack of access to wireless broadband, lack of productivity, skilled labour shortages, insufficient electricity and lack of adequate knowledge of digitalisation and enabling H&S digitalisation laws and regulations lack of implementation of safety regulations.

## 5 Conclusion and Recommendation

The study assessed the issues and challenges facing implementing H&S practices in the Nigerian construction industry in the Era of the 4IR. The study identified twenty-four factors that can affect H&S practices in the Nigerian construction industry in the Era of the 4IR. Hence, the descriptive analysis ranked ten of the H&S challenges, including working at high elevation, the size of the project, the risk of job losses due to digitalisation, lack of implementation of safety regulations, constant amendments to safety laws, lack of skills in the use of technologies, manual handling of objects inadequate infrastructure and unavailability of digital tools specialists, poor H&S controls, and high costs of construction materials. The study conducted among construction professionals in Lagos State, Nigeria, revealed that the majority of respondents were males with varying years of experience in H&S practices. The most common professions among the respondents were civil engineers and builders, and they were primarily involved in contracting firms and government ministries.

The analysis of respondents' rankings indicated that working at high elevations, the size of projects, and the risk of job losses due to digitalisation were the top three issues and challenges facing the construction industry in adopting H&S practices in the Era of 4IR.

In conclusion, 4IR is a digital tool in modern construction practices in developed and developing countries. However, the outlined challenges are major factors deterring the employment of 4IR tools in H&S practices in the Nigerian construction industry in the ERA of 4IR. Health and safety practices in the Nigerian construction industry in the era of 4IR can be achieved through comprehensive training programmes, addressing infrastructure and communication challenges, and creating awareness about the benefits and opportunities offered by emerging technologies. By prioritising H&S and embracing technological advancements, the construction industry can enhance safety performance, mitigate risks, and promote sustainable development in developing countries like Nigeria.

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## References

1. Adewuyi TO, Odesola IA (2015) Factors affecting material waste on construction sites in Nigeria. J Eng Technol (JET) 6(1):82–99
2. Afolabi A, Amusan L, Owolabi D, Ojelabi R, Joshua O, Tunji-Olayeni P (2018) Assessment of the linkages and leakages in a cloud-based computing collaboration among construction stakeholders. In: Construction research congress 2018, pp 673–683
3. Aghimien D, Aigbavboa C, Meno T, Ikuabe M (2021) Unravelling the risks of construction digitalisation in developing countries. Constr Innov 21(3):456–475
4. Ahn CR, Lee S, Sun C, Jebelli H, Yang K, Choi B (2020) Wearable sensing technology applications in construction safety and health. J Constr Eng Manag 11:03119007
5. Akinradewo O, Aigbavboa C, Aghimien D, Oke A, Ogunbayo B (2023) Modular method of construction in developing countries: the underlying challenges. Int J Constr Manag 23(8):1344–1354
6. Alhajeri M (2011) Health and safety in the construction industry: challenges and solutions in the UAE (Doctoral dissertation, Coventry University)
7. Anyanwu CI (2013) Project cost control in the Nigerian construction industry. Int J Eng Sci Invention 2(12):65–71
8. Bashir AM, Suresh S, Proverbs DG, Gameson R (2010) Barriers towards the sustainable implementation of lean construction in the United Kingdom construction organisations. In: ARCOM doctoral workshop, vol 1
9. Belel ZA, Mahmud H (2012) Safety culture of Nigerian construction workers–A case study of Yola. Int J Sci Eng Res 3(9):1–5
10. Bilau AA, Witt E, Lill I (2015) A framework for managing post-disaster housing reconstruction. Procedia Econ Finan 21:313–320
11. Birkel HS, Veile JW, Müller JM, Hartmann E, Voigt KI (2019) Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. Sustainability 11(2):384

12. Choi M, Ahn S, Seo J (2020) VR-Based investigation of forklift operator situation awareness for preventing collision accidents. Accid Anal Prev 136:105404
13. Choudhry RM, Fang D, Ahmed SM (2008) Safety management in construction: best practices in Hong Kong. J Profess Iss Eng Educ Pract 134(1):20–32
14. CIDB (2006) Malaysian construction industry master plan 2006–2015. Kuala Lumpur, CIDB
15. Cooper M, Cotton D (2000) Safety training: a special case? J Eur Ind Train 24:481–490
16. Darko E, Löwe A (2016) Ghana's construction sector and youth employment. Overseas Development Institute, London, UK
17. Dorji K, Hadikusumo BH (2006) Safety management practices in the Bhutanese construction industry. J Constr Developing Countries 11(2):53–75
18. Elinwa AU, Joshua M (2001) Time-overrun factors in Nigerian construction industry. J Constr Eng Manag 127(5):419–425
19. Frimpong BE, Sunindijo RY, Wang C (2020) Towards improving performance of the construction industry in Ghana: a SWOT approach. Civ Eng Dimens 22:37–46
20. Fugar FDK, Ashiboe-Mensah NA, Adinyira E (2013) Human capital theory: Implications for the Ghanaian construction industry development. J Constr Proj Manag Innov 3:464–479
21. Gamil YA, Abdullah M, Abd Rahman I, Asad MM (2020) Internet of things in construction industry revolution 4.0: recent trends and challenges in the Malaysian context. J Eng, Des Technol 18(5):1091–1102
22. Gaspar M, Julião J, Cruz M (2018) Organisational strategies induced by the fourth industrial revolution: workforce awareness and realignment. In: International Conference on Innovation, Engineering and Entrepreneurship. Springer, Cham, pp 330–336
23. Greguric I (ed) (2021) Philosophical issues of human cyborgization and the necessity of prolegomena on cyborg ethics. IGI Global
24. Haslam C, Atkinson S, Brown SS, Haslam RA (2005) Anxiety and depression in the workplace: effects on the individual and organisation (a focus group investigation). J Affect Disord 88(2):209–215
25. Idoro GI (2011) Effect of mechanisation on occupational health and safety performance in the Nigerian construction industry. J Constr Developing Countries 16(2):27–45
26. Johansen E, Walter L (2007) Lean construction: prospects for the German construction industry. Lean Constr J 3(1):19–32
27. Kheni NA (2008) Impact of health and safety management on safety performance of small and medium-sized construction businesses in Ghana. Ph.D. Thesis, Loughborough University, Loughborough, UK
28. Kheni NA, Gibb AG, Dainty AR (2006) The management of construction site health and safety by small and medium-sized construction businesses in developing countries: a Ghana case study. In: Proceedings of the 22nd annual ARCOM conference, pp 295–304
29. Kihuga AG (2018) Project initiation process, monitoring and evaluation team capacity, compliance with legal framework and building projects success: the case of building projects in Roysambu Constituency, Nairobi County, Kenya (Doctoral dissertation, University of Nairobi
30. Kirwan B (1998) Human error identification techniques for risk assessment of high risk systems—part 2: towards a framework approach. Appl Ergon 29(5):299–318
31. Lin C, He D, Kumar N, Choo KKR, Vinel A, Huang X (2018) Security and privacy for the internet of drones: challenges and solutions. IEEE Commun Mag 56(1):64–69
32. Lopes M, Haupt TC, Fester FC (2012) The influence of clients on construction health and safety in South Africa. Occupational Health Southern Africa
33. Mbande C (2010) Overcoming construction constraints through infrastructure delivery. In Proceedings: the Association of Schools of Construction of Southern Africa (ASOCSA), Fifth Built Environment Conference, pp 18–20
34. Meltzer DJ (2013) Preemption and textualism. Mich L Rev 112:1
35. Meno T (2020) An assessment of risk associated with digitalisation in the South African construction industry. University of Johannesburg (South Africa)

36. Menzel NN, Gutierrez AP (2010) Latino worker perceptions of construction risks. Am J Ind Med 53(2):179–187
37. Mitchell D (2018) What is health and safety and what does it mean for me? | Envico®. Envico Ltd.
38. Musonda I (2012) Construction health and safety (H&S) performance improvement—a client-centred model. University of Johannesburg, South Africa
39. Mustapha Z, Aigbavboa CO, Thwala WD (2016) A mini-factor health and safety compliance: a multivariate factorial analysis. J Constr Proj Manage Innov 6(1):1353–1362
40. Newman C, Edwards D, Martek I, Lai J, Thwala WD, Rillie I (2020) Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. In: Smart and sustainable built environment. https://doi.org/10.1108/SASBE-02-2020-0016
41. Ofori G (2019) Construction in developing countries: need for new concepts. J Construct Develop Count 23(2):1–6
42. Ogunbayo BF, Aigbavboa C, Thwala W (2023) A maintenance management framework for municipal buildings in developing economies. Routledge
43. Ogunbayo AE, Sabiu S, Nyaga MM (2023) Evaluation of extraction and enrichment methods for recovery of respiratory RNA viruses in a metagenomics approach. J Virol Methods 314:114677
44. Ogundipe KE, Ajao AM, Ogunbayo BF, Amusan LM (2015) Post consolidation effects of banking sector recapitalization on Nigerian construction industry (Lagos and Ogun state case study). Covenant J Res Built Environment (CJRBE) 3(2):68–80
45. Ogundipe KE, Ogunbayo BF, Ajao AM, Ogundipe ULNA, Tunji-Olayeni PF (2018) Survey datasets on categories of factors militating against safety practices on construction sites. Data Brief 19:2071–2078
46. Okafor CC, Aigbavboa C, Thwala WD (2021) A Delphi approach to evaluating the success factors for the application of smart mobility systems in smart cities: a construction industry perspective. Int J Constr Manag 1–10
47. Olutuase SO (2014) A study of safety management in the Nigerian construction industry
48. Omoraka AE (2022) A principal component analysis of supply chain management skills for the Nigerian construction industry. Int J Constr Manag 22(12):2413–2421
49. Otairu A, Umar AA, Zawawi NAWA, Sodangi M, Hammad DB (2014) Slow adoption of PPPs in developing countries: survey of Nigerian construction professionals. Procedia Eng 77:188–195
50. Pallant J (2020) SPSS survival manual: a step by step guide to data analysis using IBM SPSS. Routledge
51. Peter L, Noury N, Cerny M (2014) A review of methods for non-invasive and continuous blood pressure monitoring: pulse transit time method is promising? Irbm 35(5):271–282
52. Pringle TE, Frost SD (2003) The absence of rigor and the failure of implementation: occupational health and safety in China. Int J Occup Environ Health 9(4):309–319
53. Ramutloa L (2010) Department of Labour Republic of South Africa. Amended Occupational Health and Safety Act
54. Rea LM, Parker RA (2014) Designing and conducting survey research: a comprehensive guide. John Wiley & Sons
55. Ridley J, Channing J (eds) (2008) Safety at work. Routledge
56. Sánchez Mena AA, Martí Parreño J (2017) Drivers and barriers to adopting gamification: teachers' perspectives
57. Smallwood J, Haupt T, Shakantu W (2009) Construction health and safety in South Africa: status and recommendations. In: CIDB report, 1–42
58. Teo Ai Lin E, Theo H, Feng Y (2008) Construction health and safety performance in developing and developed countries: a parallel study in South Africa and Singapore. In: Evolution of and directions in construction safety and health: proceedings of CIB w99 14th Rinker international conference, pp 9–11 March, 2008, Gainesville, Florida, pp 485–499
59. The Council for Scientific and Industrial Research (CSIR) (2018) Industry 4.0 PLM Centre of Technology. CSIR, Pretoria

60. World Economic Forum (WEF) (2016) Shaping the future of construction—a breakthrough in mindset and technology. Prepared in collaboration with the Boston Consulting Group. WEF, Geneva
61. Zhou Z, Irizarry J, Li Q (2013) Applying advanced technology to improve safety management in the construction industry: a literature review. Constr Manag Econ 31(6):606–622

# Assessing Benefits of Monitoring and Evaluation Practices: The Construction Industry Perspective

**Babatunde F. Ogunbayo, Clinton O. Aigbavboa, Molusiwa S. Ramabodu, and Samuel A. Adekunle**

## 1 Introduction

According to Tengan and Aigbavboa [34] and Kusek and Rist [19], M&E is a systematic process designed to progressively gather information to keep stakeholders engaged in projects informed about the evolving dynamics of quality, cost, and efficiency. It helps facilitate organizational learning and aids in managerial decision-making [34]. Locatelli et al. [20] and Seiso et al. [33] define M&S as a clear objective for projects to guide its delivery process. The M&S objectives are also set out in projects for proper production control throughout the project's life. As Kihuha [18] and Ogunbayo et al. [26, 27] noted, M&E is the process of scrutinizing the project's progress to ensure that stakeholders meet construction objectives. Ogunbayo et al. [25] and Adekunle et al. [2] asserted that the M&E procedure simplifies project processes toward executing the construction production process effectively. In their study, Tengan and Aigbavboa [34] advanced that the M&E practices serve as managerial functions to organize project resources effectively with construction projects. The

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practice helps the construction become more efficient by drawing on the lessons of both triumphs and failures and becoming increasingly cost-effective [16, 35].

M&E practices in developing countries construction industry are becoming increasingly more efficient through drawing on lessons learned on project success and failures and making project process more effective [21, 24]. To achieve this, M&E practice should be implemented by stakeholders as early as possible in the processes for a construction project's life cycle [4, 5, 26, 27]. This will help establish responsibilities, display transparency to stakeholders, and integrate information into future project planning [13, 25]. Ahsan and Gunawan [3] asserted that M&E practice is crucial in ensuring the continued retention of benefits achieved by construction projects. Construction project stakeholders have adopted M&E practices as part of the quality assurance process. Through M&E practice, Kanyamuna et al. [17] posits that stakeholders can clarify goals and prepare a realistic outline, clearly articulating the required resources for the construction process.

Studies have shown that using M&E practices to guide the project process has different benefits for the construction industry [17, 26, 27, 35]. The study of Papke-Shields et al. [30] indicated that M&E practices guide projects to be delivered as planned. Implementing M&E practices in construction activities by project stakeholders will reduce construction material wastage [36]. The study of Bohn and Teizer [8] showed that the benefits of including M&E in projects are that it helps eradicate corruption in the construction process and improves communication among stakeholders. Mwangu and Iravo [22] state that using M&E practices for construction activities helps guide projects delivered within budget and successful for the project teams involved. The use of M&S practices in management practices helps eliminate disagreement among stakeholders and creates standard procedures among stakeholders for construction activities [7].

According to Boulmetis and Dutwin [9], M&E gives insights into the relative importance of activities, leading to the successful execution of projects and increasing flexibility and expertise in construction procedures. Newcombe [23] posits that M&S practices in construction activities will benefit the construction industry by providing appropriate steps for implementing procedures and maintaining quality service throughout the life cycle of the projects. Further, Kusek and Risk [19] assert that M&E practices can help the construction industry develop strategic planning for activities within projects. In their study, [11] noted that adopting M&S practices for construction activities will lead to appropriate knowledge creation for professionals within the industry.

Rakodi [31] study establishes that M&S practices ensure that construction projects are projected in the right direction. As shown in Table 1, M&S practices are valuable for improving project efficiency and facilitating strategic decision-making crucial for successfully implementing construction projects, contributing significantly to the construction industry's performance [28]. In spite of the professional's efforts in adopting the M&E practices for the construction process in the construction industry, understanding its benefits among stakeholders needs to be established. Also, fewer studies have established the benefit of M&E practices within the developing economies' construction industry [7, 22, 26, 27, 34]. Hence, this study assesses the

**Table 1** Benefits of monitoring and evaluation practices in the construction industry

| Benefit of M&E | Authors | Countries |
|---|---|---|
| Construction projects delivered as planned | Papke-Shields et al. [30]<br>Ogunbayo et al. [26, 27] | The U.S.A<br>South Africa |
| Reduction of construction material wastage | Valadez and Bamberger [36]<br>van den Burg et al. [37] | The U.S.A<br>The Netherland |
| Eradicate corruption in the construction process | Bohn and Teizer [8]<br>Hira and Busumtwi-Sam [14] | The U.S.A<br>Canada |
| Improved communication among stakeholders | Bohn and Teizer [8] | The U.S.A |
| Construction project delivered within budget | Mwangu and Iravo [22]<br>Hira and Busumtwi-Sam [14] | Kenya<br>Canada |
| Project team achieved success | Mwangu and Iravo [22]<br>Hobson et al. [15] | Kenya<br>The UK |
| Eliminates disagreement among stakeholders | Badom [7]<br>Aydin and Öztürk [6] | Nigeria<br>Turkey |
| Standard view among stakeholders | Badom [7]<br>van den Burg et al. [37] | Nigeria<br>The Netherland |
| Successful execution of projects | Boulmetris and Dutwin [9]<br>Danforth et al. [12] | The U.S.A<br>The U.S.A |
| Increases flexibility and expertise | Boulmetris and Dutwin [9]<br>Abbato [1] | The U.S.A<br>Australia |
| Appropriate steps are implemented | Newcombe [23]<br>Aydin and Öztürk [6] | The U.S.A<br>Turkey |
| Quality service is maintained | Newcombe [23]<br>Ogunbayo et al. [26, 27] | The U.S.A<br>South Africa |
| Strategic planning | Kusek and Rist [19]<br>Hira and Busumtwi-Sam [14] | The U.S.A<br>Canada |
| Knowledge creation | Conard and Hilchey [11]<br>van den Burg et al. [37] | Canada<br>The Netherlands |

*Source* Authors review (2024)

benefits of M&E practices through the perspective of professionals in the South African construction industry.

## 2 Methodology

This study was conducted among professionals working on construction projects within the South African construction industry. The respondents were selected based on their experience and involvement in construction projects' M&E process and procedure. Due to many ongoing construction projects (government and private projects) and with M&E units established within their construction process, the

Mpumalanga province of South Africa was chosen for this study. Fifty questionnaires were administered to the respondents through systematic random sampling, with thirty-six retrieved. The sampling method was used due to the easier elimination of possible clustering when adopted [32] and the possibility of covering all the elements evenly [26, 27]. The questionnaire was designed on a five-point Likert scale using Strongly Disagreeing = 1, Disagreeing = 2, Neutral = 3, Agreeing = 4, and Strongly Agree = 5, and it recorded a 72% response rate. The data collected from respondents were screened and cleaned before the analysis. Respondents were asked about fourteen benefits of M&E practices in projects in the construction industry identified from the literature through the questionnaire.

The study encompassed a descriptive analysis incorporating percentage, frequency, mean item score, and standard deviation measures. This was undertaken to analyze the outcomes of the Likert inquiries within the research questionnaire. After computation, the benefits of M&E practices identified were sorted from the highest to lowest. The computation relied on the weighted responses provided by participants for each question. Further, it was aligned with the scores selected by respondents, communally considered as analytically agreed-upon indicators of comparative significance. This helped this study assess the benefits of M&E practices based on the construction industry perspective. Descriptive statistical tools were used to analyze how respondents ranked (*R*) various items in the survey questionnaire. The study used descriptive statistical tools to analyze the ratings provided by participants for different questions in the survey questionnaire. In descriptive research, means $\bar{x}$ are significant because they reveal average participant scores on a given measure [29]. Bryman [10] elucidates that through a descriptive statistic, standard deviation ($\sigma X$) explains the sample that computes the numbers spread across the mean.

## 3 Results

Figure 1 shows the gender of the respondents. The result shows that 30.56% (11), while 69.44% (25) of respondents are male construction professionals within the study area.

Figure 2 illustrates the years of experience in M&E practices among respondents. The findings indicate that 25% (9) of participants have 0–5 years of experience, 41.67% (15) possess 6–10 years of experience, 19.44% (7) have 11–15 years of experience, and 13.89% (5) of respondents possess more than 16 years of experience in M&E practices within the construction industry.

In Fig. 3, the respondents' professions within the construction industry are depicted. It shows that 22.22% (8) of the participants are civil engineers, 27.78% (10) are construction managers, 19.44% (7) are construction project managers, 25% (9) are quantity surveyors, and 5.56% (2) represent other professions, including an architect and a consultant working within the construction industry.

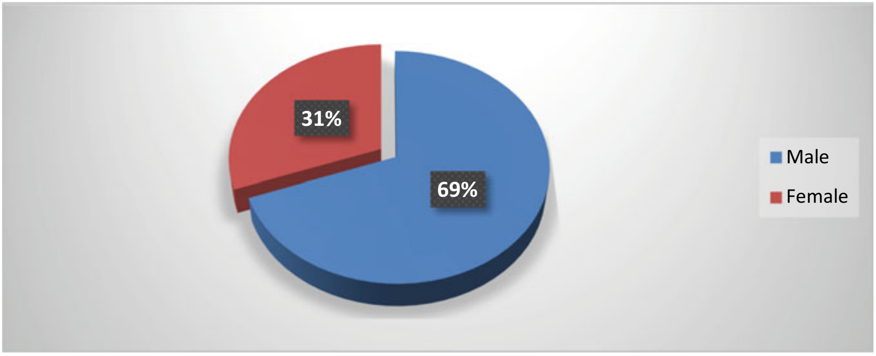


**Fig. 1** Gender of the respondents

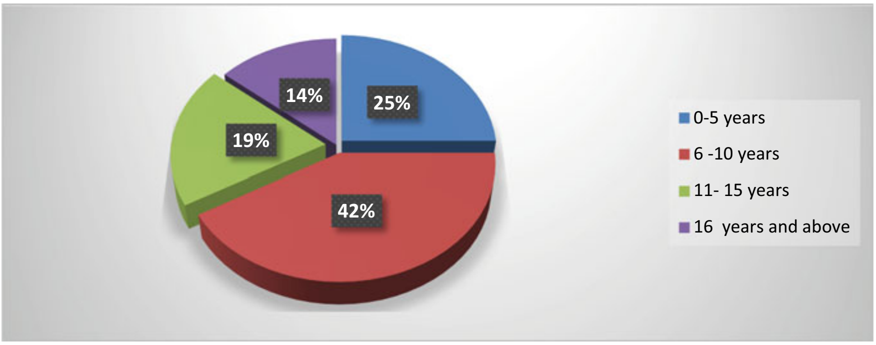


**Fig. 2** Years of experience of respondents in M&E practices

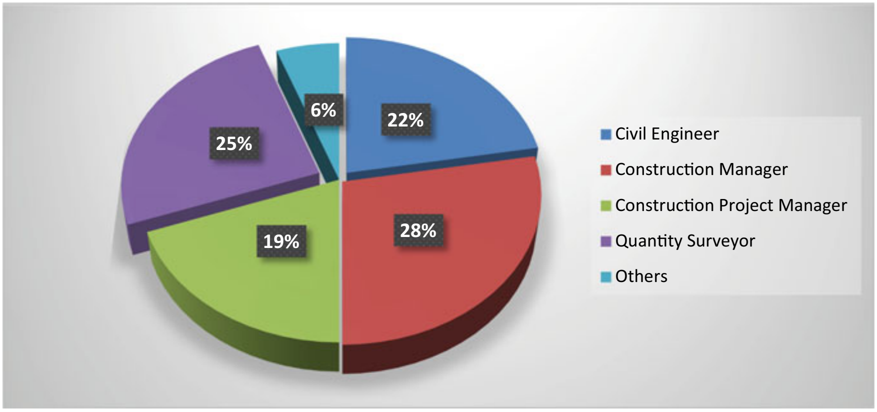


**Fig. 3** Respondents' professions in the construction industry

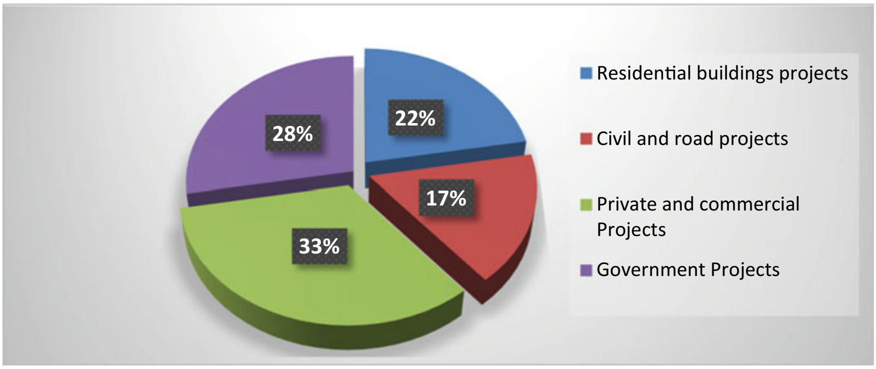


**Fig. 4** Project types' respondents involved in the construction industry

Figure 4 presents the various project types in which respondents are involved within the construction industry. The results revealed that 22.22% (8) of the participants engage in residential building projects, 16.67% (6) are involved in civil and road projects, 33.33% (12) participate in private and commercial construction projects, while 27.78% (10) are associated with government construction projects.

Table 2 illustrates the respondent ranking of the benefits of M&E practices in construction projects. The outcomes show the top and low-ranked benefits of M&E practices within construction project delivery, and they include construction projects delivered as planned was ranked 1st with a $\bar{x}$ of 4.28 and a $\sigma X$ of 0.701; ranked 2nd was the reduction of construction material wastage and eradicate corruption in the construction process with a $\bar{x}$ of 4. 25 and a $\sigma X$ of 0.906, while improved communication among stakeholders and construction project delivered within budget was ranked 4th with a $\bar{x}$ 4.22 and $\sigma X$ of 0.797; project team achieves success was ranked 6th with a $\bar{x}$ of 4.19 and a $\sigma X$ of 0.749; while eliminates disagreement among stakeholders was ranked 7th with a $\bar{x}$ of 4.17 and a $\sigma X$ of 0.910; standard view among stakeholders was ranked 8th with a $\bar{x}$ of 4.14 and a $\sigma X$ of 0.762; while successful execution of projects with a $\bar{x}$ of 4.11 and a $\sigma X$ of 0.820 was ranked 9th; increases flexibility and expertise was also ranked 10th with a $\bar{x}$ of 4.06 and a $\sigma X$ of 0.826. Further, appropriate steps are implemented, ranked 11th with a $\bar{x}$ of 3.89 and a $\sigma X$ of 1.008; quality service is maintained, ranked 12th with a $\bar{x}$ of 3.86 and a $\sigma X$ of 0.931, whereas strategic planning and knowledge creation were also ranked 13th with a $\bar{x}$ of 3.75 and a $\sigma X$ of 1.052

## 4 Discussion of Findings

The study assessed the benefits of M&S practices from the construction industry's perspective. The study result indicated that construction projects delivered as planned, reduction of construction material wastage, eradicate corruption in the

**Table 2** Ranking of benefits of M&E practices by respondents

| s. no. | Benefits of monitoring and evaluation | $\overline{x}$ | $\sigma X$ | $R$ |
|---|---|---|---|---|
| 1 | Construction projects delivered as planned | 4.28 | 0.701 | 1 |
| 2 | Reduction of construction material wastage | 4.25 | 0.906 | 2 |
| 3 | Eradicate corruption in the construction process | 4.25 | 0.841 | 2 |
| 4 | Improved communication among stakeholders | 4.22 | 0.797 | 4 |
| 5 | Construction project delivered within budget | 4.22 | 0.797 | 4 |
| 6 | Project team achieved success | 4.19 | 0.749 | 6 |
| 7 | Eliminates disagreement among stakeholders | 4.17 | 0.910 | 7 |
| 8 | Standard view among stakeholders | 4.14 | 0.762 | 8 |
| 9 | Successful execution of projects | 4.11 | 0.820 | 9 |
| 10 | Increases flexibility and expertise | 4.06 | 0.826 | 10 |
| 11 | Appropriate steps are implemented | 3.89 | 1.008 | 11 |
| 12 | Quality service is maintained | 3.86 | 0.931 | 12 |
| 13 | Strategic planning | 3.47 | 1.207 | 13 |
| 14 | Knowledge creation | 3.47 | 1.207 | 13 |

construction process, improved communication among stakeholders, and construction projects delivered within budget were the highest-ranked (1st–4th) benefits of M&S practices in the construction industry. The finding aligns with Papke-Shields et al. [30] and Valadez and Bamberger [36] that the benefits of M&S practices in construction are to guide construction projects to be delivered as planned and to reduce construction material wastage. It also aligns with the study of Bohn and Teizer [8] that M&S practices benefit the construction industry by eradicating corruption and corrupt practices in the construction process and creating improved communication among stakeholders. It also agrees with Mwangu and Iravo [22] that the benefit of effective M&E practices in construction is that it ensures that construction projects are delivered within budget. The study's findings imply that the use of M&E practices will lead to construction projects delivered as planned, reduction of construction material wastage, eradicate of corruption in the construction process, improved communication among stakeholders, and projects delivered within budget, if well implemented for construction process within the construction industry.

The findings also showed that the project team achieves success, eliminates disagreement among stakeholders, better understanding among construction stakeholders, successful execution of projects, and increased flexibility and expertise were mediumly ranked (7th–12th) benefits of M&S practices in the construction industry. The study affirmed the finding of Mwangu and Iravo [22] that one of the benefits is that the project team will be able to succeed in their construction process. The study also agrees with Badom [7] that M&S practices will help eliminate stakeholder disagreement and provide standard views among stakeholders. The findings further support Boulmetris and Dutwin [9] that M&S practices will lead to the successful execution of projects and increase construction professionals' flexibility and expertise in construction operations. The findings indicate that M&E practices will increase the performance and outcomes of construction professionals. It also helps reduce conflict among construction stakeholders, including clients involved in construction projects.

Further, the findings indicated that appropriate steps are implemented, quality service is maintained, and strategic planning and knowledge creation are the least ranked (11th–14th) benefits of M&S practices in the construction industry. This supports Newcombe [23] that M&S practices in construction operations will create appropriate steps that can be implemented for construction activities. This also supports Kusek and Rist [19] and Conard and Hilchey [11] that M&S practices will guide in creating strategic planning and knowledge based on information gathered from construction activities. This implies that construction activities will benefit from effective M&S practices toward achieving sustainable projects and strategic planning for construction projects.

## 5 Conclusion and Recommendation

The study assessed the benefits of M&S practices from the perspective of construction professionals in the South African construction industry. The study identified construction projects delivered as planned, reduction of construction material wastage, eradicate corruption in the construction process, improved communication among stakeholders, and construction projects delivered within budget were the major benefits of including M&S practices in the construction projects. The study established that M&S practices in construction will always lead to continuous improvement of the construction activities within the industry. The M&S practices will also continue to expose construction professionals to activities that require attention through proper planning and a better understanding of the stages of projects they are involved in. Further, the study asserted that M&S practice is a simple tool that can guide professionals to achieve their construction goals. The study suggested that to continue enjoying the benefits of using M&S practices in the construction industry, professional institutions should create more awareness about the benefits of implementing M&S practices in the design, production, and handing over construction stages.

Further, required training should be organized on the benefits of using M&S practices for construction activities among construction professionals. The study concluded that government and construction professionals should enforce M&S at the tender stage of construction projects. Also, required training and seminars should be provided to stakeholders to understand better the benefits of M&S practices on activities within the construction industry. The study enriches the body of knowledge by enabling professionals in project delivery to identify benefits anticipated in M&S practices in achieving their construction objectives.

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## References

1. Abbato S (2023) Digital evaluation stories: a case study of implementation for monitoring and evaluation in an Australian community not-for-profit. Am J Eval. https://doi.org/10.1177/10982140221138031
2. Adekunle SA, Ikuabe M, Aliu J, Ogunbayo B, Aigbavboa C, Oyewo WO, Ejohwomu O (2023) Understanding safety of construction sites: construction site workers' experience. In: Emerging debates in the construction industry. Routledge, pp 292–306. https://doi.org/10.1201/9781003340348
3. Ahsan K, Gunawan I (2010) Analysis of cost and schedule performance of international development projects. Int J Project Manage 28(1):68–78. https://doi.org/10.1016/j.ijproman.2009.03.005
4. Akinradewo O, Aigbavboa C, Oke A, Coffie H, Ogunbayo B (2022) Unearthing causative factors of cost overrun on Ghanaian road projects. The Baltic J Road Bridge Eng 17(4):171–188. https://doi.org/10.7250/bjrbe.2022-17.584
5. Alberto M, Timur N (2013) Earned value-based performance monitoring of facility construction projects. J Facil Manag 11(1):69–80. https://doi.org/10.1108/14725961311301475
6. Aydin IZ, Öztürk A (2023) Identifying, monitoring, and evaluating sustainable ecotourism management criteria and indicators for protected areas in Türkiye: the case of Camili biosphere reserve. Sustainability 15(4):2933. https://doi.org/10.3390/su15042933
7. Badom LN (2016) Project monitoring and evaluation: A critical factor in budget implementation, infrastructure development, and sustainability. Presented at the Nigerian Institute of Quantity Surveyors' National Workshop, 27–28 July, Makurdi, Benue State, Nigeria
8. Bohn JS, Teizer J (2010) Benefits and barriers of construction project monitoring using high-resolution automated cameras. J Const Eng Manag 136(6):632–640. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000164
9. Boulmetis OM, Dutwin VH (2005) Programme evaluation in education. Int J Educ 4(2):4–7
10. Bryman A (2011) Research methods in the study of leadership. In: The SAGE handbook of leadership, pp 15–28
11. Conrad CC, Hilchey KG (2011) A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ Monit Assess 176:273–291. https://doi.org/10.1007/s10661-010-1582-5
12. Danforth K, Ahmad AM, Blanchet K, Khalid M, Means AR, Memirie ST, Watkins D et al (2023) Monitoring and evaluating the implementation of essential packages of health services. BMJ Glob Health 8(1):e010726. https://doi.org/10.1136/bmjgh-2022-010726
13. Golder B, Gawler M (2005) Stakeholder analysis. Resources for implementing the WWF standards in conservation project and programme management, 1–8. https://awsassets.panda.org/downloads/1_1_stakeholder_analysis_11_01_05.pdf
14. Hira A, Busumtwi-Sam J (2021) Improving mining community benefits through better monitoring and evaluation. Resour Policy 73:102138. https://doi.org/10.1016/j.resourpol.2021.102138
15. Hobson K, Hamilton J, Mayne R (2016) Monitoring and evaluation in UK low-carbon community groups: benefits, barriers and the politics of the local. Local Environ 21(1):124–136. https://doi.org/10.1080/13549839.2014.928814
16. Ikuabe M, Aghimien D, Aigbavboa C, Oke A, Adekunle S, Ogunbayo B (2023) Espousal of zero carbon emission in buildings: empirical Analysis of Propelling Measures. In Emerging debates in the construction industry. Routledge, pp 98–111. https://doi.org/10.1201/9781003340348

17. Kanyamuna V, Kotzé DA, Phiri M (2019) Monitoring and evaluation systems: the missing strand in the African transformational development agenda. World J Social Sci Human 5(3):160–175. https://doi.org/10.12691/wjssh-5-3-6
18. Kihuha P (2018) Monitoring and evaluation practices and performance of global environment facility projects in Kenya: a case of United Nations Environment Programme. Unpublished master's thesis). Kenyatta University, Nairobi, Kenya. https://ir-library.ku.ac.ke/bitstream/handle/123456789/18806/Monitoring%20and%20evaluation%20practices%20and%20performance%20of....pdf?sequence=1
19. Kusek JZ, Rist RC (2004) Ten steps to a results-based monitoring and evaluation system: a handbook for development practitioners. The International Bank for Reconstruction and Development / The World Bank, Washington
20. Locatelli G, Mancini M, Gastaldo G, Mazza F (2013) Improving projects performance with lean construction: State of the art, applicability, and impacts. Organ, Tech & Manage Const: An Int J 5(Special):775–783. https://hrcak.srce.hr/file/164802
21. Masoetsa TG, Ogunbayo BF, Aigbavboa CO, Awuzie BO (2022) Assessing construction constraint factors on project performance in the construction industry. Buildings 12(8):1183. https://doi.org/10.3390/buildings12081183
22. Mwangu AW, Iravo MA (2015) How monitoring and evaluation affects the outcome of constituency development fund projects in Kenya: a case study of projects in Gatanga Constituency. Int J Acad Res Bus Soc Sci 5(3):13–31. https://doi.org/10.6007/IJARBSS/v5-i3/1491
23. Newcombe R (2003) From client to project stakeholders: a approach. Construct Manage Econ 21(8):841–848. https://doi.org/10.1080/0144619032000072137
24. Ogunbayo SB, Mhlanga N (2022) Effects of training on teachers' job performance in Nigeria's public secondary schools. Asian J Asses Teach Learn 12(1):44–51. https://doi.org/10.37134/ajatel.vol12.1.5.2022
25. Ogunbayo BF, Aigbavboa CO, Thwala WD, Akinradewo OI, Edwards D (2022) Validating elements of organisational maintenance policy for maintenance management of public buildings in Nigeria. J Qual Maint Eng 29(5):16–36. https://doi.org/10.1108/JQME-05-2021-0039
26. Ogunbayo BF, Aigbavboa C, Thwala WD (2023) A maintenance management framework for municipal buildings in developing economies. Taylor & Francis, London. https://doi.org/10.1201/9781003344681
27. Ogunbayo BF, Aigbavboa CO, Murenden L, Ramabodu MS, Ogunbayo SB (2023) Assessment of lean guided construction project monitoring and evaluation practices: issues and challenges. In: Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31), pp 1127–1137. https://doi.org/10.24928/2023/0110
28. Otieno FAO (2000) The roles of monitoring and evaluation in projects. Project Manage Scient J 1(5):41–44 (2nd International Conference on Construction in Developing Countries: Challenges facing the construction industry in developing countries)
29. Pallant J (2020) SPSS survival manual: a step by step guide to data analysis using IBM SPSS. McGraw-hill education (UK). https://doi.org/10.4324/9781003117407
30. Papke-Shields KE, Beise C, Quan J (2010) Do project managers practice what they preach, and does it matter to project success? Int J Project Manage 28(7):650–662. https://doi.org/10.1016/j.ijproman.2009.11.002
31. Rakodi C (1982) The role of monitoring and evaluation in project planning in relation to the upgrading of unauthorized housing areas. Public Admin Develop 2(2):129–146. https://doi.org/10.1002/pad.4230020205
32. Rea LM, Parker RA (2014) Designing and conducting survey research: a comprehensive guide. John Wiley & Sons, San Francisco
33. Seiso MP, Ogunbayo BF, Aigbavboa CO (2023) Joint ventures in the South African construction industry: factors militating against success. Buildings 13(5):1299. https://doi.org/10.3390/buildings13051299

34. Tengan C, Aigbavboa C (2016) Stakeholder Engagement and Participation in Monitoring and Evaluation of Construction Projects in Ghana In: Proceedings of the DII-2016 Conference: Investment Strategies for Africa: Achieving Solutions for Renewable Energy and Sustainable Development. 31 August - 2 September 2016, Livingstone, Zambia. 2016-046. file:///C:/Users/hp/Downloads/uj_20862+SOURCE1+SOURCE1.2-1.pdf
35. Tengan C, Aigbavboa CO, Oke AE (2018) Evaluation of UFPA quality assessment criteria for monitoring and evaluation system in the Ghanaian construction industry. Afr J Sci Technol Innov Dev 10(2):177–181. https://doi.org/10.1080/20421338.2017.1423008
36. Valadez J, Bamberger M (2012) Monitoring and evaluating social programs in developing countries: a handbook for policymakers, managers and researchers. Economic Development Institute of The World Bank. https://www.perfeval.pol.ulaval.ca/sites/perfeval.pol.ulaval.ca/files/publication_192.pdf
37. van den Burg SWK, Skirtun M, van der Valk O, Cervi WR, Selnes T, Neumann T, Roebeling P et al (2023) Monitoring and evaluation of maritime spatial planning—a review of accumulated practices and guidance for future action. Mar Policy 150:105529. https://doi.org/10.1016/j.marpol.2023.105529

# Minimizing Patent Defects in Low-Cost Housing

**P. Ndlovu and James Olabode Bamidele Rotimi**

## 1 Introduction

The construction industry has contended with quality performance issues for a considerable time, despite extensive research efforts aimed at addressing these challenges [4, 14, 29, 32, 35]. One sector severely affected by poor quality is housing, leading to adverse consequences for households, particularly in low-cost housing projects [35]. The negative impact of substandard quality on health and well-being outcomes in low-cost housing has been well-documented [28]. According to Barton and Grant's model [7], both the natural and built environments significantly influence a population's health, and the concept of a healthy building, introduced by Ho et al., aims to encourage positive well-being for occupants and to improve their efficiency.

Defects in buildings pose threats to the health, safety, and well-being of occupants [2] A healthy building is an integral part of a healthy built environment where all health risk factors are prevented, and optimal conditions for individual users' health and well-being are achieved [3]. This includes providing stimulating and healing-oriented conditions that fulfill the specific needs of individual users, especially vulnerable ones. On the other hand, an unhealthy building exposes users to health risk factors without attaining optimal conditions, particularly for vulnerable individuals [2, 9, 31].

At the completion stage and after the handover of projects, there are often extensive lists of patent defects that negatively affect users. Construction failures are attributed to imperfections and inadequacies [18, 30, 35] during the implementation process. Unfortunately, project stakeholders tend to adopt a lackadaisical attitude toward

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these flaws and their origins, only taking action when they become unavoidably apparent. Many low-cost housing projects suffer from an indifferent mindset, leading to undocumented and unresolved defects, which result in a substantial inventory of flaws upon project completion. These inadequacies come with significant financial implications.

This paper aims to explore the intrinsic defects prevalent in low-cost housing projects and to understand their nature. It also proposes measures to mitigate their occurrence before the project reaches its final stage. The research seeks to achieve the following objectives: (1) identify patent defects commonly encountered during the completion stage of low-cost housing projects, (2) examine their underlying causes and their impact on the health and well-being of users, and (3) advocate strategies to reduce the prevalence of such overt defects during project finalization.

## 2 Literature Review

Low-cost housing serves as a crucial solution to housing shortages, offering affordable living options for vulnerable populations. The presence of patent defects in such housing impacts the health and overall well-being of its inhabitants. This study explores the common patent defects found in low-cost housing and their implications on the occupants' health and quality of life.

Patent defects in construction encompass inherent shortcomings or imperfections arising during the building process, affecting the structures' quality, performance, and durability. These defects encompass design flaws, material deficiencies, workmanship errors, and inadequate maintenance [6, 27]. Design flaws pertain to improper structural calculations [12], insufficient drainage systems [13], or a lack of attention to environmental considerations [17]. Material deficiencies result from the use of substandard or incompatible materials, which lead to degradation, corrosion, or structural instability. Workmanship errors arise from poor construction practices, inadequate skill or supervision, and shortcuts during the building process. Inadequate maintenance exacerbates defects over time, as neglecting minor issues can lead to significant structural problems. The existence of these defects not only compromises the health, safety, and functionality of buildings but also imposes financial burdens on owners and occupants.

In the context of low-cost housing, patent defects refer to visible and identifiable flaws in the structure, design, or construction. Such issues include building cracks water penetration (leaks), poor ventilation, inadequate insulation, substandard building materials, faulty plumbing, and improper electrical systems [6, 27]. The prevalence of patent defects in low-cost housing can be attributed to cost-cutting measures and inadequate quality control. These deficiencies have far-reaching consequences on the well-being of the occupants, highlighting the urgent need to address and rectify these issues to ensure the provision of safe and habitable living environments.

## *2.1 Risks and Health Concerns Posed by Patent Defects*

Patent defects in low-cost housing pose significant risks and health implications for its occupants, jeopardizing their well-being and quality of life. These defects can lead to various adverse health outcomes, exacerbate existing health conditions, and compromise the safety and security of the residents. Several studies have highlighted the importance of addressing patent defects to safeguard the health and safety of low-cost housing occupants.

### 2.1.1 Building Cracks and Structural Instability Defects

Building cracks in low-cost housing lead to potential structural instability, indoor environmental hazards, and various health concerns. The prevalence of building cracks is common in low-cost housing due to cost-cutting measures and the use of substandard construction materials [21, 35]. Building cracks can compromise the structural integrity of low-cost housing units. Cracks that develop in load-bearing elements, such as walls, columns, and beams, can weaken overall stability. Over time, if these cracks are not addressed, they may worsen and lead to partial or complete structural failure. The risk of collapse can endanger the lives of occupants and neighboring properties, especially during seismic events or adverse weather conditions.

Building cracks can allow water infiltration, creating an environment conducive to mold and mildew growth. Moisture intrusion through cracks can lead to dampness, which promotes the proliferation of mold spores in walls, ceilings, and floors [26]. Mold and mildew release airborne allergens and mycotoxins that can trigger respiratory issues, allergies, and asthma in occupants [8, 22, 34]. Prolonged exposure to indoor environmental hazards like mold can lead to chronic health problems and reduce the quality of life for the residents [8, 22].

Cracks in building components can negatively affect indoor air quality. Gaps in walls, windows, and doors can allow the infiltration of outdoor pollutants, dust, and harmful particulate matter into the living spaces. Poor indoor air quality (IAQ) can lead to respiratory problems, cardiovascular issues, and other health complications. Vulnerable populations, such as children, the elderly, and individuals with pre-existing health conditions, are particularly at risk of adverse health effects due to compromised IAQ.

In addition to structural instability, building cracks can create physical safety hazards for occupants [25, 33]. Uneven surfaces caused by cracks may lead to trips, slips, and falls, particularly in poorly lit areas. Moreover, if left unattended, cracks can widen, creating larger openings that pose entrapment risks for children and pets. Cracks on floors and pavements within the housing complex can also increase the risk of accidents for residents and visitors.

Living in a structurally compromised environment can have a psychological impact on the well-being of occupants [20]. The constant fear and uncertainty about the building's safety can lead to heightened stress levels and anxiety. Moreover, the lack of action or timely repairs by housing authorities may create feelings of neglect and helplessness among residents.

### 2.1.2 Indoor Air Quality and Respiratory Health

One of the most common health risks associated with patent defects in low-cost housing is poor indoor air quality. Defects like inadequate ventilation and water infiltration [5, 10] can promote the growth of mold and mildew, leading to airborne allergens and toxins. Exposure to these pollutants can trigger or worsen respiratory conditions, such as asthma and allergies [11, 22]. Prolonged exposure to poor indoor air quality can also increase the risk of respiratory infections and other respiratory diseases [11]. Indoor air quality (IAQ) plays a critical role in the health and well-being of occupants, and its significance becomes even more pronounced in low-cost housing, where patent defects can have adverse effects on IAQ. Among the most prevalent health risks associated with patent defects in such housing is the issue of poor indoor air quality. The presence of defects like inadequate ventilation and water infiltration can create an environment conducive to the growth of mold and mildew, which in turn leads to the release of airborne allergens and toxins, significantly impacting respiratory health [11].

One of the primary concerns arising from poor IAQ in low-cost housing is the exacerbation of respiratory conditions, particularly asthma and allergies. Studies have shown that occupants living in environments with subpar ventilation and mold infestation are more susceptible to asthma attacks and allergic reactions [11]. The inhalation of allergens and other pollutants released from mold and mildew can trigger respiratory symptoms in individuals with pre-existing conditions or even lead to the development of new respiratory issues in otherwise healthy occupants.

Prolonged exposure to poor IAQ in low-cost housing can have serious long-term health consequences. Research has linked such exposure to an increased risk of respiratory infections and other respiratory diseases. Inadequate ventilation, along with the accumulation of harmful pollutants, can facilitate the spread of infectious agents within the confined indoor environment, heightening the chances of respiratory infections [11, 22]. Furthermore, poor IAQ has been associated with the development of chronic respiratory diseases, such as chronic obstructive pulmonary disease (COPD), which can significantly impact the quality of life and overall health of affected individuals (Ibid.).

Children and vulnerable populations are particularly susceptible to the adverse effects of poor IAQ in low-cost housing. Children's respiratory systems are still developing, making them more sensitive to environmental pollutants. Exposure to indoor air pollutants during their early years can lead to long-term respiratory issues and a higher risk of asthma development [11]. Similarly, vulnerable populations, such as the elderly and individuals with pre-existing respiratory conditions, face greater health risks from poor IAQ, as their bodies may have reduced capabilities to cope with the added strain on their respiratory systems.

### 2.1.3 Water Penetration (Leaks) and Associated Health Risks

Water penetration in buildings, resulting from patent defects such as leaks and dampness, presents a significant health risk to occupants. When left unresolved, these issues can create an environment conducive to the growth of mold, bacteria, and other harmful microorganisms, leading to a myriad of health problems. Several studies have emphasized the adverse health implications of water penetration in buildings [1], especially in low-cost housing projects.

The presence of water-related defects provides the ideal conditions for mold growth, a particularly concerning health hazard. Mold releases spores into the air, and when inhaled, these spores can trigger or worsen respiratory issues, such as asthma and allergies. Individuals with pre-existing respiratory conditions are especially vulnerable to the adverse effects of mold exposure [1, 2, 22]. Additionally, prolonged exposure to mold spores and other airborne contaminants can cause respiratory irritation and exacerbate symptoms, leading to frequent coughing, wheezing, and difficulty breathing. Moreover, water penetration can contribute to the proliferation of bacteria and other harmful microorganisms. Damp environments provide the perfect breeding grounds for bacteria, which can pose health risks when they come into contact with the occupants or when they are inhaled [23]. Bacterial infections can lead to a range of health issues, from mild skin irritations to more severe respiratory infections.

In low-cost housing projects, the impact of water penetration on health is even more concerning. These housing units often lack proper waterproofing and water drainage systems, making them more susceptible to water infiltration and leaks. Moreover, inadequate ventilation and limited resources for prompt repairs can exacerbate the problem, allowing moisture to accumulate and persist over extended periods. This scenario significantly increases the likelihood of mold and bacterial growth, posing a greater health risk to the inhabitants, particularly vulnerable groups such as children and the elderly.

Long-term exposure to mold and water-related issues can lead to chronic health problems. The effects of mold exposure may not be immediately apparent but can manifest gradually over time, resulting in persistent health issues and diminished quality of life. Children exposed to mold and damp environments are at risk of developing respiratory problems that can persist into adulthood [8, 11]. Similarly, the elderly, whose immune systems may be weaker, are more susceptible to infections caused by harmful microorganisms present in water-damaged areas.

### 2.1.4 Mental Health and Well-Being

Living in housing with visible patent defects can significantly impact the mental health and well-being of the occupants. Constant exposure to subpar living conditions, including structural flaws and limited amenities, can lead to heightened stress levels and decreased overall life satisfaction [23]. The psychological distress resulting from the lack of a safe and comfortable living environment can have far-reaching consequences on mental health, potentially leading to anxiety, depression, and a diminished sense of self-worth.

### 2.1.5 Safety and Security Concerns

Structural defects and poor construction practices can compromise the safety and security of low-cost housing occupants. Deficiencies in building materials, improper installation of electrical systems, and weak structural foundations can lead to accidents, injuries, and property damage. Inadequate fire safety measures and a lack of emergency exits can further escalate the risks during unforeseen incidents.

### 2.1.6 Impact on Children and Vulnerable Populations

Patent defects in low-cost housing have a more pronounced impact on children and vulnerable populations. Children, in particular, are highly susceptible to health issues arising from exposure to poor indoor air quality and hazardous building conditions [11]. Vulnerable populations, such as the elderly and individuals with pre-existing health conditions, are also at higher risk of experiencing health complications due to patent defects in their living environments.

Patent defects in low-cost housing have severe health implications, affecting indoor air quality, safety, and overall well-being. The presence of these defects highlights the importance of investing in quality construction, regular maintenance, and effective remediation measures to ensure that affordable housing remains a safe and healthy option for vulnerable populations.

## 3 Research Methodology

The objective of this research was to investigate strategies for reducing patent defects in construction. Data was gathered through a purposive sampling method, which involved the participation of a population from different backgrounds related to the low-cost housing sector. These participants included human settlements inspectors, municipal inspectors, architects, civil engineers, project managers, development managers, quantity surveyors, safety officers, contractors, house owners, and suppliers. The study employed a mixed-methods approach, incorporating both quantitative and qualitative methodologies. Questionnaires were distributed to 150 participants, resulting in 101 completed responses. Additionally, semi-structured interviews were scheduled with 10 research participants; however, only eight face-to-face interviews were eventually conducted. The data collected were analyzed using content and thematic analysis techniques. The inclusion of a diverse range of stakeholders, representing various roles within the housing sector, allowed for a comprehensive exploration of the underlying causes of patent defects in low-cost housing projects.

## 4 Findings and Discussion

Through extensive research and analysis, this study has identified common patent defects in construction, including design flaws, material deficiencies, workmanship errors, and inadequate maintenance. These defects have been shown to significantly impact the health, safety, and overall well-being of occupants, particularly in vulnerable populations. The study highlights the association between patent defects and their adverse effects on indoor air quality, respiratory health, and safety hazards. Additionally, it emphasizes the importance of adhering to quality standards, implementing proper construction practices, and investing in skilled labor and high-quality building materials to minimize the occurrence of defects. The discussions further underscore the need for collaborative efforts between stakeholders to address these challenges effectively. By presenting a comprehensive analysis of the implications of patent defects in low-cost housing, this study contributes valuable knowledge to the construction industry and informs the development of strategies to improve the quality and sustainability of low-cost housing initiatives.

**Profile of Participants**: To determine strategies utilized to minimize patent defects in low-cost housing projects, it was important to validate the familiarity of participants in dealing with patent defects in low-cost housing. The results showed that 93% of respondents indicated being familiar with dealing with patent defects in low-cost housing projects. The experience of participants in low-cost housing ranged from 35% of respondents having 10–15 years of experience in low-cost housing projects, 25% indicated they have 5–10 years of experience, and 23% indicated they can submit 1 to 5 years of experience. The results indicated that 80% of participants indicated that cracks and leaks are defects often found in low-cost housing, while 70% identified plumbing issues and 55% identified painting, structural instability and misalignment, and unevenness of floors identified by 50% of respondents.

**Patent Defects in Low-Cost Housing**: The findings of the study revealed that cracks and plumbing problems emerged as the most prevalent patent defects within the low-cost housing sector. At the practical completion stage of these projects, a multitude of factors were identified as major contributors to the occurrence of these defects. These factors included inadequate supervision, poor workmanship, utilization of substandard building materials, and a lack of sector-specific training for individuals responsible for house inspections. To mitigate the health risks associated with patent defects in low-cost housing, addressing indoor air quality issues is crucial. Implementing proper ventilation systems, regular maintenance practices, and prompt remediation of water leaks and dampness can significantly improve IAQ and reduce the presence of harmful pollutants. Additionally, promoting proper hygiene practices, such as cleaning and proper waste disposal, can help minimize the release of airborne allergens and pollutants within the indoor environment. Patent defects, such as water leaks and dampness, can create favorable conditions for the growth of mold, bacteria, and other harmful microorganisms. These contaminants can exacerbate respiratory issues, cause skin irritation, and even lead to infections in vulnerable individuals

[15]. Long-term exposure to mold and water-related issues can contribute to chronic health problems, particularly in children and the elderly.

Poor indoor air quality resulting from patent defects in low-cost housing poses significant risks to respiratory health. Mold infestation, inadequate ventilation, and water infiltration are among the key culprits contributing to compromised IAQ. The consequences of these issues can lead to worsened respiratory conditions, respiratory infections, and long-term respiratory diseases. Prioritizing indoor air quality improvement measures is essential to safeguarding the health and well-being of occupants, particularly vulnerable populations living in low-cost housing. To mitigate the health risks associated with water penetration, timely and effective repairs and remediation are essential. Implementing adequate waterproofing measures during construction and ensuring proper ventilation can help prevent water infiltration in the first place. Additionally, regular inspections and proactive maintenance can identify and address water-related issues promptly, reducing the potential for mold and bacterial growth.

The patent defects leading to water penetration in buildings pose serious health risks to occupants, particularly in low-cost housing projects. The growth of mold, bacteria, and other harmful microorganisms can result in respiratory issues, skin irritations, and infections. Long-term exposure to these contaminants can lead to chronic health problems, especially in vulnerable individuals such as children and the elderly. Implementing preventive measures and prompt remediation is crucial in safeguarding the health and well-being of occupants and ensuring a safe living environment.

**Defect Rectification Strategies**: In light of the research findings, this paper concludes by proposing recommendations to improve the execution, monitoring, and remediation of patent defects in housing projects, specifically in the context of low-cost housing. These practice-based recommendations aim to minimize the occurrence of patent defects and enhance the overall quality of low-cost housing initiatives. This paper has explored the detrimental impact of patent defects on the health and safety of occupants in low-cost housing projects. To address these issues and improve the execution, monitoring, and remediation of patent defects, the following practice-based recommendations are proposed (Table 1).

**Adherence to Quality Standards**: It is important to establish and enforce stringent quality standards for low-cost housing projects. Implementing quality control measures throughout the construction process can help identify and rectify potential defects at an early stage. This includes regular inspections and quality checks by qualified professionals to ensure that construction materials, techniques, and workmanship meet approved standards.

**Training and Skill Development**: Investing in the training and skill development of construction workers and contractors is essential. Properly trained and skilled labor can significantly reduce the occurrence of defects arising from poor workmanship. Training should focus on best practices, safety protocols, and the use of appropriate construction methods and materials.

**Table 1** Defects and mitigation strategy

| Defects | Mitigation strategies |
|---|---|
| Lack of adherence to quality standards | – Implement stringent quality control measures during construction<br>– Regular inspections and quality checks by qualified professionals<br>– Ensure materials, techniques, and workmanship meet approved standards |
| Inadequate training and skill development | – Invest in training and skill development for construction workers and contractors<br>– Focus on best practices, safety protocols, and appropriate construction methods and materials |
| Use of substandard building materials | – Prioritize the use of high-quality, durable, and resistant building materials<br>– Avoid using substandard materials to prevent long-term costs of repairs |
| Poor waterproofing and drainage | – Incorporate effective waterproofing measures during construction<br>– Implement proper drainage systems to direct rainwater away from the foundation |
| Delayed detection and remediation of defects | – Encourage residents to report patent defects promptly<br>– Establish a transparent and accessible mechanism for issue reporting<br>– Take prompt action to address reported defects to prevent further deterioration |
| Lack of comprehensive building inspections | – Conduct thorough inspections at key stages of the project, including pre-handover<br>– Qualified inspectors should assess structural integrity, ventilation, plumbing, electrical systems |
| Lack of awareness and collaboration | – Raise awareness among residents about the importance of maintaining the building's integrity and reporting defects<br>– Conduct educational campaigns to inform residents about potential hazards<br>– Encourage collaboration between stakeholders for better project outcomes |

**Use of High-Quality Building Materials**: Low-cost housing projects often face budget constraints, leading to the use of substandard materials [24]. However, the long-term cost of repairing defects outweighs the initial savings. By prioritizing the use of high-quality building materials that are durable and resistant to environmental factors, the likelihood of defects can be minimized.

Proper Waterproofing and Drainage: Effective waterproofing measures should be incorporated during the construction phase to prevent water infiltration and dampness. Proper drainage systems should be implemented to direct rainwater away from the building foundation, reducing the risk of water-related defects that can compromise the structure's stability and indoor air quality.

**Early Detection and Prompt Remediation**: Encouraging residents to report any signs of patent defects is crucial for early detection and timely remediation. Housing authorities and project developers should establish a transparent and accessible mechanism for occupants to report issues [19]. Prompt action should be taken to address reported defects to prevent further deterioration and potential health risks.

**Comprehensive Building Inspections**: Conducting comprehensive building inspections at key stages of the project, including pre-handover, is essential. Qualified inspectors should assess the building's structural integrity, ventilation systems, plumbing, electrical systems, and other crucial elements. Regular inspections during the construction and post-occupancy phases can help identify and rectify defects promptly.

Raising awareness among residents about the importance of maintaining the building's integrity and reporting defects is vital. Educational campaigns can inform residents about potential hazards related to patent defects and the significance of reporting issues promptly. Encouraging collaboration between stakeholders, including developers, contractors, local authorities, and residents, can lead to better outcomes. Engaging stakeholders at various stages of the project can foster a sense of responsibility and shared commitment to maintaining housing quality and safety.

**Implications of the Study**

The implications of this study are significant as it provides valuable insights into the persistent performance quality issues prevalent in the construction industry, with a specific focus on the low-cost housing subsector. By identifying and analyzing the dominant patent defects and their underlying causes, this research contributes valuable knowledge to the ongoing efforts aimed at improving the quality of construction projects. Understanding the nature and origins of these defects can help stakeholders, including developers, contractors, and policymakers, devise targeted strategies to prevent and address them more effectively. By addressing these challenges, the construction industry can enhance the overall quality, safety, and sustainability of low-cost housing projects, ultimately benefiting the well-being and quality of life of the inhabitants. Moreover, the findings of this study can inform the development of best practices and guidelines to ensure that low-cost housing initiatives provide safe, habitable, and durable living environments for vulnerable populations, thereby addressing pressing social and housing challenges.

Overall, this study sheds light on the persistent performance quality issues in the construction industry, particularly within the low-cost housing subsector. By identifying the dominant patent defects and their root causes, this research contributes to the ongoing efforts to address the challenges associated with quality in construction projects.

## 5 Conclusion

This study investigated strategies utilized to utilize patent defects in low-cost housing projects. The results revealed that the following defects in low-cost housing in their order of importance: cracks, leaks, plumbing issues, structural instability, skewed windows, walls doors, uneven floors, paint, chips on plaster, electrical issues, and leaking roof. These issues were dominant in most low-cost housing projects. In order to utilize these defects, the results showed strategies that are utilized namely: (1) the use of quality materials, (2) training and supervision of construction workers to maintain workmanship and improve the standard, (3) engaging experienced professionals with relevant experience in housing, (4) proper planning and realistic budgeting.

This study has the following weakness. Since it is the first attempt to develop the online proctoring software acceptance model, other factors might be added to the model to cater to the unexplained variance of 25%. Second, this study was carried out at a rural university, the online proctoring software acceptance model has to be applied to other universities including urban universities. This study focused on the acceptance of online proctoring software for assessment, future studies need to focus on the continuous use of online proctoring software for assessment.

In conclusion, minimizing patent defects in low-cost housing requires a concerted effort from all stakeholders involved in the construction and maintenance processes. Implementing quality standards, training skilled labor, using high-quality materials, proper waterproofing, and drainage, along with early detection and prompt remediation, are essential steps toward improving the overall quality of low-cost housing projects. By adopting these recommendations, housing initiatives can provide safe, healthy, and sustainable living environments for vulnerable populations while reducing the occurrence of patent defects.

## 6 Ethics Statement

Not applicable.

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## References

1. Agyekum K, Ayarkwa J, Koranteng C, Adinyira E (2013) Preliminary assessment of dampness in walls of residential buildings in fours climatic zones in Ghana. J Sustain Develop 6(9):51–61
2. Agyekum K, Salgin B, Donso AK (2017) Creating awareness on the negative impact of dampness on the health of occupants: a case for inhabitants living in damp buildings in Ghana. Int J Develop Sustainab 6(8):611–627

3. Alhorr YM, Arif M, Katafgiotou M, Mazroei A, Kaushik A, Elsarrag E (2016) Impact of indoor environmental quality on occupant well-being and comfort: a review of the literature. Int J Sustain Built Environ 5(1):1–11
4. Alencastro J, Fuertes A, Fox A, Wilde P (2019) The impact of defects on energy performance of buildings: quality management in social housing developments. In: Energy Procedia 158 (2019) 4357–4362, 9th International Conference on Applied Energy, ICAE2017, 21–24 August 2017, Cardiff, UK
5. Ali AS, Kamaruzzaman SN, Sulaiman R, Peng Y (2010) Factors affecting housing maintenance cost in Malaysia. J Facil Manag 8(4):285–298
6. Awasho TT, Alemu SK (2023) Assessment of public building defects and maintenance practices: Cases in Mettu town, Ethiopia, Heliyon, 9
7. Barton H, Grant M (2006) A health map for local human habitat. Perspect Publ Heal, Sage J 126(6)
8. Bush RK, Portnoy JM, Saxon A, Terr AI, Wood RA (2006) The medical effects of mold exposure. J Allergy Clin Immunol 117(2):326–333. https://doi.org/10.1016/j.jaci.2005.12.001
9. Egan M, Kearns A, Mason P, Tannahill C, Bond L, Coyle J, Beck S, Crawford F, Hanlon P, Lawson L, McLean J, Petticrew M, Sautkina E, Thomson H, Walsh D (2010) Protocol for mixed method study investigating the impact of investment in housing regeneration and neighbourhood renewal on health and well-being of residents: the GoWell programme. BMC Med Res Methodol, No 10
10. El-Haram M, Horner M (2002) Factors affecting housing maintenance cost. J Qual Maint Eng 8(2):115–123
11. Fsadni P, Bezzina F, Fsadni C, Montefort S (2018) Impact of School air quality on children's respiratory health. Indian J Occupat Environ Med 22(3):156–162
12. Hanson JH (2021) How structural engineers find errors in analysis and design results. Pract Period Struct Design Construct 28(2). https://doi.org/10.1061/(ASCE)SC.1943-5576.0000560
13. Ishak S, Chohan A, Ramly A (2007) Implications of design deficiency on building maintenance at post-occupational stage. J Build Apprais 3:115–124. https://doi.org/10.1057/palgrave.jba.2950061
14. Jiboye AD (2011) Evaluating public housing performance: providing a basis for residential quality improvement in Nigeria. Middle-East J Sci Res 9(2):225–232
15. Kim D, Chen Z, Zhou L, Huang S (2018) Air pollutants and early origins of respiratory diseases. Chronic Disease Translat Med 4(2):75–94
16. Kiong C, Sui Pheng L (2005) Assessment of defects at construction and occupancy stages. J Perform Constr Facil 19(4):283–289
17. Kleidorfer M, Mikovis C, Jasper-Tonnies A, Huttenlau M, Einfalt T, Rauch W (2014) Impact of a changing environment on drainage system performance. Proced Eng 70:943–950
18. Lizarralde G, Root D (2006) The informal construction sector and inefficiency of low cost housing markets. Construct Manage Econ 26(2):103–113
19. Low SP (2001). Improving maintenance and reducing building defects through ISO 9000. J Qual Mainten Eng 7(1):6–24
20. Marais L, Sharp C, Pappin M, Lenka M, Cloete J, Skinner D, Serekoane J (2013) Housing conditions and mental health of orphans in South Africa. Health & Place 24. https://doi.org/10.1016/j.healthplace.2013.08.004
21. Maseti M, Ayesu-Koranteng E, Amoah C (2023) Causes of poor workmanship in low cost housing construction in South Africa. Sustain Educ Develop, 40–51. https://doi.org/10.1007/978-3-031-25998-2_4
22. Mendell MJ, Mirer AG, Cheung K, Tong M, Douwes J (2011) Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence, environmental health perspectives 119(6). https://doi.org/10.1289/ehp.1002410
23. Mendell M, Macher JM, Kumagai K (2018) Measurement moisture in buildings and adverse health effects: a review. Indoor Air 28(4)
24. Mills A, Love PED, Williams P (2009) Defects cost in residential construction. J Const Eng Manage 135:12–16. https://doi.org/10.1061/(ASCE)0733-9364(2009)135

25. Okuntade T (2014) Effects of faulty construction on building maintenance. Int J Tech Enhance Emerg Eng Res 2:73–79
26. Prowler D (2016) Mold and moisture dynamics, whole building design guide (WBDG), Heinz Trechsel, R.A. FASTM, NAVFAC Washington, Washington, DC
27. Sulieman MZ, Omar NN, Mydin MAO (2014) Structural component defects of low-cost housing: a case study at Taman Bandar Perdana, Sungai Petani, Malaysia. Matec Web of Conferences, EDP Sciences
28. Aoul KAT, Hagi R, Abdelghani R, Syam M, Akhozheya B (2021) Building envelope thermal defects in existing under construction housing in the UAE, infrared thermography diagnosis and qualitative impact analysis. Sustain 13:2230. https://doi.org/10.3390/su13042230
29. Tam CM, Deng ZM, Zeng SX, Ho CS (2000) Quest for continuous quality improvement for public housing construction in Hong Kong. Constr Manag Econ 18(4):437–446. https://doi.org/10.1080/014461900050024851
30. Trangkanont S, Charoenngam C (2014) Critical failure factors of public-private partnerships low cost housing program in Thailand. Eng, Construct Architect Manag 21(4)
31. Udofia EA, Yawson AE, Aduful KA, Bwambale FM (2014) Residential characteristics as correlates of occupants' health in Greater Accra Region, Ghana. BMC Publ Heal J 14
32. Van der Merwe R, Mahachi J (2021) An investigation of South African low-cost housing roof anchor systems. J South Afr Institution Civil Eng 63(4):24–34
33. Waziri BS (2016) Design and construction defects influencing residential building maintenance in Nigeria. Jordan J Civil Eng 10:313–323. https://doi.org/10.14525/JJCE.10.3.3605
34. World Health Organisation (2009) WHO guidelines for indoor air quality: dampness and mould
35. Zunguzane N, Smallwood J, Emuze F (2012) Perceptions of the quality of low-income houses in South Africa: Acta Structilia 19(1):19–38

# Impacts of Artificial Lighting on Human Behaviour In-Office Buildings—A Systematic Literature Review

**Mohamed Salaheldin Amin Mohamed and Eziaku Onyeizu Rasheed**

## 1 Introduction

In developed countries, most individuals allocate approximately 90% of their daily routines to indoor activities [3]. The workplace environment is a fundamental part of human life, as it occupies roughly a third of our lifetimes [13]. Therefore, workers who spend extended hours in offices with insufficient lighting may experience negative impacts on their well-being and productivity, such as eye fatigue, pain around the eyes, dizziness, drowsiness, and overall discomfort [22]. The examination of the artificial lighting implications on employee productivity holds significance as it facilitates organizations in comprehending the manners by which lighting conditions can exert influence upon the performance and general well-being of their workforce.

Empirical research has evidenced that appropriate indoor lighting conditions play a pivotal role in enabling employees to sustain levels of productivity and comfort needed within their designated office premises [5]. The potential cost impact of lighting conditions on office workers' productivity per unit area within an office building is estimated to vary between $0.57 and $3.30 per square foot, with a possible annual financial implication ranging from $220 million to $1.3 billion [7]. Factors such as maintained Illuminance values, colour temperature, glare, and colour rendering can have an impact on the productivity and well-being of office workers. Research has shown that the mental workload of subjects is affected by a maintained illuminance value and correlated colour temperature (CCT) [2]. Glare factors, such as contrast and luminance, can also influence physiological and ocular responses and performance measures like visual and reading [6]. Additionally, the colour rendering index (CRI) and correlated colour temperature (CCT) of lighting can indeed affect user acceptance in-office settings. Research suggests that LEDs with lower CRI

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values at warm colour temperatures are rated as more acceptable [15]. Therefore, it is significant to consider these factors when designing office lighting environments to optimize productivity and well-being. However, these studies have significantly examined the impact of maintained illuminance values, and colour temperature (CCT) on human behaviour, but few reviews have been included on lighting glare and Colour Rendering Index.

This systematic literature review aims to examine the effects of artificial lighting on office workers and provide a comprehensive overview of the existing research, including all factors. The review will first examine the different types of artificial lighting and their effects on human behaviour, followed by an exploration of how lighting can impact various aspects of workplace behaviour, such as productivity, mood, and health.

## 2 Method

The search for relevant studies in this review followed the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA), as outlined by Moher et al. [16]. To accomplish this, sixteen studies were selected from peer-reviewed sources and journal articles, with a specific focus on their method of measuring the impacts of artificial lighting on human behaviour in the workplace.

### *2.1 Criteria of Inclusion*

The systematic search was focused on recent articles published in English (from January 2018 to April 2023) within the Scopus databases, aiming to explore the effects of lighting on human behaviour. By limiting the search to this timeframe, the study aimed to capture the latest insights and advancements in the field. This approach ensured that the research incorporated the most current understanding of lighting's impact on aspects such as performance, well-being, and mental health in-office and workplace settings. The search keywords were included: ["artificial light*" OR light* AND "human behav*" OR perform* OR well-being OR "mental health" OR cognit* AND office* OR workplace* OR orgni?ation].

### *2.2 Criteria of Exclusion*

The exclusion criteria for study selection encompass several dimensions. Studies conducted in non-administrative office settings such as mining offices, healthcare offices or factories are excluded. Only empirical studies are considered, while theoretical, technological, and non-empirical papers are excluded. Clarity in methods and measures is essential, with studies lacking transparent data collection or analysis processes being excluded. Dependent variables should directly measure physical, psychological, or social well-being, excluding those centered-on job satisfaction or motivation. Independent variables related to artificial lighting are included, excluding those unrelated to artificial lighting, such as natural light.

### *2.3 Selection of Studies*

The screening and review of studies were conducted in a three-stage process (Fig. 1). Initially, studies were examined based on their titles to eliminate irrelevant papers. In the second stage, abstracts were carefully evaluated to identify both relevant and non-relevant papers. All identified studies were organized using a citation manager, Zotero, and duplicate records were removed. During this stage, references that clearly did not meet the inclusion criteria were excluded. In the third and final stage, the full-text articles that remained underwent further assessment. Finally, following this rigorous selection process, 16 papers were included.

### *2.4 Data Extraction and Data Analysis*

A standardized template (Table 1) was developed and tested to extract information from the papers, which consisted of four sections. The first section captured the author(s)/Year details, followed by the study's objectives in the second section. The third section encompassed the methodology employed, while the fourth section provided a summary of the findings. The analysis process aligned with two research questions and comprised two stages. Initially, content analysis was employed to gather information on different types of artificial lighting, their effects on human behaviour, and the impact of lighting on various aspects of workplace behaviour. Subsequently, the paper's findings regarding the relationship between artificial lighting and aspects of human behaviour in the workplace (such as productivity, mood, and overall well-being) were summarized on a feature-wise and individual paper basis. Based on this analysis, conclusions were drawn regarding the focus on measuring the impacts of artificial lighting on human behaviour in the workplace.

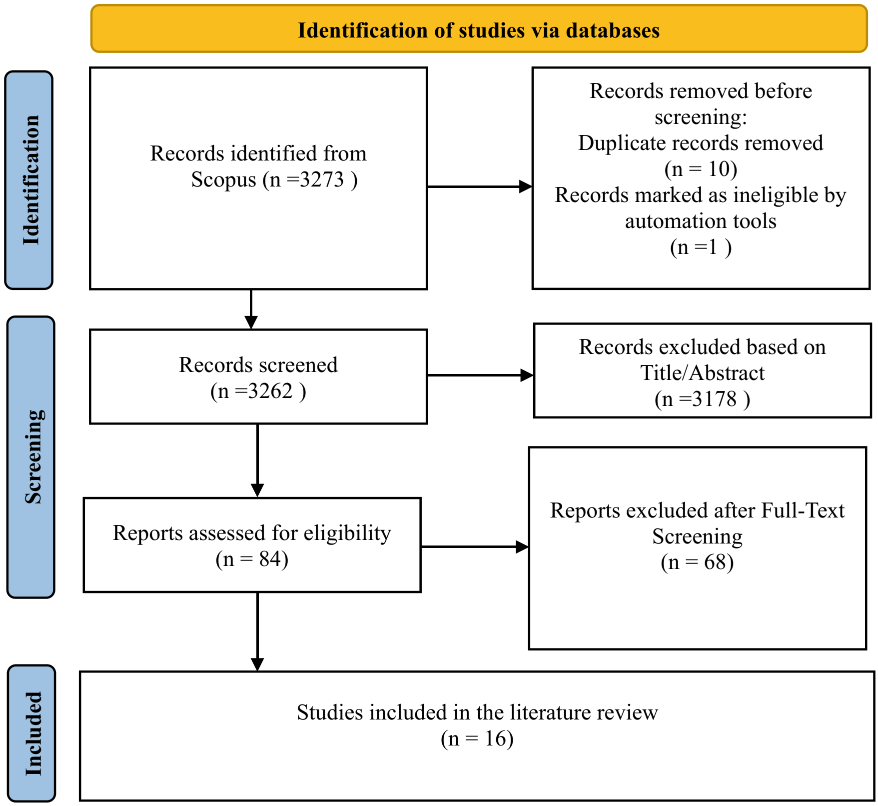


**Fig. 1** The PRISMA diagram for the selection process of included studies

## 3 Results

Based on the initial phase of the literature search, a total of 3262 studies were identified. Following a rigorous evaluation based on the predefined selection criteria, 84 full-text articles were retrieved and scrutinized. Among them, sixteen studies emerged as meeting the predetermined inclusion criteria and the studies' characteristics are shown in Table 1. The table offers a comprehensive overview of different studies focused on the impact of lighting on human well-being and performance. Each study approaches the subject from a unique perspective, examining various objectives related to lighting and employing distinct methodologies. The findings from these studies collectively emphasize the vital role of lighting in influencing the physical, psychological, and social aspects of individuals. They highlight the positive effects of sufficient and high-quality lighting on mood, well-being, productivity, and cognitive function. Conversely, studies also reveal the negative consequences of inadequate or poor lighting, such as discomfort, reduced work efficiency, and health-related issues. By consolidating and comparing the key insights from these

**Table 1** Comparative analysis of lighting effects on human well-being and performance from different studies

| No. | Author(s)/ year | Study's objectives related to lighting | Methodology | Major findings related to lighting |
|---|---|---|---|---|
| 1 | Peeters et al. [18] | Investigate effects of more intense light on alertness, mood, sleep, and light appraisals in operational work environments. Examine how these effects translate to experiences in-office settings | Two field studies conducted in spring and winter and daytime exposure to more intense light for 4 h a day for one workweek | More electric light had negative effects on sleepiness and vitality. More electric light was experienced as less pleasant |
| 2 | Cupkova et al. [4] | Develop an intelligent lighting system that can detect human emotions and adjust the lighting accordingly to improve mental | Involves training a neural network for emotion detection using the FER2013 dataset and implementing an automated lighting control system that can adjust the lighting colour based on the emotional result | Adjusting RGB LED strip colour based on the emotional state of individuals can positively impact their mental well-being and productivity in the workplace |
| 3 | Benedetti et al. [3] | Investigate impact of dynamic lighting control on visual comfort, alertness, and cognitive performance. Compare optimized dynamic lighting control to conventional lighting control | Visual Analogue Scale (VAS) for subjective alertness ratings and High Dynamic Range (HDR) vision sensors for monitoring lighting parameters | Optimal dynamic lighting control improves subjective alertness and glare indexes compared to conventional lighting control |
| 4 | Deng et al. [5] | Predict and track the real-time states of each individual and assist with decision-making for indoor environment control in smart buildings, which includes recommendations regarding the lighting levels of the rooms | A real-time monitoring framework, to evaluate indoor experiences by integrating various interconnected systems such as recognition, prediction, visualization, feedback, and control | This framework can determine optimal lighting levels that enhance occupants' work engagement, providing recommendations for appropriate indoor lighting levels |

(continued)

**Table 1** (continued)

| No. | Author(s)/ year | Study's objectives related to lighting | Methodology | Major findings related to lighting |
|---|---|---|---|---|
| 5 | Králiková et al. [13] | Examine the dependence between lighting conditions and health problems and evaluate lighting conditions in the workshop using software | Statistical methods used to examine the dependence between characteristics and health problems and lighting design software used to evaluate lighting conditions | Use of more efficient LED luminaries in the workplace can improve lighting conditions and potentially have positive effects on employee health and well-being |
| 6 | Katabaro and Yan [10] | Analyse the effects of lighting quality on the working efficiency of workers in Tanzania | Questionnaire was administered to respondents to establish their rate of satisfaction, feelings about the lighting environment, the existence of both visual and non-visual problems in their workplace, and how these factors influenced their health and working efficiency | The majority of the occupants were dissatisfied with the lighting quality in their working environment, and some respondents reported that it significantly affected their work efficiency and well-being |
| 7 | Kazemi et al. [11] | Compare the effects of different lighting sources (LED, compact fluorescent, fluorescent with warm and cool colour temperature) on performance, alertness, visual comfort level, and preferences | A repeated-measures experimental design, and A laboratory-controlled experiment was conducted on 20 postgraduate students who participated in a series of tests under four different light sources | LED and fluorescent with cool colour temperature were more Beneficial for alertness level and performance and LED was the most preferred and most comfortable lighting condition |
| 8 | Kim et al. [12] | Determine the risk-based energy savings potential of an interactive lighting system while evaluating programmatic success through the measurement of occupants' psychosocial variables | Extensive datasets available from the case study building with statistical methods to inform generalizable economic decisions and using occupant feedback about their perceptions concerning particular psychosocial variables for triangulation | Improved lighting environment, including sufficient light levels, has positively affected occupants' perception of fatigue levels, efficiency, and productivity at work |

(continued)

**Table 1** (continued)

| No. | Author(s)/ year | Study's objectives related to lighting | Methodology | Major findings related to lighting |
|---|---|---|---|---|
| 9 | Lee anf Yoon [15] | Investigate Colour Rendering Index (CRI) recommendations for LED lighting and determine the effect of CRI on colour rendition | Fidelity Index and the Gamut Index as complementary metrics to evaluate perceived colour quality, in addition to the CIE Ra and questionnaire | Colour Rendering Index (CRI) recommendations for LED lighting in spaces needing better colour rendition |
| 10 | Hamedani et al. [6] | Examine physiological, ocular, and performance responses under different lighting conditions and determine relationships between glare factors and physiological, ocular, and performance measures | Correlation analysis and multiple regression analysis | Physiological and ocular measures like Pupil Diameter, Pupillary Unrest Index, Blink Rate, Blink Amplitude, Eye Fixation Rate, and Eye Convergence can serve as indicators of visual discomfort, with PUI and BA linked to relative glare factors and FR- and PD-associated with absolute glare factors |
| 11 | Lee and Kim [14] | Investigate the effect of illuminance and correlated colour temperature of LED lighting on working memory and propose an optimal lighting environment for real-life applications | Repeated measures analysis of variance (ANOVA) was used to analyse the effect of illuminance and correlated colour temperature on working memory, and post hoc analysis was performed using the least significant difference (LSD) method | Both illuminance and correlated colour temperature were found to be significant variables affecting working memory, and the condition of bright light (1000 lx) and 5,000 K correlated colour temperature showed the best performance in working memory |
| 12 | Jarboe et al. [9] | Investigate the effectiveness of light-emitting diode lighting and provide circadian stimulus in-office spaces while minimizing energy use | Photometric simulations model in open-office area | LED lighting provides effective circadian stimulus in-office spaces |

(continued)

**Table 1** (continued)

| No. | Author(s)/ year | Study's objectives related to lighting | Methodology | Major findings related to lighting |
|---|---|---|---|---|
| 13 | Papatsimpa et al. [17] | Understand how lighting environments affect the distribution of chronotypes in the population and to use This understanding to design guidelines for workplace lighting that support human performance, health, and well-being | Mathematical model of the human circadian pacemaker to understand How light in the built environment changes the chronotype distribution in the population | Higher daytime illuminance narrows and advances the distribution of chronotype, counteracting the Delaying effects of evening light exposure on circadian phase and sleep, and is associated with better physical and mental health, improved academic performance, and enhanced mood |
| 14 | Aries et al. [1] | Assess effects of dynamic light patterns on well-being and performance and evaluate the impact of dynamic white-light LED-systems on office environments | Dual-experimental methodology to investigate the effects of a dynamic lighting pattern on human well-being and performance in both simulated and operational office environments | Dynamic light patterns can improve human well-being and performance |
| 15 | Sun et al. [20] | Investigate the effect of lighting environment on work performance and determine the optimal combination of lighting factors for improving productivity in commercial offices | Experiment conducted in a laboratory located in the Architecture Department Building at Shanghai Jiao Tong University in China, where the lighting, thermal, visual, and acoustic environment could be controlled independently | High illuminance, uniform illuminance, and high/medium CCT improve perception, learning, memory function, and tear film quality, while low illuminance, non-uniform illuminance, and moderate CCT are suitable for thinking and executive performance |

(continued)

**Table 1** (continued)

| No. | Author(s)/ year | Study's objectives related to lighting | Methodology | Major findings related to lighting |
|---|---|---|---|---|
| 16 | Zhang et al. [23] | Better understand the impact of dynamic lighting on office occupants' health, well-being, and experience | Utilized a four-month experiment with fifteen participants working in-office modules to investigate the non-visual impacts of dynamic lighting using both objective measures and subjective surveys | Dynamic lighting during the daytime can improve alertness and mood, potentially reducing feelings of sleepiness, while at nighttime, it can lead to a decrease in perceived sleep quality and sleep time |

diverse studies, the table provides valuable and comprehensive information on the relationship between lighting and human experiences across different contexts.

### *3.1 Different Types of Artificial Lighting and Their Effects on Workers at the Workplace*

The systematic literature review primarily investigates the effects of two major lighting types, fluorescent and LED, on workers in workplace settings. The transition from fluorescent to LED lighting is examined for its advantages, including energy efficiency and enhanced well-being [8, 21]. Fluorescent lighting and LED lighting have been extensively studied in terms of their effects on workers in the workplace and their effect on human health and work performance [10]. The emergence of LED lighting has revolutionized lighting technology, offering enhanced energy efficiency, colour control, and longevity in-office environments [19]. LED lighting technology can save up to 50% in costs with a return on investment of 6 months [8]. The distinct characteristics of these lighting types lay the foundation for a comprehensive understanding of their effects on human behaviour.

The impact of artificial lighting types on human behaviour encompasses a wide array of physiological and psychological dimensions [4, 11, 13]. Circadian rhythms, the internal biological clocks governing sleep–wake cycles, are profoundly influenced by the spectral composition of artificial lighting [9, 10]. Melatonin regulation, crucial for healthy sleep patterns, is intricately tied to lighting characteristics, impacting sleep quality and overall well-being [10, 23]. The effects extend to mood and emotional responses, as different lighting types can evoke varying emotional states, from relaxation to alertness [18]. The quality of sleep is also intricately linked to lighting, as improper lighting conditions can disrupt sleep patterns and lead to sleep disturbances [11]. Furthermore, cognitive performance and concentration are heavily influenced by lighting types, with appropriate illumination enhancing focus and productivity [3, 18]. Conversely, inadequate lighting can lead to eye strain and visual discomfort, hampering task engagement [12, 13]. The perception of time and space is yet another facet influenced by lighting, as lighting characteristics can alter the perception of spatial dimensions and the passage of time. A comparative analysis of artificial lighting types reveals nuanced considerations that extend beyond their immediate effects on human behaviour. The use of LED task lighting in personal workspaces has been shown to positively impact employee comfort and perception of job content, while also potentially contributing to energy and cost savings [12]. Correlated colour temperature (CCT), a measure of warmth or coolness in lighting, holds psychological implications, with cooler lighting promoting alertness and warmer lighting evoking relaxation [11]. The spectral composition of lighting, particularly its blue light content, influences melatonin suppression and circadian rhythm disruption [9, 23]. User preferences and individual differences also guide lighting choices, as individual comfort and needs vary widely. This multifaceted comparative analysis underscores the necessity of informed lighting design that considers the interplay between lighting types, human behaviour, and holistic well-being [13, 20].

Incorporating insights from studies such as Peeters et al. [18], Cupkova et al. [4], and Benedetti et al. [3], the effects of different artificial lighting types on human behaviour emerge as a complex interplay between physiological responses, emotional states, and cognitive engagement. As research delves deeper into the intricate mechanisms through which lighting influences behaviour, it becomes evident that lighting design transcends mere illumination, it is a strategic endeavor that shapes human experience and well-being. The findings from research conducted by Katabaro and Yan [10] provide a window into the tangible impacts of lighting quality on working efficiency. Dissatisfaction with the lighting environment was reported by a majority of respondents in their study, revealing a direct link between the quality of lighting and overall work efficiency. This aligns with the broader understanding that inadequate lighting can contribute to discomfort, visual strain, and subsequently diminished productivity. Similarly, the investigation by Kazemi et al. [11] on the effects of different lighting sources elucidates the interrelation between lighting, alertness, and performance. The preference for LED lighting with cooler colour temperatures highlights the potential for lighting to enhance alertness levels and ultimately impact cognitive performance.

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Additionally, the impact of lighting on chronotypes and the distribution of human biological rhythms, as explored by Papatsimpa et al. [17], underscores the profound physiological interactions between lighting and human behaviour. The intricate mathematical model developed to understand the intricate interplay between lighting and circadian rhythms highlights the potential for lighting design to significantly impact human health, performance, and mood. Furthermore, the energy-efficient attributes of LED lighting, highlighted by Jarboe et al. [9], provide an important consideration in the context of sustainable workplace design. The effectiveness of LED lighting in providing effective circadian stimulus while minimizing energy consumption supports the integration of sustainable lighting solutions in modern workplaces. While the study by Lee and Yoon [15] delves into the significance of Colour Rendering Index (CRI) recommendations for LED lighting. By evaluating the impact of CRI on colour rendition using metrics such as the Fidelity Index and the Gamut Index, alongside the CIE Ra and questionnaires, this study addresses the crucial aspect of perceived colour quality. With a focus on spaces requiring enhanced colour rendition, the research provides valuable insights into the intricate relationship between lighting and visual perception.

Moreover, Hamedani et al. [6] provide an in-depth exploration of physiological, ocular, and performance responses under different lighting conditions, specifically examining the relationships between glare factors and various measures. Through correlation analysis and multiple regression analysis, they uncover physiological and ocular indicators, including Pupil Diameter, Pupillary Unrest Index, Blink Rate, Blink Amplitude, Eye Fixation Rate, and Eye Convergence, that serve as valuable markers of visual discomfort. Moreover, their findings illuminate the interplay between these indicators and relative and absolute glare factors, offering valuable insights into the intricate mechanisms through which lighting can impact visual comfort and performance.

## 3.2 *Impact of Lighting on Workplace Behaviour*

Lighting conditions in the workplace can influence workplace behaviour, including actions, interactions, and attitudes displayed by individuals within a professional setting [11, 12, 20].

### 3.2.1 Productivity and Lighting

The impact of lighting on workplace behaviour is particularly pronounced in relation to productivity. Research such as that of Peeters et al. [18] demonstrates that maintained illuminance can affect alertness, mood, sleep, and overall perception of light. The study examines two lighting scenarios within the office, utilizing 31 LED luminaires, which involve low illuminance: dim light (10–100 lx), and high illuminance: bright light ($\geq$ 1000 lx), as typically investigated in controlled laboratory environments. The study found that increasing maintained illuminance did not lead to positive results and resulted in negative effects on sleepiness, vitality, and mood. Cupkova et al. [4] further contribute by introducing intelligent lighting systems that adapt to human emotions, showcasing how lighting can play a role in mental well-being and productivity. The study highlights the potential benefits of autonomous intelligent lighting systems, including the elimination of distractions caused by manual configuration and the positive impact on productivity, health, and well-being.

Additionally, Benedetti et al. [3] explore the optimization of dynamic lighting control, revealing its positive influence on alertness and cognitive performance. The study suggests that higher illuminance levels and higher CCT may contribute to increased alertness and positive affect in-office users. However, the study does not provide specific lux values for the lighting conditions tested. Deng et al. [5] extend this by proposing real-time monitoring frameworks for indoor environments, suggesting that lighting levels can be adjusted to enhance occupants' work engagement. The study analysed the impact of various maintained illuminance values (i.e. 200 lx, 500 lx, and 1000 lx) on work engagement among office workers. The study revealed that both higher (1000 lx) and lower (200 lx) illuminance values have a detrimental effect on work engagement when compared to the 500-lx level. These studies underline lighting's contribution to enhancing task performance, reducing errors, and influencing cognitive workloads, thereby shaping workplace behaviour.

### 3.2.2 Mood and Emotional Well-Being

Lighting's impact on mood regulation is a vital component of workplace behaviour. Dynamic lighting, as explored by Benedetti et al. [3] evaluated the impact of dynamic lighting control on office users' visual comfort, alertness, and cognitive performance. The study found that study showed that exposure to optimized dynamic lighting control over several days was superior in terms of subjective alertness and glare indexes compared to conventional lighting control. However, Aries et al. [1], examined the effects of dynamic lighting patterns on human well-being and performance in both laboratory and field settings. The study found in the field study, suggested higher satisfaction with constant light levels compared to dynamic light patterns. Lee and Kim [14] investigated the effects of illuminance levels and correlated colour temperatures on working memory. They used an automatic LED lighting device with six different lighting conditions, including two illuminance conditions (400 lx and 1000 lx) and three correlated colour temperature conditions (3000 K, 5000 K, and 7000 K). The study showed that both illuminance and correlated colour temperature significantly affected working memory. The performance of working memory was found to be better in the bright light condition (1000 lx) compared to the relatively dim condition (400 lx). Kazemi et al. [11] found that LED lighting with cooler colour temperatures was preferred by participants, suggesting its potential to positively influence emotional responses and overall well-being. Additionally, the study observed a significant increase in subjective and objective alertness levels under LED lighting with cooler colour temperatures compared to fluorescent lighting sources.

### 3.2.3 Health and Wellness

Lighting's role in supporting circadian rhythms, preventing health issues, and reducing fatigue is a critical aspect of workplace behaviour. Papatsimpa et al. [17] emphasize lighting's impact on chronotypes, showcasing how it can influence human health, performance, and mood. The study shows that individuals exposed to light during late evenings and nights, with the usual indoor evening lighting of 35 lx, over 20% of people could develop a preference for staying up later, potentially leading to more sleep-related issues due to differences in sleep schedules. Hamedani et al [6] delve into physiological responses under various lighting conditions, indicating the potential for lighting to impact employee well-being and comfort levels. The study found that glare factors, both absolute (luminance and illuminance values) and relative (contrast), can predict physiological and ocular responses, such as Pupil Diameter (PD), Pupillary Unrest Index (PUI), Blink Rate (BR), and Blink Amplitude (BA). Kim et al. [12] connect improved lighting environments to reduced fatigue levels, affirming lighting's contribution to employee health and productivity. The study examined a single floor equipped with the same number of dimmable ceiling-mounted LED lighting fixtures (1839 lm/fixture) and desk lamps, each with less luminous flux compared to the existing fluorescent ceiling fixtures (2800 lm/fixture). The study found that the new interactive LED lighting improved workers' overall productivity and efficiency and reduced fatigue.

## 4 Discussion

The studies cited in the previous sections provide valuable insights into the impact of lighting on workplace behaviour. According to this systematic literature review findings, this study emphasizes two crucial aspects: fluorescent and LED lighting, the primary types of artificial lighting significantly influencing workers' productivity due to their common usage in-office buildings. Also, the study investigates the impact of lighting on workplace behaviour, encompassing productivity, cognitive performance, and well-being [11]. The analysis delves deeply into the realm of artificial lighting, focussing on the transition from conventional fluorescent lighting to modern LED lighting. Historically, fluorescent lighting dominated due to energy efficiency and widespread use in offices. However, the emergence of LED lighting offers improved energy efficiency, colour control, and durability, fostering cost-effective, visually comfortable, and productive workspaces [1, 11]. Significantly, LED lighting's ability to mimic various lighting patterns, as demonstrated by studies such as Aries et al. [1] and Zhang et al. [23], holds the potential to positively influence worker alertness, mood, and overall well-being. The study by Kazemi et al. [11] accentuates the significance of correlated colour temperature (CCT) and spectral composition, underscoring LED lighting's capacity to evoke diverse emotional states. Moreover, individual preferences and comfort preferences, as illuminated by Kim et al. [12], underline the pivotal role of informed lighting design in catering to individual needs. Economically, the shift toward LED lighting not only promises cost savings due to its prolonged lifespan but also aligns seamlessly with contemporary sustainability objectives. The research conducted by Jarboe et al. [9] underscores LED lighting's potential to offer optimal circadian stimulus while minimizing energy consumption, thereby bolstering the integration of energy-efficient lighting solutions within contemporary workplaces.

The review meticulously explores the intricate relationship between lighting conditions and workplace behaviour, encompassing physiological, emotional, and cognitive aspects. Studies such as Peeters et al. [18] shed light on the pivotal role of sustained illuminance in shaping alertness, mood, sleep quality, and overall light perception. Nevertheless, the research also highlights the necessity for a balanced approach, as excessively high or low illuminance levels can have detrimental effects, a notion underscored by Deng et al. [5]. Emotional well-being constitutes another key area profoundly impacted by lighting, with dynamic lighting patterns and correlated colour temperature variations playing a pivotal role in evoking distinct emotional responses. Benedetti et al. [3] and Aries et al. [1] emphasize lighting's potential to enhance alertness, cognitive performance, and mood regulation. Furthermore, the implications of lighting on health and overall well-being emerge as a crucial dimension. The review underscores lighting's intricate interplay with circadian rhythms, sleep patterns, and chronotypes, a facet aptly demonstrated by Papatsimpa et al. [17]. The complex interrelation between glare factors and physiological responses, as illuminated by Hamedani et al. [6], unveils insights into the nuanced mechanisms through which lighting can significantly influence visual comfort.

The review underscores the influence of fluorescent and LED lighting on worker productivity and behaviour. LED lighting's adaptability and mimicry of different patterns positively affect well-being and mood. Synthesizing the research findings underscores the critical need for strategic lighting design that accounts for the intricate interplay between lighting types and their consequential impact on human behaviour, thereby fostering work environments characterized by heightened productivity, satisfaction, and overall well-being.

However, there are still research gaps that need to be addressed. Below are research gaps and critical analyses that could be explored in the context of the studies cited.

Cupkova et al. [4], Kim et al. [12], Kazemi et al. [11], and Sun et al. [20], have used questionnaires to study the effects of lighting on participants. However, their sample sizes were small and often limited to a single group. For instance, Kazemi et al. [11] found it challenging to generalize their results beyond the postgraduate students they surveyed. Similarly, Kim et al. [12] and Sun et al. [20] studied only 10 occupants and young college students, respectively, making it difficult to apply their findings to general office workers. To improve the validity of such studies, it is suggested that future research should include larger and more diverse groups of at least 30 participants from various ages, genders, and occupations. Several research papers, such as those conducted by Zhang et al. [23], Kazemi et al. [11], and Deng et al. [5], have noted issues with the evaluation methods and data analysis used to study the impact of lighting on office workers. For instance, Deng et al. [5] used Digital ID (DID) to assess indoor comfort, but this raised privacy concerns due to the private information contained in the DID database.

Besides, Lee and Kim [14], and Katabaro and Yan [10], have examined the effects of lighting on office workers' visual comfort, productivity, and well-being. However, these studies faced limitations in their experimental techniques, model approaches, and conditions. For instance, Lee and Kim [14] did not account for temporal variables such as morning and afternoon that could affect working memory. Katabaro and Yan [10] did not clearly distinguish between sunlight and artificial light during illuminance measurements. To address these issues, it is recommended that future research consider the possibility that task performance in the morning and afternoon affects working memory. Studying performance with multi-factorial designs in a human-centered optimized manner can lead to a deeper understanding of lighting effects on task performance and improved lighting design and operation in buildings overall.

Finally, further research is required on the impact of lighting glare and colour rendering on human behaviour which has not been studied deeply in the most of research, affecting visual performance and comfort. Briefly, several studies have examined the impact of lighting on office workers, but there are still limitations and gaps in the research that need to be addressed. Future research should include larger and more diverse groups, utilize a range of sources, isolate the effects of individual design parameters, and consider temporal variables. Additionally, further research is needed on the impact of lighting glare and the Colour Rendering Index (CRI) which is the most utilized and globally recognized measure for evaluating colour quality on human behaviour. By addressing these issues, we can gain a deeper understanding of lighting effects and improve lighting design and operation in buildings overall.

## 5 Conclusion

The body of research examining the influence of different artificial lighting types on workplace behaviour yields a multifaceted understanding. Fluorescent and LED lighting have received considerable attention, with fluorescent lighting's energy efficiency contrasting LED lighting's innovative features. LED lighting demonstrates superiority over fluorescent lighting in enhancing worker performance and productivity due to its innovative features and potential benefits on circadian rhythm regulation, emotional responses, cognitive performance, and visual comfort. This exploration has unveiled a range of effects on human behaviour, encompassing circadian rhythm regulation, emotional responses, cognitive performance, and visual comfort. Optimizing correlated colour temperature (CCT) to align with cooler colours, reducing glare through proper lighting design, and ensuring high colour rendering index (CRI) values can collectively enhance worker productivity and well-being in the workplace. Furthermore, maintaining illuminance levels at an appropriate balance, considering both the intensity and quality of light, contributes to creating an environment that fosters optimal performance and positive employee experiences.

The reviewed studies emphasize the complex interplay between lighting conditions and human responses in professional settings. Productivity studies highlight the nuanced effects of illuminance on alertness, mood, and sleep, while dynamic lighting control demonstrates the potential for cognitive performance enhancement. Mood and emotional well-being analyses underline the importance of user preferences in dynamic lighting's impact. Health-wise, lighting's role in circadian rhythms and preventing health issues emerges as vital. While research strides have illuminated the intricate connection between lighting and workplace behaviour, gaps in sample sizes, participant diversity, evaluation methods, and data analysis persist. Ethical considerations and experimental design issues also need addressing. Additionally, unexplored factors like lighting glare and the Colour Rendering Index present avenues for further investigation. As such, a full approach to future research is crucial for comprehensively understanding and controlling the potential of artificial lighting's impact on the workplace environment.

As this review presents a systematic analysis of empirical studies conducted in the past five years on the effects of artificial lighting on employee productivity, cognitive performance, and well-being, its strength lies in its methodical approach to gathering and scrutinizing recent research, focussing specifically on peer-reviewed articles from a single database. However, future research could benefit from broadening the scope to include other types of academic work, such as doctoral dissertations and research reports. Furthermore, the use of more specialized databases like the Web of Science Core Collection, PsycINFO, and PubMed could yield more extensive results.

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## References

1. Aries MBC, Beute F, Fischl G (2020) Assessment protocol and effects of two dynamic light patterns on human well-being and performance in a simulated and operational office environment. J Environ Psychol 69. https://doi.org/10.1016/j.jenvp.2020.101409
2. Bao J, Song X, Li Y, Bai Y, Zhou Q (2021) Effect of lighting illuminance and colour temperature on mental workload in an office setting. Scient Rep 11(1). https://doi.org/10.1038/s41598-021-94795-0
3. Benedetti M, Maierová L, Cajochen C, Motamed A, Münch M, Scartezzini JL (2019) Impact of dynamic lighting control on light exposure, visual comfort and alertness in office users. J Phys: Conf Series 1343(1). https://doi.org/10.1088/1742-6596/1343/1/012160
4. Cupkova D, Kajati E, Mocnej J, Papcun P, Koziorek J, Zolotova I (2019) Intelligent human-centric lighting for mental wellbeing improvement. Int J Distrib Sensor Netw 15(9). https://doi.org/10.1177/1550147719875878
5. Deng M, Wang X, Menassa CC (2021) Measurement and prediction of work engagement under different indoor lighting conditions using physiological sensing. Build Environ 203. https://doi.org/10.1016/j.buildenv.2021.108098
6. Hamedani Z, Solgi E, Hine T, Skates H (2020) Revealing the relationships between luminous environment characteristics and physiological, ocular and performance measures: an experimental study. Build Environ 172. https://doi.org/10.1016/j.buildenv.2020.106702
7. Harris L, Heschong L, Heerwagen JH, Jones CC (1998) Potential productivity benefits from high quality lighting in Federal buildings (No. CONF-980815-). Dept. of Energy, Washington, DC (US). https://www.osti.gov/biblio/20006345.
8. Hussin MZ, Shukor SFA, Sin NDM, Yusof Y, Nor MZM, Rahman NHA (2021) Integration of LED-based lighting in academic buildings for energy efficiency considerations. Bull Elect Eng Inform 10(1):93–100. https://doi.org/10.11591/eei.v10i1.2513
9. Jarboe C, Snyder J, Figueiro MG (2020) The effectiveness of light-emitting diode lighting for providing circadian stimulus in office spaces while minimizing energy use. Light Res Technol 52(2):167–188. https://doi.org/10.1177/1477153519834604
10. Katabaro JM, Yan Y (2019) Effects of lighting quality on working efficiency of workers in office building in Tanzania. J Environ Pub Heal. https://doi.org/10.1155/2019/3476490
11. Kazemi R, Choobineh A, Taheri S, Rastipishe P (2018) Comparing task performance, visual comfort and alertness under different lighting sources: an experimental study. EXCLI J 17:1018–1029. https://doi.org/10.17179/excli2018-1676
12. Kim AA, Wang S, McCunn LJ (2019) Building value proposition for interactive lighting systems in the workplace: combining energy and occupant perspectives. J Build Eng 24. https://doi.org/10.1016/j.jobe.2019.100752
13. Králiková R, Lumnitzer E, Džuňová L, Yehorova A (2021) Analysis of the impact of working environment factors on employee's health and wellbeing; workplace lighting design evaluation and improvement. Sustainability (Switzerland) 13(16). https://doi.org/10.3390/su13168816

14. Lee CW, Kim JH (2020) Effect of LED lighting illuminance and correlated color temperature on working memory. Int J Optics. https://doi.org/10.1155/2020/3250364
15. Lee SJ, Yoon HC (2021) LED lighting system for better color rendition space: the effect of color rendering index. J Asian Architect Build Eng 20(5):556–565. https://doi.org/10.1080/13467581.2020.1799801
16. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA, PRISMA-P Group (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Rev 4(1):1. https://doi.org/10.1186/2046-4053-4-1
17. Papatsimpa C, Schlangen LJM, Smolders KCHJ, Linnartz JPMG, de Kort YAW (2021) The interindividual variability of sleep timing and circadian phase in humans is influenced by daytime and evening light conditions. Scientific Rep 11(1). https://doi.org/10.1038/s41598-021-92863-z
18. Peeters ST, Smolders KCHJ, Vogels IMLC, de Kort YAW (2021) Less is more? effects of more vs. less electric light on alertness, mood, sleep and appraisals of light in an operational office. J Environ Psychol 74. https://doi.org/10.1016/j.jenvp.2021.101583
19. Shankar A, Krishnasamy V, Babu BC (2020) Smart LED lighting system with occupants' preference and daylight harvesting in office buildings. Energy Sourc, Part A: Recov, Utilizat Environ Effects. https://doi.org/10.1080/15567036.2020.1859650
20. Sun C, Lian Z, Lan L (2019) Work performance in relation to lighting environment in office buildings. Indoor Built Environ 28(8):1064–1082. https://doi.org/10.1177/1420326X18820089
21. Uken E, Bevan G, Smith R (2013) LED tube retrofits for fluorescent lighting in offices. In: 2013 Proceedings of the 10th Industrial and Commercial Use of Energy Conference, 1–4.
22. van Duijnhoven J, Aarts MPJ, Kort HSM (2021) Personal lighting conditions of office workers: an exploratory field study. Light Res Technol 53(4):285–310. https://doi.org/10.1177/1477153520976940
23. Zhang R, Campanella C, Aristizabal S, Jamrozik A, Zhao J, Porter P, Ly S, Bauer BA (2020) Impacts of dynamic led lighting on the well-being and experience of office occupants. Int J Environ Res Public Health 17(19):1–27. https://doi.org/10.3390/ijerph17197217

# Suitability of FIDIC Contracts for Post-disaster Reconstruction of Infrastructure Projects

**Ayush Puri, Naseem Ameer Ali, and Mohamed Elkharboutly**

## 1 Introduction

SFCCs are widely used in the construction industry, including post-disaster reconstruction projects. These contracts are readily available "off-the-shelf" and are produced and sold by industry bodies recognised by government and construction stakeholders [27].

The popularity of these contracts is understandable, given that creating a contract from scratch for each project can be daunting and costly [16, 36, 47, 50]. Moreover, it is widely accepted that standard contracts offer a fair and equitable distribution of risks among the parties involved, thus ensuring a level playing field [16, 36, 47]. Additionally, with all the resources and training materials available from industry experts, they are assumed to be well-understood by industry stakeholders [36].

While there are benefits to using SFCCs, using them as a universal solution for all kinds of projects, including post-disaster reconstruction projects, is impractical and has been criticised for its inadequacy. Ali and Wilkinson [3] and Rameezdeen and Rodrigo [47] criticised SFCCs for their complexity of language, readability, and need for excessive modifications. Additionally, the use of routine legislation, policies, and processes was highlighted as a drawback by various post-disaster reconstruction stakeholders [31, 49]. Li [33] also criticised the use of inadequately modified SFCCs in post-disaster reconstruction. Such usage introduces ambiguities and inconsistencies, ultimately increasing the likelihood of disputes and other contractual issues.

Using the FIDIC SFCC, a widely used standard form in regular construction and reconstruction, this study aims to demonstrate the challenges associated with using

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SFCCs from routine construction to post-disaster reconstruction through content analysis.

## 2 Research Methods

The literature for this study was collected from academic databases, books, and governmental and non-governmental reports, with a focus on publications in the English language. Given the interdisciplinary nature of the study, which encompasses disaster and post-disaster reconstruction, SFCCs including FIDIC, and plain language drafting, literature from these fields was identified using specific keywords such as standard forms, construction contracts, plain language, reconstruction, and post-disasters. Subsequently, papers unrelated to construction were excluded from the study to ensure relevance. Additionally, a snowball approach was also employed, exploring citations within the relevant papers to identify additional relevant literature for the study.

### *2.1 Content Analysis*

After identifying the relevant literature for the study, they were examined thoroughly to address the research question regarding the impact of construction contracts from routine construction on post-disaster reconstruction performance. This process involved several additional steps including the following:

- Differentiating between standard construction and reconstruction,
- Evaluating the strengths and weaknesses of available SFCCs like FIDIC,
- Identifying reported challenges in utilising SFCCs, and
- Understanding the reasons behind the limited applicability of existing SFCCs from routine construction in post-disaster infrastructure reconstruction scenarios.

## 3 Literature Review

After discussing the SFCCs, this section highlights the significant differences reported in the literature between standard construction and post-disaster reconstruction. These differences are highlighted to demonstrate the inherent inapplicability of SFCCs for routine projects in the context of post-disaster reconstruction.

### *3.1 Standard Forms of Construction Contracts (SFCCs)*

The origin of SFCCs can be traced back to nineteenth and twentieth century Australia and the United Kingdom [5, 7]. After that, the standard forms have evolved to suit the modern needs of project management and to strengthen contracts further with the ubiquitous aim of protecting the parties' rights [29].

Nowadays, the SFCCs are considered as a means to standardise contractual provisions in the industry [50]. Their widespread use is because of the belief that they are generally understood by the users, thereby minimising disputes from misinterpretation [27, 36]. A contract balancing the risks between parties is fundamental in construction as it directly influences their performances [32]. Furthermore, standard forms are popular because the industry believes standard forms allocate risks between parties fairly [16].

Some popular forms currently used in the industry are the FIDIC suites of contracts, the New Engineering Contract (NEC) series of contracts, and the Joint Contracts Tribunal (JCT) contract families. Due to the availability of multiple standard forms, it is difficult for parties to select the most appropriate contract for their project. In the construction industry, the choice of a contract is not only determined by factors such as the project's size, nature, and complexity but also based on parties' familiarity, preferences and inclination towards specific SFCCs [16, 20]. As a result, certain SFCCs have gained tremendous popularity and widespread adoption than others. Especially the widespread preference for FIDIC forms in international projects can be attributed to its foundation in the common law system, as highlighted by Purba and Prastowo [46] and Heaphy [24].

### *3.2 Challenges and Limitations of Current SFCCs*

SFCCs offer significant advantages in the construction industry, as they eliminate the necessity of engaging a lawyer to create a contract from scratch for each project. Nonetheless, despite continuous improvement efforts, these standard forms still fail in one crucial aspect: ensuring clear and easily understandable contracts for all stakeholders involved.

Specific challenges relating to current SFCCs are discussed in the sections.

#### 3.2.1 Readability

The readability challenge in SFCCs stems from using complex legal language, commonly known as "legalese", in the contracts. According to Ali and Wilkinson [3], including legal jargon, lengthy and puzzling sentences, and multiple cross-references in SFCCs pose significant challenges for parties involved as they struggle to comprehend the precise terms and conditions to which they are legally obligated to adhere.

The challenge is further exacerbated in large projects, where extensive contract modifications across multiple negotiations further impede comprehension. These negotiations also involve changes to numerous documents spanning hundreds of pages, which lead to conflicts and inconsistencies between documents. Bell [7] further reinforces this notion by highlighting that in most modified contracts, parties often have insufficient time to thoroughly review and understand the heavily modified terms, leading to inconsistencies between their expectations and the actual content of the contract. These issues can lead to significant disputes during project execution. However, since the construction industry operates on a "relational basis", there is a prevalent tendency for parties to prioritise trust over considering the potential legal consequences [35].

### 3.2.2 Misinterpretations

Understanding contracts can be incredibly daunting, as any misinterpretations leading to non-compliance with contractual obligations could have severe legal consequences. The "duty-to-read" legal doctrine binds parties to the terms they agreed to during the contract signing. Signing a contract without a thorough understanding of its terms does not absolve the parties from their obligations, as a lack of comprehension at the time of signing does not release them from the responsibilities outlined in the contract [6, 44, 47]. This subject has led to assertions that SFCCs are one of the leading causes of contractual disputes [8].

The complex nature of the construction industry exposes it to the risk of disputes, and misunderstanding the contract itself is the root of some disputes [41]. Mohamed et al. [39] add that disputes are an eventuality in construction projects, and the best means to avoid disputes is to prevent issues from turning into a dispute. Furthermore, in the study by Mohamed et al. [39], construction claims were stated as the primary source of dispute in construction, and poorly drafted contracts were identified as one of the eight most important factors leading to claims and possible disputes.

### 3.2.3 Complexity and Adversarial Relationships

From a different perspective, parties well-versed in intricate contractual language have long been exploiting complex legal terminology and imposing demanding contract clauses for the past two centuries, placing the other party at a disadvantage due to their limited legal knowledge [13]. This problem has fostered adversarial relationships in construction, which is not healthy for the industry. Construction involves numerous stakeholders who may come from legal and non-legal backgrounds. Moreover, owners, engineers, contractors, contract administrators, etc., who primarily use these contracts, are from non-legal backgrounds [3]. These users often criticise SFCCs for being too complex for a layperson [47].

### 3.2.4 Other Limitations of SFCCs

Other limitations of SFCCs can be summarised as follows:

- They have become overly complicated and often fail to reflect the parties' true intentions [35].
- They lack clearly defined design objectives and disregard risk allocation principles [37].
- They are susceptible to impairment when modified extensively to accommodate project-specific requirements, thereby altering the intended interactions between various clauses [36].
- They are challenging for someone not regularly exposed to their use [36].
- Revisions do not happen often, and much-need changes take a long time to come into effect [36].

Despite the limitations discussed above, it is important to acknowledge several proven advantages of current SFCCs. These contracts have also undergone periodic revisions making them more refined over time. Since 1957, FIDIC Red Book has undergone five revisions (now six), with each newer version clearer than the predecessor [47]. Other contracts like NEC have also dropped the use of "shall"—a word with at least 10 different meanings [11]—which many users loathed for creating ambiguity. The section below discusses some of the advantages of the SFCCs as discussed in the relevant literature.

### 3.2.5 Advantages of SFCCs

The advantages of SFCCs can be summarised as follows:

- They standardise contractual provisions [36, 50].
- They are developed by industrial bodies and are standardised and modified when needed [36].
- They prevent drafting mistakes [38].
- Possible risks, responsibilities and consequences of breach are generally covered in advance [5, 20].
- Users of contracts are more familiar with SFCCs as they are generally accompanied by user guides that help in contract administration [38].
- SFCCs help compare tenders, as each party is assumed to understand the risk allocation offered by the contract [36].
- They may also come as contract suites, ensuring consistency between the main contract and subcontract [28]. The availability of contract suites makes standard forms more appealing to the stakeholders.
- Some SFCCs are industry negotiated and thus can help courts interpret ambiguities fairly to all parties [28].

## 3.3 Uniqueness of Post-disaster Reconstruction

Emergencies that arise in the aftermath of a disaster possess distinct characteristics, and the reconstruction process itself is inherently challenging. Furthermore, the extent of damage caused by each disaster is different, making post-disaster situations unique from one disaster to another [53]. Hence, attempting to draw comparisons between things so far apart as standard construction and post-disaster reconstruction is trivial.

What differentiates post-disaster reconstruction from standard construction is the undertaking of projects in exceptionally demanding environments under numerous constraints [2]. Some constraints that differentiate post-disaster reconstruction from routine construction are briefly discussed.

### 3.3.1 Long Relief Period

Following a disaster, the initial response from government and aid agencies is to implement temporary relief measures for affected communities promptly. However, Brandon [10] and Ophiyandri et al. [42] highlight that a long gap between the relief period and subsequent reconstruction phase leads to delays, resulting in unutilised funds remaining idle in the bank. For instance, the situation in Sri Lanka following the 2004 tsunami is an example, where even after two years after the disaster, only one-third of the available funds were used [10].

### 3.3.2 Funding Challenges and Corruption

Funding constraints pose a significant challenge in reconstruction [21]. Due to insufficient funding and housing assistance to owners in Nepal, many poor households were forced to construct much smaller houses that did not fit their needs, or they resorted to acquiring loans from informal sources at exploitative interest rates [48].

In addition to working with budgetary challenges, post-disaster reconstruction is further hindered by corruption. Safapour et al. [52] emphasise that reconstruction projects face additional losses and cost overruns resulting from corrupt practices and fraudulent activities. A notable example is post-tsunami Sri Lanka, where the absence of stringent rules and regulations led to corruption and fraud. It was discovered that political ties and influence led to the displacement of those truly in need, with funding allocated for the refurbishment of unaffected houses.

### 3.3.3 Resource Shortages and Supply Chain Disruption

The pressure to complete projects within a short period of time during reconstruction lead to resource shortages and competition for available resources [14, 26, 62].

Uddin et al. [58] found that many unskilled resources lacking construction experience were hired in Nepal after 2015 earthquake due to scarcity of skilled resources and need for rapid reconstruction. Furthermore, resource challenge is exacerbated by supply chain disruption which causes logistical delay in supply of critical resources [21].

### 3.3.4 Coordination and Collaboration Challenges

Despite having similar objectives, reconstruction efforts are often hindered by lack of collaboration among various stakeholders. Xu et al. [65] attributes this harmonisation challenge to difference in organisational structure between organisations, which impede effective coordination resulting in inefficiencies. Additionally, the lack of collaboration and coordination among stakeholders also leads to duplication of efforts, as exemplified by the reconstruction efforts following 2004 Aceh Tsunami in Indonesia, where more than 100 organisations participated in reconstruction but lacked coordination [52].

### 3.3.5 Lack of or Poor Policies

Reconstruction policy is vital in early and efficient implementation of reconstruction projects. In absence of reconstruction policies, policies for routine construction are implemented, which are unable to cater the need of large-scale reconstruction. For example, using normal building and resource consent procedure following 2004 Manawatu flood and 2005 Matata Debris Flow led to substantial backlog for consents in New Zealand [31].

### 3.3.6 Contractual and Procurement Challenges

Construction contracts and procurement method employed in procuring contractor services also play a key role in reconstruction. Reconstruction efforts in Iraq were significantly affected by lowest price bid award procurement mechanism. This approach often resulted in contractors opting for cheap materials and resources, with intention of seeking additional money through change orders during implementation [61]. Additionally, due to the large scale of post-disaster reconstruction and the urgency to complete projects under tight timelines, complex administrative procedures demanded by donors often burden the implementers and further complicate the implementation process [18].

### 3.3.7 Community Engagement and Cultural Challenges

The community is a key stakeholder in reconstruction and plays a pivotal role in its success. When community needs are not sufficiently integrated into reconstruction, it results in stakeholder dissatisfaction [64]. Following the Chilean earthquake of 2010 and the 2008 Sichuan earthquake, failure to address the requirement of minority groups led to community discontent [17].

Furthermore, using modern materials in the name of progress during reconstruction has destroyed many areas rich in cultural heritages [23, 48]. Lin and Lin [34] confirmed the importance of considering local culture in their study. Through interviews with the communities, they discovered that the urban housing model used after the Morakot Typhoon in Taiwan was ill-suited to meet the needs of indigenous communities and subsequently led to dissatisfaction.

### 3.3.8 Health and Safety Challenges

The significance of health and safety in the construction industry extends beyond worker well-being—it also influences their motivation, productivity, and the overall quality of reconstruction efforts [58]. Post-disaster situations involve handling and working around debris which may be hazardous or contagious, thus posing additional health and safety issues. It is worth noting that adopting an owner-driven housing approach in Nepal resulted in owners pressuring workers to work long hours and under unsafe working conditions. This issue led to some workers denying risky jobs, while others continued to work due to the absence of alternatives [58].

### 3.3.9 Challenging Topography and Poor Weather

Reconstruction efforts become challenging when areas are inaccessible due to topography and poor weather. Acharya et al. [1] highlight that reconstruction was challenging in Nepal due to the rugged terrain. Some areas were inaccessible after the earthquake, and poor weather caused further delays.

Geographical factors can also give rise to substantial land ownership issues and pose significant challenges in terms of relocation. For example, after Typhoon Morakot in Taiwan, the government declared 160 localities unsafe and thus had a considerable task to relocate 6316 households comprising more than 19,000 individuals [34].

### 3.3.10 Other Challenges

In the aftermath of disasters, the affected population is impacted psychologically, leading to low morale and workers' lack of productivity [56, 58, 59]. Moreover, different environmental, health, and safety concerns could lead to the suspension of work, causing additional delays and cost overruns [51].

In addition to these challenges, it is crucial to acknowledge the impact of disasters on nations that lack the financial means to support themselves during and after disasters. Disaster statistics reveal a significant trend that while developing countries report lesser economic losses than developed countries during disasters, most disaster-related fatalities have tragically occurred in underprivileged countries [60]. Kenny [30] and Anbarci et al. [4] further confirm the notion of an inverse correlation between earthquake-related fatalities and per capita income, providing additional supporting evidence for this relationship. Therefore, reconstruction projects, by principle, are expected to be executed expeditiously to restore these underprivileged nations and their vulnerable, traumatised populations to a liveable state.

However, most reconstruction works in a developed or a developing country are ad hoc without proper strategic frameworks by modifying normal processes from standard construction [26]. Consequently, there are significant inefficiencies, additional costs, and delays, as legislation for conventional construction is not tailored to address the unique challenges posed by disasters. Le Masurier et al. [31] support this notion by noting that reconstruction projects are bound to be onerous and stricken by inefficiency if handled using legislation and regulation for standard construction. Therefore, the post-disaster scenario demands specific legislation, policies, rules, and regulations, including guidance for procurement and contracting to ensure success.

While studies like Le Masurier et al. [31], Rotimi and Wilkinson [49], and Wilkinson et al. [63] have looked into legislation for disasters, the literature is silent on how construction contracts developed for routine construction can impact post-disaster performance. Looking into reconstruction contracts is especially important as several studies like Sospeter et al. [54], Bilau et al. [9], Li [33], and Hidayat and Egbu [26] in post-disaster have cited poorly drafted contracts as a chronic challenge for reconstruction and well-drafted contracts as a success factor.

## *3.4 Limited Studies on Contracts for Disasters*

SFCCs and bespoke construction contracts are mainly used in reconstruction of infrastructure projects as they are usually large in scale, involve numerous stakeholders, and require significant funding. However, when it comes to residential constructions, it is homeowners who take the initiative to rebuild their houses with limited aid funds. Therefore, the scale of the project is often small, and homeowners may lack the necessary knowledge to engage contractors through formal contractual arrangements. Since most of post-disaster reconstruction literature focuses on housing reconstruction, the attention to infrastructure reconstruction and use of SFCCs in such context tend to lose focus.

Hidayat and Egbu [26] found that infrastructure reconstruction receives less attention in the literature while housing reconstruction is at the central focus in disaster related studies. In addition, studies by Daly and Brassard [18] and Tafti and Tomlinson [55] have also highlighted that a significant portion of reconstruction funding is allocated towards housing. While restoring the homes and livelihoods of affected communities is essential, infrastructure reconstruction is equally critical, as it serves a larger population at once. Restoring public facilities such as schools, healthcare facilities, roads, and railways is essential to ensure that a country is truly back to normal. Therefore, there is a pressing need for further research in the area of infrastructure reconstruction.

Furthermore, influential agencies like the World Bank and the UN Habitat advocate an owner-driven approach to housing reconstruction for being cost-effective, sustainable, and empowering the local population [55]. This approach was also used in reconstruction following Gujarat Earthquake in India in 2001 [45, 55], Bam Earthquake in Iran in 2003 [55], and Gorkha Earthquake in Nepal in 2015 [1]. The reconstruction in Gujarat is also hailed as one of the most successful reconstruction projects in history [45]. However, as discussed earlier, in residential construction, the homeowners themselves undertake the initiative to rebuild their houses with limited aid funds. As a result, these projects often are small, and homeowners and local contractors may have limited knowledge to make formal contractual arrangements.

Conversely, SFCCs like FIDIC are commonly utilised for large-scale infrastructure reconstruction projects. However, the challenges faced in implementing these contracts often go unreported due to the prevailing lack of emphasis on infrastructure reconstruction in the existing literature.

Therefore, this study highlights the current limitations and challenges of using standard forms developed for routine construction for post-disaster reconstruction using FIDIC as an example.

## *3.5 Applicability of Available Standard Forms in Disasters*

As discussed above, SFCCs for routine construction are not drafted with disaster situations in mind; therefore, they are unsuitable for disaster situations. The post-disaster situation is more complex and evolving, demanding a quicker decision-making system than everyday scenarios. Hence, the reconstruction contracts must also meet these demands of the post-disaster situation. However, due to limited studies, like standard legislation, SFCCs developed for standard construction are also used after disasters in infrastructure reconstruction leading to inefficiencies.

The limitations of SFCCs in infrastructure reconstruction are briefly discussed in the following sections, drawing correlations with the identified challenges outlined in Sect. 3.2.

### 3.5.1 Readability and Misinterpretation

Developing nations are the ones who suffer from significant annual destruction from disasters, and reconstruction in these nations is predominantly funded by the international donor community [25, 43]. As a result, SFCCs preferred by the donors are used widely in post-disaster reconstruction. However, these contracts often prove unsuitable for the primary users in these countries. They are not user-friendly, particularly for individuals without legal qualifications, and the issue is further exacerbated when English is not their first language leading to readability challenges and misinterpretations.

According to the United Nations Office for Disaster Risk Reduction [60], Asia has been the most severely affected continent by disasters over the past two decades, consistently facing high risks due to its massive size and diverse geography. The disaster-prone areas in Asia also have a dense population, and disturbingly, within the last two decades, seven Asian countries have secured spots in the top 10 list of countries with the highest death tolls from disasters. Considering that English is not the primary language in these Asian countries, it raises a valid concern regarding the suitability of contracts used by donors for the primary users in these nations.

The users of contracts, who are often not legally trained, require contracts that are accessible and comprehensible, mainly when English is not their native language. Even in a developed country such as the United States, Drolet et al. [19] highlight the recognition of Spanish migrant workers in the Volusia County as limited English proficiency groups and socially vulnerable communities by the Federal Emergency Management due to their struggles with good English language proficiency. Therefore, it is crucial to acknowledge that the current SFCCs favoured by donors may not effectively serve the needs of contract users from the affected countries in a post-disaster context.

### 3.5.2 Complexity and Adversarial Relationships

SFCCs for routine construction are often modified to suit post-disaster needs, but modifications lead to further problems in readability and contractual risk balance, leading to further complexity. Confusion in responsibility also leads to problems with accountability for mistakes, one of the most frequent issues in reconstruction in developing countries [18]. These issues can foster adversarial relationships and disputes. Therefore, the importance of a contract tailored for post-disaster reconstruction cannot be emphasised enough.

#### 3.5.3 Other Challenges

Given the lack of familiarity of the local people and their lack of exposure to regular use of these contracts, finding resources to do contract administration becomes challenging.

Taking FIDIC as an example, this paper will further provide specific details of how SFCCs from standard construction are not suitable for reconstruction.

### *3.6 Applicability of FIDIC Forms in Reconstruction Projects*

FIDIC is the preferred contract in disaster projects by development banks and agencies that fund different disaster projects [8, 28]. FIDIC currently has eight standard forms in its suite, but two popular contracts in infrastructure reconstruction after disasters are the FIDIC Red Book and the FIDIC Orange Book. There is one another contract form called the FIDIC Green Book, but it is recommended for use in small projects, and the new 2017 version has similar procedure for claims and administration as the Red Book.

The FIDIC Multilateral Development Bank (MDB) Harmonised Construction Contract, commonly called as "Pink Book", is a SFCC that is licenced for implementation in projects by eight development banks and numerous bilateral aid and development agencies [8]. Initially released in 2005 for MDB use, this contract was derived from the FIDIC Red Book. The primary objective behind introducing a separate standard form for MDB projects was to minimise the modifications required by MDBs. As a result, although this contract is employed in post-disaster scenarios funded by MDBs, it was not originally designed to be user-friendly in disaster contexts.

The original Red Book continues to be used for reconstruction by organisations such as the United Nations and Japan International Cooperation Agency (JICA). This particular contract is intended for projects procured through the traditional procurement method, where the employer takes ownership of most of the design process. These projects would also include post-disaster projects designed by employers or funders. However, similar to the MDB version, the original intent of the Red Book does not explicitly focus on its application in post-disaster situations.

Although 60 years of testing and refinement have gone into FIDIC to bring it to its current form, there are still limitations to using it in a developing context, that too, in disaster situations. The following sections briefly discuss the use of FIDIC contracts in post-disaster reconstruction, drawing correlations with the identified challenges outlined in Sect. 3.2.

### 3.6.1 Readability and Misinterpretation

Tuffaha [57] identified several challenges when implementing FIDIC contracts in Palestine. These challenges included administrative weakness, contractors' limited legal expertise, difficulty in comprehension of English, and superfluous modification of general terms of contracts by donors and NGOs leading to misinterpretations. These challenges would be particularly concerning when looking back at the Aceh reconstruction experience in Indonesia following the 2004 tsunami. According to Daly and Brassard [18], when contractual requirements and intricate administrative procedures demanded by donors are overwhelmingly beyond the implementer's capabilities, there will be challenges in implementation, as exemplified during the Aceh reconstruction.

Besaiso et al. [8] also affirmed the challenges due to the misinterpretation of sophisticated English used in FIDIC and highlighted discomfort caused by lengthy sentences and numerous cross-references within the contract. Furthermore, the authors acknowledged that newer versions of FIDIC are notably shorter and significantly improved from the previous generations. However, they believe it can still be improved and recommended further research to enhance the clarity, conciseness, and overall structure of FIDIC.

### 3.6.2 Complexity and Adversarial Relationships

Heaphy [24] highlights that the scattered cross-referencing within FIDIC demands a detective-like effort to navigate its highly legalistic format.

Additionally, a survey conducted in 2013 provides a direct indication of the applicability of FIDIC in disaster scenarios. Castro [12] conducted a survey during the JICA grant program in Manila in 2009, involving 1000 participants. The survey findings reported the following challenges observed in the implementation of FIDIC in Southeast Asia, an area prone to frequent disasters:

- FIDIC is viewed as a contract that promotes adversarial relationships due to its extensive notice requirements and inclusion of time-barred clauses.
- Dispute adjudication boards (DABs), which can be expensive, are not commonly available in Southeast Asia, resulting in the omission of this clause in contracts.
- There is a lack of familiarity with the proper usage of FIDIC among individuals involved in its implementation.
- Using FIDIC contracts in Southeast Asia encounters language-related challenges because English is a second language primarily used for business purposes. This poses difficulties for some Southeast Asian countries that are still in the process of learning English, including understanding the language used in FIDIC contracts.
- Conflicts may arise between FIDIC and local laws in the countries where it is employed.
- Cultural sensitivity concerns Southeast Asian countries, where even valid claims are often treated as disputes.

All the challenges mentioned above hold relevance in the context of post-disaster reconstruction scenarios. Ndekugri et al. [40] have also confirmed that the cost of DABs deters their wider adoption. They note that owners are reluctant to allocate additional funds for expensive dispute resolution procedures when they face budget constraints. This situation is particularly relevant in post-disaster reconstruction projects in developing countries.

In addition, some other studies highlight the impact of massive modifications on comprehension and intended interaction between clauses. Maritz and Putlitz [36] argue that SFCCs can become flawed when contract terms are extensively modified, as these modifications alter the intended interaction between clauses. Rameezdeen and Rodrigo [47] conducted a study in Sri Lanka that supported this theory, demonstrating that modifications made to FIDIC 1987 and 1999 clauses increased the difficulty of comprehending the contract. Furthermore, the authors noted that previous studies have primarily focussed on the legal and technical consequences of modifications to standard forms, however, there has been limited research on the readability aspect.

A contract or clause that is challenging to read and comprehend could also be a focal point for a dispute. Fawzy and El-adaway [22] emphasise that the negative impacts of claims and disputes are particularly significant in international projects involving numerous multinational and multicultural stakeholders. This also applies to post-disaster scenarios, which often involve stakeholders from different nations and cultures. Disputes in post-disaster situations should be avoided, as they can impede the reconstruction process and hinder prompt recovery. Moreover, as previously mentioned, the dispute resolution mechanisms recommended by FIDIC can be costly. Therefore, it is not practical to pursue disputes through dispute boards in other countries during a post-disaster situation that is already strained financially and facing significant time constraints.

### 3.6.3 Other Challenges

Another potential obstacle in using FIDIC in reconstruction arises from its nature as a re-measurement contract, assuming that scopes and designs are fully covered and essentially perfect before the project [8, 28]. Re-measurement contracts involve quantities that may not be exact during the tendering process and are subsequently re-measured for payment [28]. However, in the real-world scenario, designs and scopes are rarely fixed before the tendering process, especially during disasters. The evolving nature of disaster situations means that scopes still need to be entirely determined, allowing for considerable variation. Managing these variations becomes challenging when lengthy procedures outlined in FIDIC need to be followed.

Hence, the existing forms of FIDIC (Red Book and Pink Book) are inadequate for post-disaster reconstruction projects, highlighting the pressing requirement for a dedicated contract that specifically addresses the unique needs of post-disaster reconstruction.

## 4 Discussion

Contracts for post-disaster reconstruction projects often necessitate rapid development and flexibility to accommodate various factors. These projects involve multiple sources of funding, stakeholders from different legal jurisdictions, and ever-changing physical conditions, all of which require highly flexible contract terms. It is crucial to avoid introducing further layers of complexity that would complicate the situation. As Hughes et al. [28] noted, the more complex something is, the more specialised expertise is required to manage it. Consequently, if the contract requires specialists for administration who are unavailable in a developing country, valuable aid funds are spent on expatriate professionals rather than the project itself.

It is vital for all stakeholders engaged in post-disaster reconstruction to acknowledge that the challenges related to procurement go beyond the mere selection of a contract. While there are various contracts to choose from, it is essential to consider whether they have been specifically designed to address performance in disaster situations. While contracts like the FIDIC Red Book and FIDIC MDB are reputable and widely used contracts globally, it must be noted that they were not originally intended for use in disaster scenarios. As a result, they may not be well-suited for such circumstances.

Unfortunately, all reconstruction projects use these SFCCs. These contracts require complex contract administration that is often beyond the capabilities of primary users in developing countries and fails to meet the specific requirements of post-disaster scenarios. As a result, project progress is hindered. The legal drafting, structure, and format of these contracts and the handling of variations, time extensions, and dispute resolution are not well-suited for disasters. Instead, they place an excessive burden on the project team, impeding the primary objective of expediting reconstruction, restoring the affected population to their pre-disaster state, or even improving their condition.

When developing a new contract or adapting an existing one to accommodate post-disaster needs, it is crucial to consider the varying likelihood, severity, and magnitude of contractual issues such as delays, insolvency risks, and contractual exits, particularly in the context of reconstruction projects [28]. Allocating risks appropriately and giving careful attention to these factors becomes imperative to ensure an effective contract that addresses the unique challenges of post-disaster scenarios.

The contract designed for post-disaster reconstruction should prioritise clarity and comprehension, especially for individuals whose first language is not English. Considering such projects' financial constraints and time sensitivity, it should enable efficient handling of change orders and extensions. Streamlining administrative processes becomes crucial to ensure that valuable resources are directed towards actual implementation rather than excessive administration. Additionally, the contract should incorporate practical and effective methods for dispute resolution tailored to the unique circumstances of post-disaster scenarios.

Additionally, there is also a pressing need for extensive research on infrastructure reconstruction following major disasters to identify strategies for expediting the reconstruction process. The restoration of infrastructure holds immense significance as it serves a massive population at once and is essential for the functioning of critical facilities such as schools, healthcare centres, transportation networks, and more. Restoring these public infrastructures is a prerequisite for returning to a sense of normalcy in affected regions. Hence, infrastructure reconstruction should receive equal attention and research focus as housing reconstruction, forming a comprehensive knowledge base for post-disaster infrastructure reconstruction.

Examining past reconstruction projects like Aceh highlights the undeniable impact of poor infrastructure on the overall efficiency of reconstruction endeavours. The inadequacy of pre-existing infrastructure systems exacerbated challenges, mainly through transportation bottlenecks that impeded progress [15]. It is worth noting that only USAID was involved in infrastructure reconstruction after the tsunami, specifically the Banda Aceh to Meulaboh road, while other aid agencies solely concentrated on housing reconstruction. Consequently, the delayed restoration of infrastructure posed additional obstacles, hampering the overall reconstruction process. Therefore, both aid agencies and governments must prioritise the development of public infrastructure in developing countries to prepare them for upcoming disasters and to mitigate resource bottlenecks during reconstruction. By doing so, the risks of disruptions caused by substandard infrastructure can be mitigated, leading to more efficient and effective reconstruction processes.

## 5 Conclusion

The existing SFCCs, including FIDIC, are ill-suited for post-disaster reconstruction projects due to their lack of alignment with the unique demands of such scenarios. However, the current body of knowledge lacks comprehensive studies on infrastructure reconstruction using these contracts, resulting in a limited understanding of the inefficiencies they create. Despite the critical importance of infrastructure restoration for a nation's functioning, most reconstruction funding and stakeholder focus is directed towards housing reconstruction. As a result, there is a pressing need to shift attention towards studying the challenges and issues related to infrastructure reconstruction, particularly from procurement and contractual perspectives.

The current SFCCs, including FIDIC, exhibit several drawbacks that hinder their effectiveness in post-disaster contexts. They heavily use legal jargon and complex cross-referencing, and their overall document structure and organisation are not user-friendly for individuals in developing countries, where English may not be the primary language. Implementing parties lacking the administrative skills to handle such contracts face increased burdens, leading to project inefficiencies. The complex processes for managing variations and time extensions under these contracts further strain already limited resources in time-sensitive and financially constrained projects.

Moreover, the project teams often disregard the existing dispute resolution methods for being inadequate and impractical.

Therefore, rather than attempting to modify existing contracts to fit post-disaster requirements, there is an urgent need to develop a tailored contract designed explicitly for post-disaster scenarios. This contract should be user-friendly, particularly for developing countries, and provide more efficient mechanisms for managing project-related issues, considering the unique challenges of post-disaster situations. With such a contract, scarce manpower and financial resources can be directed towards actual on-ground work rather than being consumed by navigating complex contractual clauses for administrative purposes.

## 6 Limitations and Future Research

This study primarily focuses on identifying the shortcomings of existing standard forms of contracts, highlighting their inapplicability in post-disaster reconstruction efforts, with FIDIC serving as an illustrative example. This study also provides future research direction for developing construction contracts tailored for post-disaster infrastructure reconstruction.

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## References

1. Acharya P, Sharma K, Pokharel GR, Adhikari R (2022) Managing post-disaster reconstruction after the 2015 Gorkha, Nepal earthquake and lessons learned. Nat Hazards Rev 23(4):04022029. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000585
2. Afkhamiaghda M, Elwakil E (2022) Challenges review of decision making in post-disaster construction. Int J Constr Manag 1–10
3. Ali N, Wilkinson S (2010) Modernising construction contracts drafting–a plea for good sense. W113-special track 18th CIB world building congress May 2010 Salford, United Kingdom
4. Anbarci N, Escaleras M, Register CA (2005) Earthquake fatalities: the interaction of nature and political economy. J Public Econ 89(9–10):1907–1933
5. Bailey J (2016) Construction law. Informa law from Routledge
6. Barnes WR (2007) Toward a fairer model of consumer assent to standard form contracts: in defence of restatement section 211(3)

7. Bell M (2009) Standard form construction contracts in Australia: are our reinvented wheels carrying us forward? SSRN Electron J. https://doi.org/10.2139/ssrn.1519608
8. Besaiso H, Fenn P, Emsley M, Wright D (2018) A comparison of the suitability of FIDIC and NEC conditions of contract in Palestine: a perspective from the industry. Eng Constr Archit Manag 25(2):241–256. https://doi.org/10.1108/ECAM-10-2016-0235
9. Bilau AA, Witt E, Lill I (2018) Practice framework for the management of post-disaster housing reconstruction programmes. Sustain (Switz) 10(11). https://doi.org/10.3390/su10113929
10. Brandon PS (2011) Extreme management in disaster recovery. Procedia Eng
11. Butt P (2013) Modern legal drafting: a guide to using clearer language, 3 edn. Cambridge University Press. https://doi.org/10.1017/CBO9781107282148
12. Castro SP (2013) Case studies of using FIDIC in Southeast Asia cultural sensitivities FIDIC and IBC legal's 5th annual: FIDIC Asia-Pacific contract users conference, Sunway resort hotel and Spa, Kuala Lampur
13. Centre for Advanced Engineering (2002) The contract in successful project management: innovations in contract forms & dispute prevention and resolution. CAE conference the contract in successful project management: innovations in contract forms & dispute prevention and resolution, Christchurch
14. Chang Y, Wilkinson S, Potangaroa R, Seville E (2011) Donor-driven resource procurement for post-disaster reconstruction: constraints and actions. Habitat Int 35(2):199–205. https://doi.org/10.1016/j.habitatint.2010.08.003
15. Chang Y, Wilkinson S, Potangaroa R, Seville E (2012) Managing resources in disaster recovery projects. Eng Constr Archit Manag 19(5):557–580. https://doi.org/10.1108/09699981211259621
16. Charlson J (2020) Construction contracts. In: Galbraith's construction and land management law for students, 7 edn, pp 140–145. https://doi.org/10.1201/9781003029250-8
17. Crawford G, Morrison C (2021) Community-led reconstruction, social inclusion and participation in post-earthquake Nepal. Dev Policy Rev 39(4):548–568. https://doi.org/10.1111/dpr.12512
18. Daly P, Brassard C (2011) Aid accountability and participatory approaches in post-disaster housing reconstruction. Asian J Soc Sci 39(4):508–533. https://doi.org/10.1163/156853111X597305
19. Drolet J, Ersing R, Dominelli L, Alston M, Mathbor G, Huang Y, Wu H (2018) Rebuilding lives and communities post-disaster: a case study on migrant workers and diversity in the USA. Aust Soc Work 71(4):444–456. https://doi.org/10.1080/0312407X.2018.1487460
20. Elkhayat Y, Marzouk M (2022) Selecting feasible standard form of construction contracts using text analysis. Adv Eng Inf 52. https://doi.org/10.1016/j.aei.2022.101569
21. Enshassi A, Chatat T, von Meding J, Forino G (2017) Factors influencing post-disaster reconstruction project management for housing provision in the Gaza strip, occupied Palestinian territories. Int. J. Disaster Risk Sci 8(4):402–414. https://doi.org/10.1007/s13753-017-0155-4
22. Fawzy SA, El-adaway IH (2012) Contract administration guidelines for U.S. Contractors working under world bank-funded projects. J Leg Aff Dispute Resolut Eng Constr 4(2):40–50. https://doi.org/10.1061/(ASCE)LA.1943-4170.0000088
23. Fayazi M, Lizarralde G (2018) Conflicts between recovery objectives: the case of housing reconstruction after the 2003 earthquake in Bam, Iran. Int J Disaster Risk Reduction 27:317–328. https://doi.org/10.1016/j.ijdrr.2017.10.017
24. Heaphy I (2013) NEC versus FIDIC. Proc Inst Civil Eng: Manage, Procurement Law 166(1):21–30. https://doi.org/10.1680/mpal.11.00006

25. Hidayat B, Egbu C (2010) A literature review of the role of project management in post-disaster reconstruction. Association of researchers in construction management, ARCOM 2010—proceedings of the 26th annual conference
26. Hidayat B, Egbu C (2011) Critical success factors associated with post-disaster reconstruction projects. Association of researchers in construction management, ARCOM 2011—proceedings of the 27th annual conference
27. Hooi LK, Yee GS, Mohd-Danuri MS, Zolkafli UKB (2020) Ambiguity extension of time provisions in standard forms of contract: an analysis of PAM 2018 contract. Malays Constr Res J: RISM Int Res Conf 2020
28. Hughes W, Champion R, Murdoch J (2015) Construction contracts law and management, 5 edn
29. Hui S, Bai-zhou H (2013) Revision of the construction project contract model text in China. 2013 6th international conference on information management, innovation management and industrial engineering
30. Kenny C (2012) Disaster risk reduction in developing countries: costs, benefits and institutions. Disasters 36(4):559–588. https://doi.org/10.1111/j.1467-7717.2012.01275.x
31. Le Masurier J, Rotimi JOB, Wilkinson S (2006) A comparison between routine construction and post-disaster reconstruction with case studies from New Zealand. Association of researchers in construction management, ARCOM 2006—proceedings 22nd annual ARCOM conference
32. Lee J, Ham Y, Yi JS, Son J (2020) Effective risk positioning through automated identification of missing contract conditions from the contractor's perspective based on FIDIC contract cases. J Manag Eng 36(3):05020003. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000757
33. Li J (2011) Analysis on key points of the post-disaster reconstruction engineering cost management. Appl Mech Mater 94–96:306–309
34. Lin JJ, Lin WI (2016) Cultural issues in post-disaster reconstruction: the case of Typhoon Morakot in Taiwan. Disasters 40(4):668–692. https://doi.org/10.1111/disa.12172
35. Loss BW, Schaffner S (2014) Construction contract language; a growing impediment to trust and cooperation Indianapolis, Indiana. https://peer.asee.org/20207
36. Maritz MJ, Putlitz U (2014) Standard form construction contracts; why the need for regular changes? Association of researchers in construction management proceedings of the 30th annual conference
37. McInnis A (2001) The new engineering contract: a legal commentary. Thomas Telford
38. Mohamed Abdel-Hamid D, Alaa El-Din Mostafa AR (2023) The effect of FIDIC red book 2017 to avoid disputes in Egyptian construction field. Ain Shams Eng J 14(5):101963. https://doi.org/10.1016/j.asej.2022.101963
39. Mohamed HH, Ibrahim AH, Soliman AA (2014) Reducing construction disputes through effective claims management. Am J Civil Eng Archit 2(6):186–196. http://pubs.sciepub.com/ajcea/2/6/2
40. Ndekugri I, Chapman P, Smith N, Hughes W (2014) Best practice in the training, appointment, and remuneration of members of dispute boards for large infrastructure projects. J Manage Eng 30(2):185–193. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000195
41. Nee T, Nadarajan S, Whyte A (2013) Reviews of cases of construction disputes in Malaysia and its relation with standard form of construction contract. Adv Mater Res 831:191–196. https://doi.org/10.4028/www.scientific.net/AMR.831.191
42. Ophiyandri T, Amaratunga D, Pathirage C (2010) Implementation of project risk management principles in community based post disaster housing reconstruction projects. COBRA 2010—construction, building and real estate research conference of the royal institution of chartered surveyors

43. Osland AC (2010) Resolving land ownership issues for a community water project: a post-earthquake development dispute in rural El Salvador. Plan Theory Pract 11(1):47–63. https://doi.org/10.1080/14649350903538046
44. Pettit D (2012) Effect of the new Australian consumer law on the use of standard-form contracts within the Australian construction industry. J Legal Aff Dispute Resolut Eng Constr 4(1):1–9. https://doi.org/10.1061/(ASCE)LA.1943-4170.0000075
45. Powell PJ (2011) Post-disaster reconstruction: a current analysis of Gujarat's response after the 2001 earthquake. Environ Hazards 10(3):279–292. https://doi.org/10.1080/17477891.2011.597839
46. Purba H, Prastowo T (2020) Potential risks occurring in FIDIC contract construction projects: a literature review 2:1–12
47. Rameezdeen R, Rodrigo A (2014) Modifications to standard forms of contract: the impact on readability. Constr Econ Build 14(2):31–40. https://doi.org/10.5130/AJCEB.v14i2.3778
48. Rawal V, Bothara J, Pradhan P, Narasimhan R, Singh V (2021) Inclusion of the poor and vulnerable: learning from post-earthquake housing reconstruction in Nepal. Prog Disaster Sci 10:100162. https://doi.org/10.1016/j.pdisas.2021.100162
49. Rotimi JOB, Wilkinson S (2014) Improving environmental management legislation to facilitate post-disaster reconstruction. Int J Disaster Resilience Built Environ 5(1):23–37. https://doi.org/10.1108/IJDRBE-09-2011-0034
50. Sadek SMA (2016) Managing standard construction contractual forms modifications in the Middle East—overview and recommendations https://www.semanticscholar.org/paper/7802dd99800d3ac9b7961107020805a349172530
51. Safapour E, Kermanshachi S (2021) Uncertainty analysis of rework predictors in post-hurricane reconstruction of critical transportation infrastructure. Prog Disaster Sci 11:100194. https://doi.org/10.1016/j.pdisas.2021.100194
52. Safapour E, Kermanshachi S, Pamidimukkala A (2021) Post-disaster recovery in urban and rural communities: challenges and strategies. Int J Disaster Risk Reduction 64:102535. https://doi.org/10.1016/j.ijdrr.2021.102535
53. Silva JD (2010) Lessons from Aceh key considerations in post-disaster reconstruction. https://mitigation.eeri.org/wp-content/uploads/LessonsFromAceh.pdf
54. Sospeter NG, Rwelamila PMD, Gimbi J (2020) Critical success factors for managing post-disaster reconstruction projects: the case of Angola. Constr Econ Build 20(3):37–55. https://doi.org/10.5130/AJCEB.v20i3.7298
55. Tafti MT, Tomlinson R (2015) Best practice post-disaster housing and livelihood recovery interventions: winners and losers. Int Dev Plan Rev 37(2):165–185. https://doi.org/10.3828/idpr.2015.14
56. Tagliacozzo S, Magni M (2018) Government to citizens (G2C) communication and use of social media in the post-disaster reconstruction phase. Environ Hazards 17(1):1–20. https://doi.org/10.1080/17477891.2017.1339012
57. Tuffaha MBM (2015) Major challenges facing the implementation of the FIDIC in construction projects in Palestine An-Najah national university. https://tinyurl.com/2p8uzfna
58. Uddin SMJ, Ganapati NE, Pradhananga N, Prajapati J, Albert A (2021) Is the workers' health and safety scenario different in post-disaster reconstruction from conventional construction? A case study in Bhaktapur, Nepal. Int J Disaster Risk Reduction 64:102529. https://doi.org/10.1016/j.ijdrr.2021.102529
59. Uddin SMJ, Tamanna M, Albert A, Pradhananga N (2022) Leveraging natural language processing to identify health and safety challenges during post-disaster reconstruction. Construction research congress 2022: health and safety, workforce, and education—selected papers from construction research congress 2022

60. United Nations Office for Disaster Risk Reduction (2020) Human cost of disasters an overview of the last 20 years 2000–2019. https://doi.org/10.18356/79b92774-en
61. Waheeb RA, Andersen BS (2022) Causes of problems in post-disaster emergency reconstruction projects—Iraq as a case study. Public Works Manag Policy 27(1):61–97. https://doi.org/10.1177/1087724X21990034
62. Walker B, de Vries HP, Nilakant V (2017) Managing legitimacy: the Christchurch post-disaster reconstruction. Int J Project Manage 35(5):853–863. https://doi.org/10.1016/j.ijproman.2016.07.007
63. Wilkinson S, Rotimi J, Mannakarra S (2014) Legislation changes following earthquake disasters. Encycl Earthq Eng 1–10
64. Xu J, Xu D, Lu Y (2016) Resident participation in post-Lushan earthquake housing reconstruction: a multi-stage field research method-based inquiry. Environ Hazards-Human Policy Dimensions 15(2):128–147. https://doi.org/10.1080/17477891.2016.1142417
65. Xu J, Xu D, Lu Y, Wang Q (2018) A bridged government–NGOs relationship in post-earthquake reconstruction: the Ya'an service center in Lushan earthquake. Nat Hazards 90(2):537–562. https://doi.org/10.1007/s11069-017-3056-3

# Managing BIM Implementation in the AEC Sector: Identifying Key Aspects and Developing a Framework

**B. K. C. Perera, H. S. Jayasena, K. G. A. S. Waidyasekara, M. Siriwardena, and K. A. R. V. D. Kahandawa**

## 1 Introduction

In the current context, Building Information Modeling (BIM) implementation has gained a significant attraction around the world. Since the mechanisms in it in designing, storing and sharing the project information by a project team, is superior to traditional methods of information generation, sharing and using, adopting BIM has become a common interest. According to Latiffi et al. [2] and [47], BIM was originated from a concept introduced by Eastman in 1970s as a response to the limitations of 2D drawings in complex construction projects [20]. Wierzbicki et al. [57] have recognized that BIM has been introduced in a combination of CAD (computer-aid drawings), AEC (architectural, engineering, and construction) technologies and chosen information management systems. The evolution of present-day BIM model has been influenced by the concept of the 'object–oriented database' and has been utilized since early 1980s, following the previous adaptation of navigational model and review model. Initially, the traditional software sets were supported by non-associative, one-way translation on interoperable platforms such as SAT, STEP, and IGES [57]. Additionally, 3D parametric modeling was primarily developed on traditional CAD platforms such as Benetly and Nemetscheck, as well as new software platforms like ArchiCAD and Revit. Even though various initiations are taken place at different timescales, BIM has been properly used in construction projects is only around in 2010 [31]. Likewise, BIM did not gain momentum in the AEC

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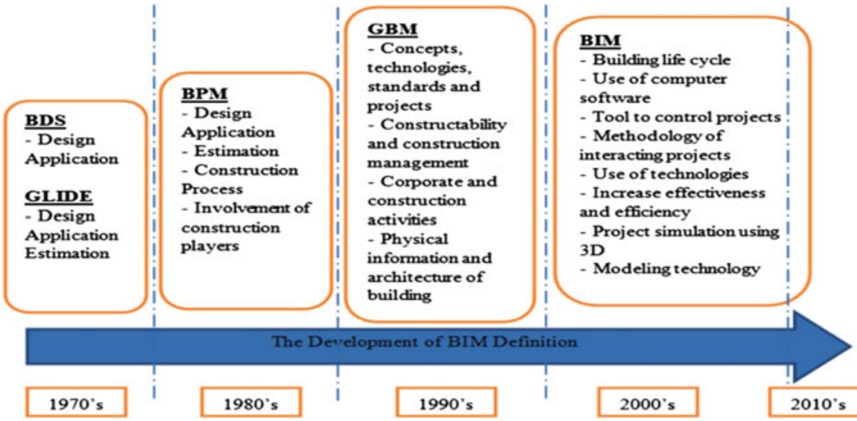



**Fig. 1** Development of BIM definition (*Source* [31])

sector overnight but rather through continuous and progressive advancements. This is further substantiated by Fig. 1, which illustrates the evolution of BIM definition over the course of its adoption. It was observed that there is an ongoing debate on whether to treat BIM as a management tool, a process, or a platform [48].

In the early stages of BIM development, its usage was initially limited to pre-construction activities [57]. However, as the technology advanced, barriers were overcome, allowing BIM to extend its reach to different construction project phases, enabling information management throughout the project life cycle [48]. From the recent practical implementation of BIM in construction projects, it is widely acknowledged that BIM offers significant benefits for the project and its stakeholders. According to the results of the study by Jin et al. [27], participants recorded the reduction of omissions, errors, and rework as the highest advantages from BIM adoptions followed by improved project quality. Doumbouya et al. [17] have reviewed the benefits of BIM adoption and identified that BIM brings improved design quality, saved construction costs, better speed of work, ease of project management, shortened the construction duration, enhanced energy efficiency, and higher operational efficiency in the building lifecycle. Many other scholars have presented similar findings in the arena of benefits of BIM with respect to different contexts [5, 10, 12]. Most of these benefits are likely to be resulted due to the ability of realistic visualization of the building, structured information management and integration of the project teamwork enabled by BIM [17, 48]. Accordingly, there is a significant potential for improving the accuracy, efficiency, and the quality of the end product by implementing BIM.

It is worth noting that the aforementioned benefits were acknowledged alongside various barriers and challenges. Consequently, the commented benefits are contingent upon factors such as level of senior management support, computer efficiency, compatibility, and technical complexity in a given project context [17]. It is evident that the implementation of BIM is not only accompanied by its benefits but also by its limitations that hinder and restrict the full realization of true value of BIM. This has been acknowledged by Bouška [8], who further stated that BIM is not yet prepared for its widespread implementation. On the other hand, there is a line of knowledge that could be associated with the effective management of BIM implementation commencing from the early stages of projects to effectively address those challenges [10, 56]. While trends in the development of necessary guidelines and instruments could be observed in practice, there has been a lack of serious effort in scientific studies thus far to address this. The proper need for such identification has been established by Ma et al. [37], where they stated that the lack of systematic BIM implementation is a source of challenges and barriers in practical projects. This knowledge gap highlights the importance of establishing a comprehensive understanding of BIM implementation management in projects, encompassing all significant aspects of it that require managerial attention. The aim of this study is set as to identify the existing BIM implementation management frameworks in construction projects with an emphasis on addressing the identified knowledge gap. This paper presents a review of current knowledge addressing this aim and proposes a research methodology to find the comprehensive list of significant aspects of BIM implementation management which could be utilized in developing a framework for future BIM implementations. The scope of the study is considered as project level collaborative BIM implementation.

Upon reviewing the extant literature, it is observed that while scholars have conducted research on enhancing implementation strategies, the underlying knowledge of what is exactly needed to manage in order to implement BIM in projects is not well-established. As a result of the rapid growth in the number of scholarly works in normative upper layer of BIM implementation such as implementation barriers, assessment and overcoming strategies, gaining the classical spotlight from the past to present [15, 23, 37, 53], the underlying basic understanding on the body of knowledge related to BIM implementation has become absent [59]. Reference material directly addressing BIM implementation management could not be identified. Nevertheless, many aspects related to BIM implementation management were found as 'incidental remarks' within studies pertaining to BIM implementation and its related fields. Consequently, attempts to conduct a systematic literature review with an identified set of keywords proved unsuccessful, as these aspects were not clearly defined in the sources, necessitating a process of manual identification. Relevant aspects were identified from various sources, including scientific papers, published standards, and the authors' prior knowledge. Subsequently, these aspects were explored in the current literature to ascertain the state of understanding. The following section elaborates on the findings from this process.

## 2 BIM Implementation

With the diffusion of BIM adoption interest in construction projects, currently BIM is being utilized in many parts of the world. Proper BIM implementation is essential for achieving the true benefits of the process. However, even though it has been quite a few periods of time since the initial implementation in construction industry, some of the recent literature sets the evidence on hindering the BIM implementation in projects [3, 25, 29]. It is addressable that, this has resulted mainly owing to the unequal dispersion of the level of BIM knowledge brought by each different team member while working collaboratively on a given specific project [40]. Meanwhile, in the systematic findings of BIM adoption in construction projects, scholarly works have been published in various yet focused arenas such as BIM implementation challenges, barriers, impact, critical strategies, factors, benefits, and assessment. Among them, it is found that only the BIM assessment research articles streamlines the determination of the level of successful implementation at either a project or an organization level. In fact, some research articles proposed strategies for overcoming the hindering barriers, but those have failed to directly imply the reflection in adopting them in each different project. BIM implementation assessment has been intrigued around 2016–2018 where most of the research articles were published from that period onwards [1, 4].

Different scholars have tended to use various thematic breakdowns for BIM implementation factors for systematic implementation [37]. As stated by Eadie et al. [19], it was identified that respondents were more focused on the quality of the output than the process to be followed. Because of that, a project carries the potential in losing feasibility and economic viability in long run. Hence, it is not only the end product's quality that matters but also the management of the process that follows to achieve it. Maybe as a result of that, neither anyone has established the requirement, nor a framework has developed to guide the BIM implementation management. However, few public guidelines such as ISO19650, AIA G202-2013, and NBIMS-US have been published to standardize the procurement of construction works via BIM. Therefore, applicable knowledge on true BIM implementation management has been derived from both scientific and non-scientific sources. It is acknowledged that the derived knowledge of non-scientific works are to be confirmed in the study.

## 3 BIM Implementation Management Aspects

Since this study is aimed to identify the ways of BIM implementation management, there is a need on understanding the aspects that need to be addressed when managing BIM implementation. As mentioned before, none of the studies have been conducted in addressing BIM implementation management in past works. Thus, it is unlike to have a list of aspects that need to be considered from the existing knowledge. Unfortunately, it has been further evident as the attempt made on finding them, was a failure. Hence, the aspects which need to address in the management of BIM implementation should be derived based on the underline principles of existing scientific knowledge, industry-established guidelines, and professional practice experience.

With the available fragmented knowledge, this literature review was conducted to identify every necessary aspect of concern in BIM implementation. Later, similar contents were grouped together in terms of their logical cohesion and presented under a main umbrella. Many interconnections and overlapping scenarios were discovered and revealed it within the text.

### *3.1 BIM Implementation Strategy*

Having a clear vision and a mission is ultimately important for any work item to proceed. Similarly, upon an establishment of the need for BIM implementation in a construction project has the ability to gain more insight into the final outcome and thus be capable of achieving successful project completion. Ma et al. [37] have identified that even though having clearly established implementation objectives aligned with the project goals are important, it has not been ranked as a significant factor among Chinese construction industry professionals. It is found that, professionals are reluctant to use BIM in projects, unless there are specifically asked to do so [52]. After all, clients have been identified as the prime driving force for BIM adoption in construction projects [7]. Thus, with the establishment of the neediness on earning benefits, clients could be more interested in using that. Likely, highlighting the business point of view and optimizing the Return on Investment (ROI) plan is necessarily important for a definite project gain [52]. The business aspect of BIM focuses on the higher-order goals of a firm and the collective value of BIM in a business. Some scholars have found that, an organizational level comprehensive strategic plan is required at the project level for successful implementation [18]. On the other hand, the business case definition sets the degree of information required in the project [28]. Thus that, the entire need on implementing BIM and how it is done, up to which level are clearly visible for everyone in the project. When drafting BIM implementation strategy following could be accommodated.

- Project implementation objectives
- Project implementation scope
- Alignment with the actual construction project.

### *3.2 Information Exchange Requirement*

In a BIM project, the management of information is the significant highlight feature when compared to traditional construction projects [21, 58]. Hence, having a clear and well-established information exchange requirement is essential [26]. Having said that, the following were identified as most prominently appeared tools in literature to scrutinize the information exchange requirement in BIM projects.

### 3.2.1 BIM Execution Plan

Reference [37] have found that the top-ranked strategy for systematic BIM implementation in Chinese construction projects is that clearly defined plan and objectives for BIM implementation. According to Sidani et al. [51], a BIM Project Execution Plan (PEP) has been utilized to lay down the BIM implementation for the entire project lifecycle. The said BIM execution plan needs to include with BIM goals and objectives, roles and responsibilities of different parties and appropriate standards that's going to follow for the project.

### 3.2.2 Establish the Information Exchange Standards and Agreements

The vendor-neutral formats are encouraged to adopt in BIM construction projects to work collaboratively while still being in independent workstations [52]. It is found that making the tasks standardized saves the project cost effectively as, it reduces the complexity in handling multi-party mutual interdependency [53]. In fact that, adhering to widely recognized data exchanging standards such as BuildingSMART IFC, OpenGis GML, COBie is important in gaining the recognition and avoiding potential loopholes in newly or custom drafted standards [26]. The Information Delivery Manual from BuildingSMART has been the spotlight around the world to communicate the data where those can be interpreted by software, itself [28]. Xu et al. [58] have established the information need and developed a framework to manage information in BIM projects throughout its entire lifetime. However, all have to be managed upon the establish degree of information required [28]. Therefore, the availability of information is a prime consideration that should take up when scrutinizing the information requirement.

Currently, in Europe using modern BIM standards in public procurement has been compulsory which shall be in accordance with ISO 19650 [51]. According to the ISO19650:1 the set information requirement are Organization information requirements, Project information requirements, Asset information requirements and exchange information requirements [14]. Apart from that, it is mentioned that some studies have been already conducted in implementing BIM along with Augmented Reality (AR) platforms to facilitate information within the project model, based on actual construction site in terms of time and cost.

#### 3.2.3 Information Delivery Planning

It is known that different phases of the projects demand different BIM information [58] Therefore, the specific information needed, type of information and the requirement should be planned ahead to avoid intermediate disruptions in delivering the project.

### *3.3 Technology and Infrastructure*

According to [37], having capabilities and skills in technology is recorded the top 3rd critical success strategy for proper BIM implementation. Moreover, it is acknowledged that technology is evolving at a higher speed. Therefore, having a stable phase and cater the ongoing trend would not lose the commercial competition. Likely, planning ahead for such situations won't leave behind the new construction business market [52]. In terms of the technology and infrastructure that need to be managed in BIM implementation has broken into two branches namely, integrated BIM tools and technologies and common data environment. Integrated BIM tools and technologies were further divided into, BIM tools, BIM objects, BIM libraries, BIM software, and hardware.

#### 3.3.1 BIM Tools and Technologies

BIM Tools

BIM itself is a technology that can be utilized to improve the management of a project easily while performing good communication and information sharing [39]. The interoperability among different BIM tools is a salient feature of BIM. With the introduction of Open BIM concept, two different model developments from different professional disciplines can be merged together and integrated well within one platform [7]. That made a huge improvement in detecting clashes in various models that developed separately. Therefore, it is important to predefine the compatible format at the initial stage to merge the two models. Most of the projects which use BIM software have been installed and run-on Windows platforms when compared to Mac OS and Linux/Unix [8]. Moreover, most of the given AR interfaces have adopted marker-less methods. Despite that, recent literature were more into the marker-based application. Unfortunately, the lack of interoperability between BIM software and AR systems was founded as a fact that impedes the utilization of BIM along with AR [51]. Further, it has been already found that for matured BIM platforms, openness, interoperability compatibility, simplicity, functionality, expandability, accurate data representation, capability of advanced life cycle energy modeling, time management and clash detection, cost estimation, facility management are indeed factors to consider [8]. Recent literature have shown the most interest in the application of

AR in BIM adoption and that has been commenced from 2018 [51]. However, as discussed by Sidan et al. [51] implementation of new technologies requires a thorough evaluation of the effectiveness of successful establishment for future adoptions.

BIM Objects

BIM objects have been integrated along with the BIM-based design process not merely drawing but also assembling and adjusting several objects such as doors, windows, walls, electrical etc. BIM objects have been identified in two different disciplines. One is as in software objects and other one is object libraries [24]. Material libraries also have been in using for rendering purposes [30].

BIM Libraries

UK government has given universal access for National BIM library which would cause considerable influence on the level of BIM adoption in a construction project [52]. Hoeber and Alsem [26] have presented few types of libraries to maintain in a project. Aside that they have recommended, to keep supertype libraries in national and international scales and subtype libraries in narrow scales as in organizational and project level.

BIM Software

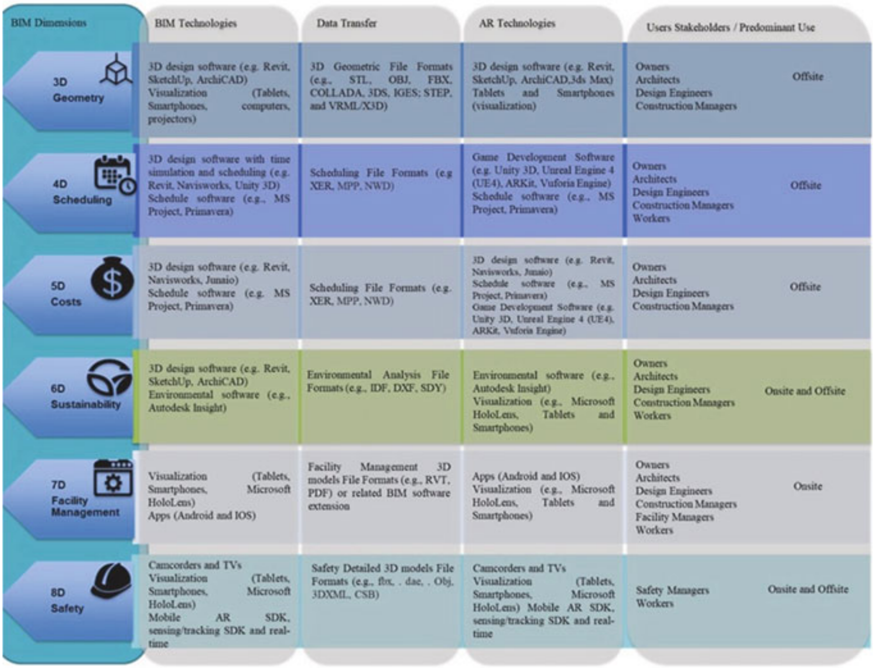
Revit has been identified as the prominently used software followed by ArchiCAD [51]. The given BIM software has not solely based on the type of BIM dimension, but also based on the different information requirements and data needed in various phases of the lifecycle of the project. Therefore, foreseen the total technology requirement at the very initial stages, would facilitate the smooth flow of project management without reversing or going back of the expected plan. Below, Fig. 2 shows a list of different software that are in use of the current industry at different BIM dimensions.

Hardware

Dowsett and Harty [18] mentioned that hardware and software have incurred a great cost among all the expenditures in implementation of BIM. As a result of such, professionals spend less in software upgrades, hardware maintenances and training etc. [18].

## *3.4 Common Data Environment*

Having a BIM-compatible, open product information platform can be utilized in generating precise and *fit-for-purpose* BIM model. Through that, a variety of models could be developed for each purpose while integrating all together. This is happening because of people use different models for each particular discipline (Collusion detection model in design stage and Asset information model for data and information delivery) [37, 43, 45, 58].



| BIM Dimensions | BIM Technologies | Data Transfer | AR Technologies | Users Stakeholders / Predominant Use | |
|---|---|---|---|---|---|
| 3D Geometry | 3D design software (e.g. Revit, SketchUp, ArchiCAD) Visualization (Tablets, Smartphones, computers, projectors) | 3D Geometric File Formats (e.g., STL, OBJ, FBX, COLLADA, 3DS, IGES; STEP, and VRML/X3D) | 3D design software (e.g. Revit, SketchUp, ArchiCAD,3ds Max) Tablets and Smartphones (visualization) | Owners Architects Design Engineers Construction Managers | Offsite |
| 4D Scheduling | 3D design software with time simulation and scheduling (e.g. Revit, Naviswork, Unity 3D) Schedule software (e.g., MS Project, Primavera) | Scheduling File Formats (e.g XER, MPP, NWD) | Game Development Software (e.g. Unity 3D, Unreal Engine 4 (UE4), ARKit, Vuforia Engine) Schedule software (e.g., MS Project, Primavera) | Owners Architects Design Engineers Construction Managers Workers | Offsite |
| 5D Costs | 3D design software (e.g. Revit, Navisworks, Junaio) Schedule software (e.g. MS Project, Primavera) | Scheduling File Formats (e.g. XER, MPP, NWD) | 3D design software (e.g. Revit, Navisworks, Junaio) Schedule software (e.g. MS Project, Primavera) Game Development Software (e.g. Unity 3D, Unreal Engine 4 (UE4), ARKit, Vuforia Engine) | Owners Architects Design Engineers Construction Managers | Offsite |
| 6D Sustainability | 3D design software (e.g. Revit, SketchUp, ArchiCAD) Environmental software (e.g., Autodesk Insight) | Environmental Analysis File Formats (e.g., IDF, DXF, SDY) | Environmental software (e.g., Autodesk Insight) Visualization (e.g., Microsoft HoloLens, Tablets and Smartphones) | Owners Design Engineers Construction Managers Workers | Onsite and Offsite |
| 7D Facility Management | Visualization (Tablets, Smartphones, Microsoft HoloLens) Apps (Android and IOS) | Facility Management 3D models File Formats (e.g., RVT, PDF) or related BIM software extension | Apps (Android and IOS) Visualization (e.g., Microsoft HoloLens, Tablets and Smartphones) | Owners Architects Design Engineers Construction Managers Facility Managers Workers | Onsite |
| 8D Safety | Camcorders and TVs Visualization (Tablets, Smartphones, Microsoft HoloLens) Mobile AR SDK, sensing/tracking SDK and real-time | Safety Detailed 3D models File Formats (e.g., fbx, . dae, . Obj, 3DXML, CSB) | Camcorders and TVs Visualization (Tablets, Smartphones, Microsoft HoloLens) Mobile AR SDK, sensing/tracking SDK and real-time | Safety Managers Workers | Onsite and Offsite |

**Fig. 2** Different software used in BIM (*Source* [51])

As a consequence of insufficient data to maintain, the common data environment has been a failure in some instances [45]. Hence, as discussed in subsection B, preparing a comprehensive yet viable data requirement is a prerequisite to sustaining the common data environment throughout the project. At the same time, the management of data is another significant aspect to consider upon the commencement of a project. The following critiques have been derived as the essentials that need to anticipate when managing data in a common data environment [9, 42, 44, 45]. Apart from the following critiques, facts relating to interoperability, open standards and data integration also need to be configured in the practical application of common data environment [18]. Before handling the common data environment selection of a database, setup and configuration and permitted access control should be confirmed at the beginning.

- Data security and intellectual property—data sensitivity
- Data classification and access control
- Data storage and transmission
- Data backup and disaster recovery
- Data retention and deletion
- Regular security audits and assessments
- Data usage rights

– Non-disclosure agreements
– Intellectual property rights.

British Standards Institute has published a separate guidance (BS EN ISO19650:5) to govern data security in UK building construction and civil engineering works. It leads the pathway on paving an appropriate data security mindset along with monitoring and auditing compliances [9]. Moreover, the open BIM data standard namely Construction Operations Building Information Exchange (COBie) has been popular in handling the data in the operational phase of the project [50]. The importance of maintaining a clear data monitoring has established by ref. [18]. Meanwhile, [45] have presented a list of quality documentation to maintain for common data environment entries and downloads. Issues and problems that may arise out of data ownership and Intellectual Property (IP) rights need to be handled carefully, because many firms are loathed to share their information and database [52].

### *3.5 Collaborative Workflows and Process (Including Communication, Coordination)*

Having a good leadership is indeed essential for proper implementation. While, upon an unpleasant communication or a collaboration, could vain the attempt on successful BIM implementation. Smith [52] has provided that, multi-disciplinary yet collaborative approaches are required to BIM adopt in any project. That's maybe because of the innate internal project characteristic which results in different team members that coming from different backgrounds yet working toward a common goal. Although they are coming in different disciplines, ultimately, it is assisting to grow well in achieving the project's aims and objectives feasibly rather than working on a silo mentality [52]. Even among the competencies relating to BIM, collaboration and communication has been recognized as the most salient competency and it has been categorized under the common competencies [55].

When it comes to collaborative working processes, human-to-human interactions and relationship matters prudently. Under the umbrella of human-to-human interactions, defining of workflows, process and collaborative engagement of project team members need to be discussed [26]. Eadie et al. [19] established that having a proper plan and continuous monitoring in the progress is very crucial in the management of BIM in delivering higher levels of project performance. As discussed earlier, BIM itself facilitates the collaborative work environment preciously owing to the drawbacks of fragmented relationships in the traditional project management [58]. Collaboration has been identified as a prime consideration in BIM implementation [34]. Interestingly, it was observed that [37] have used cooperation instead of collaboration in the study. Further, they have acknowledged that collaborative working environment and culture are ones of strategies that need to cater to accommodate a change in work entity for a successful implementation of BIM. Eadie et al. [19] findings also showed that having a proper collaboration is the key to successful

BIM which was ranked no. 1. Therefore, maintaining a proper communication and collaboration from the commencement of the project to the end of the project is highly encouraged.

### 3.6 Project Leadership

Smith [52] has revealed that leadership is one of the prominent keys for a successful BIM implementation, while avoiding problems in relation to piecemeal and disjointed approaches. In BIM projects, the project manager takes the lead in setting up BIM and it has been recommended [21]. Controversially, recent literate has provided a separate role as a BIM manager to handle and take care of the BIM works in construction projects [55].

Apart from that, Smith [52] provided that, government shall take the directive initiations primarily for proper BIM implementation. However, as the driving force of national BIM adoption, aligning with Government national BIM mandates is necessary to be solicitude into the project level implementation as well. They further stated that, BIM is more successful when it is driven by clients. Moreover, major contracting and consultancy organizations are prerequisites to maintain the supply chain as per set BIM requirements [52].

Eadie et al. [19] have revealed that, reluctance of team members in sharing information hinders the implementation of BIM. Leicht et al. [32] team communication with clients adversely impacts on 8% of occasions and among team members on 5% of occasions. In addition to that, project leadership is expected to be visionary and strategically align with the project's aim and objective. Thus that, being competent on decision-making and problem-solving is indeed as a project leader.

### 3.7 Resource Management

Under the resource management, human recourse and financial resource have been discovered. The fact that other related components in resource management are covered in other sub sections unnecessary repetitions are avoided. Even though, BIM is mostly involved in technology, still the human resource is irreplaceable [55]. Eadie et al. [19] identified lack of expertise within the project team and organization hinders the adoption of BIM in construction industry. Succar et al. [53] have presented that few competency areas that are required to have within an individual to work with BIM. Moreover, they have further elaborated on different competency levels needed in different BIM maturity stages. Corresponding to that, the required competencies and level of competency are particular from one another. Such that, make a note of the exact skill needed from the project participants and then fulfilling the mismatching skill gaps would manage the human resource efficiently. The growing demand toward the technology developments, compels the strong enhanced digital capability [38].

When managing the human resource, the skills, training engagement and attitude of people are needed to be considered. Training has been identified as a prominent branch of BIM implementation and further discussed in sub-section G separately. The attitude of people can be argued that it mostly deals with cultural influence and thereby level of acceptance of the change. That is because of the accompanied cultural difference along with adopting BIM for a project. BIM adoption may result in changes of employees' roles, behavior, workflows, and skills [6]. Moreover, as a result of mutual synergy in between project participants, defining the shared roles and responsibilities has been identified as an important factor [28]. They have suggested to detail the project participants' role and responsibilities in terms of the scope of work, depth, and weight of the construction business functions.

On the other hand, financial resource has been discovered as main challenge in implementing BIM for construction projects [22, 23]. Most practitioners have used BIM in the design and construction stages and abandoned BIM in the operational and maintenance stages. Due to the lack of additional project finance to support BIM, resist its usage at the operational phase of the project [19]. Financial support for BIM secured the top 3rd rank for considerations on proper BIM implementation in many countries [37]. As a result of isolated ad hoc use of BIM caused high implementation cost [52]. Some researchers have found that staff training and development cost incurred a high percentage from the overall expenses of the project [21, 52]. According to Eadie et al. [19], investment costs have been an issue to not to use BIM. Though BIM lacks immediate benefits, it is accepted that BIM implementation gains rich benefits in Returns on Investment [19].

### *3.8 Training and Education (Skills Development)*

In terms of providing training in BIM implementation, it does not limit to teaching BIM software but also educating in open BIM concepts, BIM management and collaborative working approaches [52]. The BIM training cost is high and as a result of that learning curve is steep [8]. In Eadie et al. [19] study, they found that BIM implementation requires significant investment on training cost (ranked 7 of 13). Some of the people have believed that no difference in use of BIM in a construction project in gaining profits. Moreover, lack of expertise within the project and within the organization specially recorded high concerns. Therefore, providing training and education streamline the better performance in the project. Uhm et al. [55] have shown a framework of competencies along with the job role. While, Mandicak et al. [38] have presented a potential list of digital competencies and BIM skills. In addition to that, a skill assessment aids in identifying the skill gap and improvement of personnel. Succer et al. [53] also have provided BIM competencies and assessment guide. Notwithstanding that, regular or periodic training development programs as in workshops, crash courses, peer learning to address ongoing difficulties, technology updates are well recommended.

### *3.9 Change Management*

According to Smith [52] Chinese have faced cultural resistance to adopt BIM in their construction project. It is true that, introducing novel working culture over an *used to do practice* is really challenging [52]. Even though many scholars have pointed out that BIM adoption of culture as a negative concern, [6], pointed out that, by making awareness of the project team members on the benefits of BIM, it will positively trigger the adoption. However, it is well acknowledged that the initiation of BIM implementation in a construction project comes along with a change management process [37]. Mainly, the technology application and use of different software made the difference among project members [6]. Ma et al. [37] have provided that, leadership is a key measure to tackle change management well in the process and to sustain during the process. Further, adopting ad hoc settings in terms of technical, organizational and financial conditions within the project context is recommended to overcome the difficulties [37]. According to Alankarage et al. [6] study, negative cultural change cannot merely attenuate by training or education, but by adopting an innovative design like behavioral design would make possible changes. Hence, for a successful BIM implementation testifying the readiness of the change adoption and change impact assessment are nifty tools that can utilize to plot the strategies ahead [36]. Having said that, the strategies are not common and can differ from project to project or organization to organization [35].

### *3.10 Stakeholder Engagement*

Eadie et al. [19] identified, the lack of client demand, cultural resistance, legal issues in ownership, IP and insurance causes hindering the BIM implementation. Owing to the special requirement demanded by BIM, some stakeholders are concerned on matching the BIM competency. In fact, they further mentioned that, educating stakeholders in BIM benefits would attract them for better engagement. Such that, identification of relevant stakeholders, and analyzing stakeholders' interests, competencies, and capabilities to perform the project would hinder the drawbacks of uncertainties. Interestingly, it has been identified that, facility managers are secondly benefited by BIM implementation in a project after clients [19]. Besides that, it has already been found that, mutual adjustments along with different stakeholders to the project improve the effectiveness of the proper technology implementation [18]. Yet, it was not limited for a given phase but also bridged each different phase such as design, construction, operation etc.. During the stakeholder analysis, benefits, satisfaction, and concerns are also crucial to consider in deciding stakeholder engagement. [18] stated that, current culture allows the stakeholders to incorporate their personal and organizational interests and reflections rather than building performance within the context. On the other hand, collaborative planning and regular communication among stakeholders also essential to be updated on the current status of the project [26]. Fazli et al. [21], mentioned that BIM itself leads to good coordination and communication between stakeholders. According to Sidani et al. [51] study, scholars had an attempt in introducing an AR and multiscreen (AR-MS) system as a BIM table to bring all the discussions, cooperation, and communications to one place. It reduces complex discussions but accommodates a user-friendly interface, saves time and stores all the information until end of the process.

### *3.11 Quality Assurance and Control—BIM Performance*

With the use of BIM technology, it is itself improves the quality of the project while reducing waste, rework, time and enhancing functionality in the entire lifecycle of a project [52]. Similarly, the quality of underlined project management of the BIM project is significant to attain. A successful implementation lies with a sustainable adoption of the technology till the end of a particular project. Although just because the above-discussed aspects are fulfilled in a project, unlikely to guarantee a smooth workflow for the project. Through following a quality assurance or control checkups intermittently could trail the direction well with the comparison to early defined BIM project goals. Despite that, a sustainable quality control over project management again reflects, the quality of the final outcome of the project [16]. Leygonie et al. [33] have developed a quality management framework for facility management BIM projects. It has content with quality assurance and control checklist, periodic tests and tools to be used. Chen and Luo [13] have developed a comprehensive BIM based quality model to use in design and construction stages. The Finish document COBIM2012—series 6: Quality assurance has published a handbook for quality measures in BIM projects. Overall, every stipulated standards that are published by reputed institutes such as BSI, BuildingSMART, General Services Administration, make sure to guide the professionals for a better quality project procurement [9, 16]. Thus, adhering to set standards and continuous improvement in quality check-ups would reinforce the quality of project delivery.

### *3.12 Contractual and Legal Considerations/Standard Conventions, Protocols*

Owing to the engagement of many team members within a project, legal liability of accuracy, and quality of the information in a BIM environment have been critical considerations within the project. As discussed above, by regulating data management, the accuracy, comprehensiveness and quality of the model can be sustained [52]. Such that, contractual and legal considerations are mandate tools to sign up in the BIM implementation process. As a consequence of growing demand in BIM National BIM Guide (by National Specification—NATSPEC) in Australia, National

Guidelines for Digital Modeling (by Corporate Research Centre for Construction Innovation CRC-C1), Australian and New Zealand Revit standards (ANZRS), BIM-MEPAUS guidelines and models were established [52]. Further, BuildingSMART has made a significant influence in promoting BIM in Australia which resulted in establishing Open BIM Alliance in Australia [52].

In Singapore Construction and Real Estate Network (CORENET) e-Plan check system was introduced to verify the regulatory compliance [52]. Currently, New Engineering Contracts (NEC4 ECC) and Join Contractor's Tribunal (JCT CE) suits include the contractual provisions for BIM adoption [46]. China has issued Chinese National Standards – Unified Standards for BIM Application [52]. Smith [52] have revealed that, national BIM maturity models are mostly encouraged when compare to the individual organization models which are owned privately. Likely, the standards are more preferred in the industry. Having said that, organizational or project-level standards are poorly developed when compared to national and industry-level standards [28]. It is acknowledged that, those are influenced by managerial issues of corporate or project strategies and owing to the dynamic nature in internal purpose, formats, and details. Jung and Joo [28] have brought up that, two types of standards: process standards and product standards.

According to Eadie et al. [19] observation, UK government requests as-built information (Construction, Design and management regulation), but contractors are providing as-designed information. They are reluctant to give because 3D is more time-consuming than 2D. The BIM protocol which is developed by AIA has been recognized as a well-scrutinized BIM protocol and it has been used widely in projects [52]. Eadie et al. [19] proposed that the incorporation of issues of electronic documentation and facilitation of new collaborative practices are more necessary than simple additional contractual condition amendments. Project management information systems including CIC has been recommended as good tools for 'clarifying and systemizing project execution plans, procedures, and manuals ([28]: p. 131). AIA digital practice documents include the digital data licensing agreement—AIA 2013a, project digital data protocol form—AIA 2013b and project BIM protocol form—AIA 2013c [11].

In the context of legal considerations, the below sub-elements are observed as important in addressing when implementing BIM [9, 26, 42, 43, 50].

- BIM agreements and protocols
- Intellectual property (IP) rights
- Liability and indemnity
- Data protection and confidentiality
- Subcontractor and supplier agreement
- Dispute resolution mechanism
- Compliance with host countries' national policies.

BSI [9], BS EN ISO19650:5 consists with data protection over a loss, theft, misuse, disclosure or modification of sensitive data and intellectual property. Further, it does carry with fines for regulatory breaches as well. US National Institute of Building Science (NIBS) has carried out an investigation on introducing project-based liability insurance, especially for covering risks associated with the integrated procurement approach [52]. According to CIC BIM protocol, BIM model can be suspended owing to non-payment by the client whereas as in other instance, model has to be irreversibly transferred [46]. Model ownership has been ranked the most prominent contractual issue in the industry, since it is developed by many parties to the contract [46]. Article 7 of AIA B101 (AIA2017) has given that, model authors own their product IP, but are obliged to grant nonexclusive license to project owner. According to OhioDAS [41] the total model ownership lies with the project owner. Explicit provision of traditional procurement for Contractors in China inhibits the BIM implementation due to the discouragement of collaboration to some extent [52]. Fazli et al. [21] presented that, industry has a perception that, the combination of BIM lacks the legal validity whereas 2D plotted drawings only carry the validity.

## 4 Proposed Research Design and Discussion

The review of literature identified many of the significant aspects that require managerial attention within the scope of BIM implementation. Though their importance may vary owing to factors such as the level of BIM adoption, government involvement, project strategies, goals, and objectives; a full list of such aspects is the first requirement to achieve in the pathway to develop a comprehensive framework of BIM implementation management. These will then be required to be structured into a framework that can offer structured multi-dimensional understanding since it needs to cover to an extent of satisfying breadth of all different significant aspects and depth of each branch of aspects to a level compatible with an effective strategizing of the implementation. Consequently, the study assumes such existence of an underlying structure that manifests itself differently in various BIM implementation experiences, due to contextual differences in each of them. Therefore, even though the research takes objectivism as its ontological standing; the empirical evidence is likely to be within the variable experiences of different BIM implementations. For a context of this nature, Saunders et al. [49] recommends taking Critical Realism philosophical stand. Since, the significant aspects of BIM implementation management are to be appropriately structured through the analysis, and the findings of the literature review could present the initial framework, an iterative process of induction and deduction, termed Retroduction is identified as the approach to theory development [49, 54].

However, the abridged knowledge due to the lack of empirical studies in the area can be mapped with the relevant experiences that could have spread in many different sources which contribute to heighten the validity of study findings. The primary source of data is within the individuals who have experienced in BIM implementation, making the semi-structured personal interviews as a preferred mode of enquiry. However, it is also observed that many of such experience is recorded in many non-scientific published sources such as company websites and blogs. Some experiences are also shared in online forums such as LinkedIn discussions. These sources become valuable for data triangulation. Further to these, it is also identified that many BIM


**Fig. 3** Proposed methodology in developing the framework

guidelines, standards, reports, protocols and policy documents relevant to BIM are formulated by collating experience of the development teams and presenting another group of data sources.

A qualitative thematic analysis will scrutinize the data to develop and validate the BIM implementation management structure. The priori codes will come from the literature findings, and further codes will be identified from data through the analysis process. Axial coding will be used to appropriately structure the codes. The final code-structure will become the basis for the framework intended to be found through this study. Data interpretations will present the explanation for all identified significant aspects of the framework. Figure 3 shows the proposed methodology for developing the BIM implementation from current fragmented knowledge.

## 5 Conclusion

BIM enjoys a wide interest around the world for many benefits it brings into construction. Yet, the challenges associated with BIM implementation hinder and restrict full realization of true value of BIM implementation. There is a line of knowledge associated with effective management of BIM implementation to support addressing the challenges effectively. The review of current literature showed the existence of many different significant aspects that require managerial attention for successful BIM implementation. However, the current scientific knowledge on these is incomplete. To address this issue a research study is proposed to identify the BIM implementation management framework to support both wide and deeper comprehension of BIM implementation management. The study takes a Critical Realism research philosophy with Retroductive approach to theory. A qualitative thematic analysis with data from multiple sources is proposed. The developed framework will offer BIM implementers a comprehensive framework to manage their BIM implementation efforts effectively. The framework will also offer the scientific community with a structured approach to deepen their studies in BIM implementation aspects.

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## References

1. Abdirad H (2017) Metric-based BIM implementation assessment: a review of research and practice. Architectural Eng Des Manag 13(1):52–78.https://doi.org/10.1080/17452007.2016.1183474
2. Ahmad-Latiffi A, Mohd S, Kasim N, Fathi MS (2013) Building information modeling (BIM) application in Malaysia construction industry. Int J Constr Eng Manag 2(4A):1–6
3. Ahmed S (2018) Barriers to implementation of building information modeling (BIM) to the construction industry: a review. J Civil Eng Constr 7(2):107. https://doi.org/10.32732/jcec.2018.7.2.107
4. Aibinu AA, Papadonikolaki E (2020) Conceptualizing and operationalizing team task interdependences: BIM implementation assessment using effort distribution analytics. Constr Manag Econ 38(5):420–446. https://doi.org/10.1080/01446193.2019.1623409
5. Al-Ashmori YY, Othman I, Rahmawati Y, Amran YHM, Sabah SHA, Rafindadi AD, Mikić M (2020) BIM benefits and its influence on the BIM implementation in Malaysia. Ain Shams Eng J 11(4):1013–1019. https://doi.org/10.1016/j.asej.2020.02.002
6. Alankarage S, Chileshe N, Rameezdeen R, Edwards DJ, Samaraweera A (2023) Exploring BIM-triggered organisational and professional culture change: a systematic literature review. Constr Innov 23(1):229–247. https://doi.org/10.1108/CI-04-2021-0084
7. Bosch-Sijtsema P, Isaksson A, Lennartsson M, Linderoth HCJ (2017) Barriers and facilitators for BIM use among Swedish medium-sized contractors—we wait until someone tells us to use it. Vis Eng 5(1):3. https://doi.org/10.1186/s40327-017-0040-7
8. Bouška R (2016) Evaluation of maturity of BIM tools across different software platforms. Procedia Eng 164:481–486. https://doi.org/10.1016/j.proeng.2016.11.648
9. British Standards Institution (BSI) (2022) ISO 19650—building information modelling (BIM). [online] Bsigroup.com. https://www.bsigroup.com/en-GB/iso-19650-BIM/
10. Bryde D, Broquetas M, Volm JM (2013) The project benefits of building information modelling (BIM). Int J Proj Manag 31(7):971–980. https://doi.org/10.1016/j.ijproman.2012.12.001; https://www.researchgate.net/publication/259390230_BIM_-_History_and_Trends
11. Celoza A, de Oliveira DP, Leite F (2023) Qualitative analysis of the impact of contracts on information management in AEC projects. J Constr Eng Manag 149(3):04022185. https://doi.org/10.1061/JCEMD4.COENG-12359

12. Chahrour R, Hafeez MA, Ahmad AM, Sulieman HI, Dawood H, Rodriguez-Trejo S, Kassem M, Naji KK, Dawood N (2020) Cost-benefit analysis of BIM-enabled design clash detection and resolution. Constr Manag Econ 39(1):55–72. https://doi.org/10.1080/01446193.2020.1802768
13. Chen L, Luo H (2014) A BIM-based construction quality management model and its applications. Autom Constr 46:64–73. https://doi.org/10.1016/j.autcon.2014.05.009
14. Churcher D, Davidson S, Kemp A (eds) (2019) Information management according to BS EN ISO 19650—guidance part 1: concepts, 1st edn. UK BIM Alliance
15. Criminale A, Langar S (2017) Challenges with BIM implementation: a review of literature. https://www.researchgate.net/publication/317842173
16. Donato V, Lo Turco M, Bocconcino MM (2018) BIM-QA/QC in the architectural design process. Architectural Eng Des Manage 14(3):239–254. https://doi.org/10.1080/17452007.2017.1370995
17. Doumbouya L, Gao G, Guan C (2016) Adoption of the building information modeling (BIM) for construction project effectiveness: the review of BIM benefits. Am J Civil Eng Architecture 4(3):74–79. https://doi.org/10.12691/ajcea-4-3-1
18. Dowsett RM, Harty CF (2013) Evaluating the benefits of BIM for sustainable design: a review In: Smith SD, Ahiaga-Dagbui DD (eds) Processing 29th annual ARCOM conference, 2–4 September 2013, reading, UK, Association of researchers in construction management, pp 13–23
19. Eadie R, Browne M, Odeyinka H, McKeown C, McNiff S (2013) BIM implementation throughout the UK construction project lifecycle: an analysis. Autom Constr 36:145–151. https://doi.org/10.1016/j.autcon.2013.09.001
20. Eastman CM, Fisher D, Lafue G, Lividini J, Stoker D, Yessios C (1974) An outline of the building description system (Research report no. 50). Carnegie-Mellon University, p 22
21. Fazli A, Fathi S, Enferadi MH, Fazli M, Fathi B (2014) Appraising effectiveness of building information management (bim) in project management. Procedia Technol 16:1116–1125. https://doi.org/10.1016/j.protcy.2014.10.126
22. Gamil Y, Rahman IAR (2019) Awareness and challenges of building information modelling (BIM) implementation in the Yemen construction industry. J Eng, Design Technol 17(5):1077–1084. https://doi.org/10.1108/JEDT-03-2019-0063
23. Georgiadou MC (2019) An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. Constr Innov 19(3):298–320. https://doi.org/10.1108/CI-04-2017-0030
24. Hjelseth E (2010) Exchange of relevant information in BIM objects defined by the role- and life-cycle information model. Architectural Eng Design Manag 6(4):279–287. https://doi.org/10.3763/aedm.2010.idds5
25. Hochscheid E, Halin G (2018) A model to approach BIM adoption process and possible BIM implementation failures. Creative construction conference 2018—proceedings, pp 257–264. https://doi.org/10.3311/ccc2018-034
26. Hoeber H, Alsem D (2016) Life-cycle information management using open-standard BIM. Eng Constr Archit Manag 23(6):696–708. https://doi.org/10.1108/ECAM-01-2016-0023
27. Jin R, Hancock C, Tang L, Chen C (2017) Empirical study of BIM implementation–based perceptions among Chinese practitioners. J Manag Eng 35(5):04017025–1–04017025–11. https://doi.org/10.1061/(ASCE)ME.19435479.0000538
28. Jung Y, Joo M (2011) Building information modelling (BIM) framework for practical implementation. Autom Constr 20(2):126–133. https://doi.org/10.1016/j.autcon.2010.09.010
29. Jupp JR (2013) Incomplete BIM implementation: exploring challenges and the role of product lifecycle management functions. Product Lifecycle Manag Soc 409:630–640. https://doi.org/10.1007/978-3-642-41501-2_62
30. Khalili A (2021) An XML-based approach for geo-semantic data exchange from BIM to VR applications. Autom Constr 121:103425. https://doi.org/10.1016/j.autcon.2020.103425
31. Latiffi AA, Brahim J, Fathi MS (2014) The development of building information modeling (BIM) definition. Appl Mech Mater 567:625–630. https://doi.org/10.4028/www.scientific.net/amm.567.625

32. Leicht R, Fox S, Mäkelainen T, Messner J (2007) Building information models, display media, and team performance: an exploratory study, VTT working paper. Available on-line at http://www.vtt.fi/inf/pdf/workingpapers/2007/W88.pdf
33. Leygonie R, Motamedi A, Iordanova I (2022) Development of quality improvement procedures and tools for facility management BIM. Dev Built Environ 11:100075. https://doi.org/10.1016/j.dibe.2022.100075
34. Lin TH, Liu CH, Tsai M, Kang SC (2015) Using augmented reality in a multiscreen environment for construction discussion. J Comput Civ Eng 29(6):04014088
35. Lines BC, Vardireddy PKR (2017) Drivers of organizational change within the AEC industry: linking change management practices with successful change adoption. J Manag Eng 33(6):04017031. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000548
36. Liu F, Jallow AK, Anumba CJ, Wu D (2014) A framework for integrating change management with building information modeling. Comput Civil Build Eng 2014:439–446. https://doi.org/10.1061/9780784413616.055
37. Ma X, Chan APC, Li Y, Zhang B, Xiong F (2020) Critical strategies for enhancing BIM implementation in AEC projects: perspectives from Chinese practitioners. J Constr Eng Manag 146(2):05019019. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001748
38. Mandičák T, Mésároš P, Behún M, Behúnová A (2020) Development of digital and managerial competencies and BIM technology skills in construction project management. In: Knapcikova L, Balog M, Peraković D, Periša M (eds) New approaches in management of smart manufacturing systems. Springer International Publishing, pp 159–175. https://doi.org/10.1007/978-3-030-40176-4_10
39. Mesároš P, Mandičák T, Behúnová A (2022) Use of BIM technology and impact on productivity in construction project management. Wireless Netw 28(2):855–862. https://doi.org/10.1007/s11276-020-02302-6
40. Migilinskas D, Popov V, Juocevicius V, Ustinovichius L (2013) The benefits, obstacles and problems of practical BIM implementation. Procedia Engineering 57:767–774. https://doi.org/10.1016/j.proeng.2013.04.097
41. OhioDAS (Ohio department of administrative services) (2020) State of Ohio building information modelling (BIM) protocol. Columbus, OH, OhioDAS. https://www.transportation.ohio.gov/programs/bim
42. PAS (2013) 1192–2:2013: Specification for information management for the capital/delivery phase of construction projects using building information modelling (First published). BSI
43. Patacas J, Dawood N, Kassem M (2020) BIM for facilities management: a framework and a common data environment using open standards. Autom Constr 120:103366. https://doi.org/10.1016/j.autcon.2020.103366
44. Preidel C, Borrmann A, Mattern H, König M, Schapke S-E (2018) Common data environment. In: Borrmann A, König M, Koch C, Beetz J (eds) Building information modeling. Springer International Publishing, pp 279–291. https://doi.org/10.1007/978-3-319-92862-3_15
45. Radl J, Kaiser J (2019) Benefits of implementation of common data environment (CDE) into construction projects. IOP Conf Ser: Mater Sci Eng 471:022021. https://doi.org/10.1088/1757-899X/471/2/022021
46. Ragab MA, Marzouk M (2021) BIM adoption in construction contracts: content analysis approach. J Constr Eng Manag 147(8):04021094. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002123
47. Reddy KP (2012) BIM for building owners and developers: making a business case for using BIM on projects. Wiley, United State of America
48. Saraireh IMAQ, Haron AT (2020) Understanding the conceptual of building information modeling: a literature review. Int J Civil Eng Technol 11(1):165–171. https://doi.org/10.34218/ijciet.11.1.2020.018
49. Saunders MNK, Lewis P, Thornhill A (2019) Research methods for business students, 8th edn. Pearson Education Limited
50. Shin S, Moon H, Shin J (2022) BIM-based maintenance data processing mechanism through COBie standard development for port facility. Appl Sci 12(3):1304. https://doi.org/10.3390/app12031304

51. Sidani A et al (2021) Recent tools and techniques of BIM-based augmented reality: a systematic review. J Build Eng 42:1–13. Available at: https://doi.org/10.1016/j.jobe.2021.102500
52. Smith P (2014) BIM implementation—global strategies. Procedia Eng 85:482–492. https://doi.org/10.1016/j.proeng.2014.10.575
53. Succar B, Sher W, Williams A (2013) An integrated approach to BIM competency assessment, acquisition and application. Autom Constr 35:174–189. https://doi.org/10.1016/j.autcon.2013.05.016
54. Suddaby R (2006) From the editors: what grounded theory is not. Acad Manag J 49(4):633–642. https://doi.org/10.5465/amj.2006.22083020
55. Uhm M, Lee G, Jeon B (2017) An analysis of BIM jobs and competencies based on the use of terms in the industry. Autom Constr 81:67–98. https://doi.org/10.1016/j.autcon.2017.06.002
56. Ullah K, Lill I, Witt E (2019) An overview of BIM adoption in the construction industry: benefits and barriers. In: Lill I, Witt E (eds) 10th Nordic conference on construction economics and organization (Emerald reach proceedings series, vol 2), Emerald Publishing Limited, Bingley, pp 297–303. https://doi.org/10.1108/S2516-285320190000002052
57. Wierzbicki M, De Silva CW, Krug DH (2011) International conference on construction applications of virtual reality, 2011. In: CONVR2011, vol 11. Retrieved 29AD
58. Xu X, Ma L, Ding L (2014) A framework for BIM-enabled life-cycle information management of construction project. Int J Adv Rob Syst 11(8):126. https://doi.org/10.5772/58445
59. Zomer T, Neely A, Sacks R, Parlikad A (2021) A practice-based conceptual model on building information modelling (BIM) benefits realisation. In: Toledo Santos E, Scheer S (eds) Lecture notes in civil engineering. Springer, pp 1–98. https://doi.org/10.1007/978-3-030-51295-8_29

# Ethics Provisions Within New Zealand Professional Codes of Conduct, Towards a Construction-Wide Code of Ethics

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## 1 Introduction

The objective of this study is to critically compare the ethics provisions contained within codes of conduct used by construction professional bodies that operate membership within the New Zealand (NZ) construction industry. The content is also compared with ethics provisions highlighted as important in previous literature [26]. The broader research aim is that through harmonising ethics provisions across codes of conduct, that this may help pave the way towards a code of ethics for the NZ construction industry, applied on an opt-in project-by-project basis. Such a code of ethics could capture those construction practitioners who both belong to professional bodies and those who do not. The harmonisation will help to fill any gaps that may currently exist across the codes of conduct. Furthermore, a code of ethics may

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include standard and specific opt-in terms, such as relating to societal and environmental sustainability objectives. See the research methodology below for a roadmap towards drafting and testing such a code of ethics.

Uff [28] raised the potential for a construction industry code of conduct to address issues throughout the industry in a paper published in the Society of Construction Law UK (SCLUK). This was followed by Uff [27] and Thornton [26] also published by the SCLUK, and subsequent calls for a code of ethics, such as from McCarthy [16] in Australia. A construction code of ethics could be opted into on a project-by-project basis. This could capture those working as project managers, professional quantity surveyors (PQSs), estimators, and contract administrators who do not belong to construction professional bodies. Professional bodies, such as the project management institute (PMI), New Zealand Institute of Quantity Surveyors (NZIQS), the Royal Institute of Chartered Surveyors (RICS), and Engineering New Zealand. And each has its own code of conduct for its members to abide by. However, there is no requirement in New Zealand (NZ) for such practitioners to be registered or belong to any professional body. Moreover, there is an absence of research into construction ethics in NZ, despite the previous calls for a construction code of ethics.

Ethics is generally defined in terms of moral behaviour. The Cambridge Dictionary [10] defines 'ethics' as a 'noun—a system of accepted beliefs that control behaviour, especially such a system based on morals.' While 'morals' are defined as a 'plural noun—standards for good or bad character and behaviour' [11]. To be more specific what constitutes 'good' and 'bad' ethical behaviour in construction requires more specific definition.

Enforcing ethical conduct for commercial construction projects is largely absent from NZ legislation. This perhaps reflects that setting standards for moral good and bad behaviour may not adequately reflect the reality of contracting and maintaining parties' 'freedom to contract' their own terms. For example, some may consider that it is not good 'behaviour' for clients to transfer risks onto contractors. NZ courts may deem contract terms as 'unfair' under Section 46L of the Fair Trading Act [18]. The scope only relates to 'consumer contracts' or 'small trade contracts.' Section 46L provides when contract terms are 'unfair':

**46L When Term in Consumer Contract or Small Trade Contract Is Unfair**

(1) A term in a consumer contract or small trade contract is unfair if the court is satisfied that the term—
   - (a) would cause a significant imbalance in the parties' rights and obligations arising under the contract; and
   - (b) is not reasonably necessary in order to protect the legitimate interests of the party who would be advantaged by the term; and
   - (c) would cause detriment (whether financial or otherwise) to a party if it were applied, enforced, or relied on.

(2) In determining whether a term of a consumer contract or small trade contract is unfair, the court may take into account any matters it thinks relevant, but must take into account—

(a) the extent to which the term is transparent; and
(b) the contract as a whole.

(3) For the purpose of subsection (1)(b), a term in a consumer contract or small trade contract must be presumed not to be reasonably necessary in order to protect the legitimate interests of the party who would be advantaged by the term, unless that party proves otherwise.

The Building Research Authority of New Zealand [6] provides that 'The Fair-trading Act also covers unfair contract terms. This relates to clauses in standard form consumer contracts (contracts that consumers must accept on a take-it-or-leave-it basis)' and potentially not where both parties can negotiate their own terms.

Section 27 of the NZ Commerce Act [1] prohibits anti-competitive arrangements that lesson competition and the [8] provides guidance for detecting 'bid rigging' where contractors share their prices and decide who's is going to be lowest in what is meant to be a competitive tender situation. However, the above legislation covering fair commercial contracting practices does not appear to address parties' conduct during the construction stage.

The Consumer Guarantees Act [30] requires those providing services to take 'reasonable skill and care.' This is the test to establish negligent breach, conduct that fails to comply with what any other reasonably competent professional would have done given similar circumstances and accounting for available codes, standards, and trade literature, may be considered negligent. The test to establish what constitutes reasonable skill and care was first established in Bolam v. Friern Hospital Management Committee [4] and extended to other professionals such as construction consultants, who, like doctors, cannot guarantee successful operations.

However, what constitutes what might breach 'reasonable skill and care' ethical behaviour is not defined. The concept of parties' 'freedom to contract' is also reflected in the Consumer Guarantees Act [30]. Section 43 allows parties to contract out of the Act where goods or services are supplied and 'acquired in trade', and accounting for the 'bargaining power' between the parties.

Ethics legislation covers health professionals in NZ. And the Licenced Building Practitioners (LBP) scheme was launched in November 2007 following an amendment to the Building Act (2004) to cover builders [15]. However, enforcing ethics standards for construction professionals is generally left to professional bodies using complaints panels to investigate breaches of their codes of ethics.

Given the potential conflict between enforcing ethics standards versus maintaining parties 'freedom to contract' it is perhaps difficult to provide blanket legislation requiring 'moral' 'good behaviours' covering all construction projects. A preferable approach could be a construction code of ethics which can be opted into on a project-by-project basis. The code of ethics could cover key ethics considerations, such as maintaining project confidentiality, respecting copyrights, and carrying out certification duties impartially. In a similar fashion, the SCL UK has already published a Delay and Disruption Protocol [22] to help address content often absent in standard forms of construction contracts such a how to manage concurrent delay events. The Protocol does not have contractual effect, but provides a means of handling such events where the contract is silent. Potentially contracting parties could opt into the Protocol on a project by project basis, similar manner as to how a code of ethics could be opted into too. In the interim, the findings can help inform construction professional bodies in NZ construction about what ethics provisions may be considered important and where their existing codes of conduct may have gaps in ethical requirements for their members. The findings also support the NZ Construction Sector Accord which includes an objective to 'act with collective responsibility [9].

## 2 Research Methodology

Content of ethics provisions in the following construction professional body codes of ethics used in NZ are compared and analysed to saturation in terms of ethics provisions recommended in previous literature.

- New Zealand Institute of Quantity Surveyors (NZIQS) Code of Conduct [17],
- Registered Architect's Board (RAB) Code of Minimum Standards of Ethical Conduct for Registered Architects [19],
- Engineering New Zealand Code of Ethical Conduct [12], and
- Royal Institute of Charted Surveyors (RICS) Rules of conduct [20].

The RAB codes of ethics covers members in the New Zealand Institute of Architects. The recommended ethics content from previous literature relate to fair reward, integrity, objectivity, honesty, accountably, fairness, and reliability [26] as summarised under 3.3 types of breaches below. A thematic content analysis of the documentation is applied to critically compare content and highlight any potential gaps of ethics content within the codes of conduct. Such a qualitative analysis approach carries the risk of subjective interpretation by the researcher. To help address this, all content is analysed by all the co-authors of this paper.

The four codes of conduct were selected to best represent construction professionals belonging to professional bodies and working in NZ construction. It is acknowledged that some construction professional in NZ may belong to other professional bodies such as the Chartered Institute of Building (CIOB) or other general interest organisations such as the Society of Construction Law (NZ) (which has no code of conduct). However, those professionals are likely to also belong to the four professional bodies whose codes of conduct are analysed in this study. The NZIQS, NZIQ, and Engineering NZ are based on NZ. The RICS is based in the UK though has memberships within NZ and provides for interesting comparison with those based in NZ. All codes of conduct were current as of July 2023. Further research could compare ethics content of overseas codes of conduct. This could help towards harmonising ethics provisions to better meet the needs of a global world.

Thornton [26] first suggested a construction code of ethics and developed the framework of ethics provisions considered important for such a code. Little attention has followed over the past two decades towards achieving this objective. This limits the quantum of scholarly articles from which to draw on. Therefore, the ethics provisions recommended by Thornton [26] remain current and have been selected to form the framework used in this study to compare with the ethics content in the codes of conduct analysed.

## 3 Literature Review

### *3.1 Enforcement and Reporting of Ethical Breaches*

Uff [28] discusses the enforcement of ethical standards and informing the public of those who have breached them. Professional bodies typically have their own complaints panels to investigate ethics breaches. However, their findings and decisions often remain private. This means that the public lacks the means to know of unethical behaviour by parties. Professional bodies may also be reluctant to initiate investigations or complaints about one of its own members. This means that enforcing ethical standards may prove difficult. Moreover, not all construction participants belong to professional bodies, making enforcement of unethical breaches difficult, particularly given the patchy legislation covering ethics in NZ.

### *3.2 Types of Ethical Breaches*

Previous literature about ethics in construction tends to define unethical behaviour as including: bid shopping, lying, unreliable contractors, claims games (e.g. inflated claims, false claims), threats, conflict of interest, bid collusion, fraud, and professional negligence [13]. Strahorn, Gajendran, and Brewer [15] found trust to be integral to the experiences of construction professionals and good and bad interpersonal relationships evidence in traditional procurement. Likewise, Strahon, Brewer, and Gajendran [15] found trust to be key to addressing the risk of poor communication between project managers and their clients.

Uff [28] defined ethical breaches into three distinct stages, the initiating stage, construction stage, and the post-construction stage. The initiating stage can include ethical breaches during tendering: breaching confidentiality of tenders, deliberately negotiating with the winning contractor to further reduce their price, grossly underpriced tenders being awarded, and major foreseeable variations not being communicated to the other parties. This could have major flow on effects to the public if there are delays to the completion of public projects. Ethical breaches during the construction stage can include enforcing a ‘duty to warn’ when the parties are not contractually obliged to do so. While courts have ruled a duty to warn in tort in some instances, this has not been applied universally. Other issues might include concealing of ethics, over billing of works, and biased evaluations of extensions of time. The post-construction stage may include ethics considerations relating to settling of final accounts, over inflated claims and counter claims, extending processes leveraging power imbalances by filing for adjudication or arbitration. Ameh and Odusami [3] found quantity surveyors most subject to bribery in Nigerian construction and call for greater focus on ethics in construction education and further research into measures to curb ethical breaches. Similalrly, Sinha, Thomas, and Kulka [21] also called for greater focus on ethics and ethical decision-making when teaching engineers. Thornton [26] outlines seven qualities that should be included in codes of ethics. These are:

- Fair Reward—Clear risk allocation, scope of work, providing rate and valuation breakdowns, and define what is and is not acceptable conduct in terms of tendering, claiming, valuing, and payments.
- Integrity—Parties should evaluate and manage risks, and assign, eliminate, or share the risk ethically.
- Objectivity—Declaring conflicts of interest.
- Honesty—Avoiding corruption, bribery, claims fraud, collusive tendering, kickbacks, and forged documents to support claims.
- Accountability—Duty to warn of dangers, potential losses, or issues in the pre-contract information, from both the contractor and client-side representatives.
- Fairness—Act impartially when evaluating claims.
- Reliability—Operating within competency and declaring any scope that not competent in.

These seven recommended ethics provisions will form the basis of evaluating provisions in professional codes of ethics in this study, based on the following definitions summarised from Thornton [26]:

Fair Reward:

The construction industry can involve complex payment provisions and numerous contract variations. Both contractors and client-side parties may utilise opportunities to take 'advantage' and unreasonably gain financially from the other. This may be done through contractual factors such as maximising undefined or incomplete scope of works, interim payment provisions that are based on value of work rather than progress milestones, and valuating extension of time delays in the works. Related unethical practices might include contractors claiming scope not included in the tender where they have no breakdowns of rates or prices, interim claims and valuations being unfairly and inaccurately evaluated and late interim payments.

A code that accounts for fair reward should include factors such as clear risk allocation, scope of work, providing rate and valuation breakdowns, and define what is and is not acceptable conduct in terms of tendering, claiming, valuing, and payments.

Integrity:

Ethical integrity is largely based on risk allocation. Although risk is generally managed, eliminated, or shared in the contract prior to the beginning of the contract it is not always done so fairly. Not all parties involved in the construction industry are as well informed or educated on contractual risk management. Parties may knowingly transfer risks onto smaller less informed parties, such as large main contractors transferring substantial contractual risks onto less informed subcontractors.

Therefore, a code of ethics should include general principles that parties should evaluate and manage risks, and assign, eliminate, or share the risk ethically.

Objectivity:

The construction industry involves a complex range of roles and relationships meaning conflicts of interest can arise. It is unethical for parties not to disclose conflicts of interest. Examples of conflicts would include a PQS owning shares in a construction company that the client hired based on the PQS's evaluation of tenders. Ethically the PQS should clearly disclose their conflict of interest so that the client may that appropriate measures, whether that be retiring the PQS or an adjustment to their role.

Honesty:

Globally, the construction industry is prone to corruption, bribery, claims fraud, collusive tendering, kickbacks, and forged documents to support claims. These behaviours involving lying and misleading other parties are clearly unethical and can have major effects on projects and the construction industry's reputation. It is therefore important that any code of ethics prohibits such behaviour.

Accountability:

This involves delivering what is expected and to provide warning where such delivery becomes unlikely. Contracting parties are obligated to undertake the scope of work contractually required. However, issues can arise when the specifics of the scope are unclear clear in pre-contract or contract documents.

A code of ethics should require a duty to warn of dangers, potential losses, or issues in the pre-contract information, from both the contractor and client-side representatives. Notably the 2013 version of NZS3910 Conditions of contract for building and civil engineering construction [23], added clause 5.21 Advance notification. This requires the Engineer and Contractor to notify each other of anything that may materially affect the contract price, delay completion, or result in a compliance breach.

Fairness:

A complexity in the construction industry involves the contract administrator acting impartially when carrying out certification duties, when they are employed by the client, and so may feel biased by the client's interests when evaluating contractor claims. Therefore, a code of ethics should require impartiality. Clause 6.2 of NZS3910 does define the Engineer's role as both representing the client, and to value and certify claims 'fairly and impartially' and 'independently of either party'.

Reliability:

A code of ethics should also require consultants to disclose to the client any areas of work for which they are not competent. This enables the client to recruit a replacement. This is also reinforced by refs. [16] and [14].

### *3.3 Extent of Ethical Breaches*

Ethical breaches have been found prevalent in the construction industry abroad. Vee and Skitmore [29] found that survey of 31 participants in Australia comprising project managers, architects, and building contractors and all had witnessed or experienced some degree of unethical behaviour. Ho [13] surveyed a cross section of nearly 300 construction practitioners in the US, including architects, engineers, construction managers, general contractors, and subcontractors. 84 per cent said that they observed unethical behaviour in the past year, while 34 per cent reported that they had witnessed 'many, many' instances of unethical behaviour in the past year. Bowen et al. [5] surveyed architects, construction managers, quantity surveyors, and consulting engineers and found that 22–32% of the participants had observed 'conflicts of interest' (32%), confidentiality and propriety information breaches (24%), and overall, 78% had observed ethical breaches of professional responsibility one way or another. Abdul-Rahman, Wang, and Yap [2] found through survey questionnaire in Malaysia that quality problems on projects often arise due to ethical breaches. The Commerce Commission NZ [7] that interviewed participants in the non-residential construction sector in Auckland, Wellington and Christchurch and found a low level of understanding of anti-competitive behaviour, in particular 'cover pricing.' Cover pricing is where one contractor submits a tender bid that appears believable but is intentionally higher than that of another contractors. This breaches ethics related to Honesty (corruption, bribery, claims fraud, collusive tendering, kickbacks, and forged documents to support claims) recommended by Uff [27]. The Commerce Commission NZ [8] released subsequent guidelines for detecting bid rigging. Other than this, there appears to be an absence of NZ specific research into construction ethics.

The following section compares ethics provisions in construction codes of ethics used in NZ with each other, and the above recommended provisions in previous literature. The findings are discussed in relation to those of previous studies.

## 4 Data Analysis and Discussion

Following is a summary of the content contained in the professional body codes of conduct when compared to the ethics provisions recommended by Thornton [26]:

As shown in Table 1 below, Fair Reward is covered by 0/4 codes of conduct. Integrity is covered by 0/4 codes of conduct. Objectivity is covered by 4/4 codes of conduct. Honesty is covered by 4/4 codes of conduct. Accountability is covered by 4/4 codes of conduct. Fairness is covered by 4/4 codes of conduct. Reliability is covered by 4/4 codes of conduct.

Most of the recommended ethics provisions were covered by all codes of conduct in some capacity. One key gap appears to be that of Integrity—general principles that parties should evaluate and manage risks, and assign, eliminate, or share the risk ethically. Another is Fair Reward. However, it should be noted that professional bodies require their members to define their scope of services, and state prices and rates for variations. This typically addresses 'Fair reward.'

All codes of conduct clearly require members to declare any conflicts of interest (Objectivity) and to carry out claim certification duties impartially (Fairness). NZS3910 also requires this of the Engineer to the contract (contract administrator). All codes of conduct also require members to only act within the scope of their competencies and to notify of any work that is outside their competency (Reliability).

All codes of conduct require members to act honestly/trustworthy/fairly/transparently/without bias. Only Engineering NZ [12] clause 4.b. more specifically addresses corruption, bribery, claims fraud, collusive tendering, kickbacks, and forged documents to support claims (Honesty) with the following:

Engineering NZ [12] clause 4.b:

*b. must not*

*i. offer or promise to give to any person anything intended to improperly influence a decision relating to your engineering activities; or*

*ii. accept from any person anything intended to improperly influence your engineering activities; or*

*iii. otherwise engage in, or support, corrupt practices.*

In terms of Accountability (duty to warn of dangers, potential losses, or issues in the pre-contract information, from both the contractor and client-side representatives), all codes of conduct require members to warn of anything that may have an adverse baring on performance. However, NZIQS [17] clause 16 only requires its members to warn about anything that may delay progress:

NZIQS [17] clause 16:

16. A member must, in the case of unavoidable delay, communicate to the client the progress being made in respect of the instructions issued to the member.

**Table 1** Ethics content

| | NZIQS [17] | RAB [19] | Engineering NZ [12] | RICS (2021) |
|---|---|---|---|---|
| Fair reward | | | | |
| Integrity | | | | |
| Objectivity | 18, 19 | 52 | 5 | Rule 1 |
| Honesty | 17 | 47 | 5 | Rule 3 |
| Accountability | 16 | 58, 58B | 3, 4, 6 | Rule 2 |
| Fairness | 17 | 48, 53 | 5 | Rule 1 |
| Reliability | 10 | 51, 58 | 4 | Rule 2 |

However, there appears to be little requirement for members to evaluate and manage risks in an ethical manner (Integrity). This is reinformed by Uff [28] who also highlighted major foreseeable variations not being communicated to the other parties as a key ethics consideration to be addressed.

All codes of conduct generally contained requirements for members to act with Honesty. However, none specifically addressed factors highlighted by Ho [13] being bid shopping, unreliable contractors, bid collusion, and Uff [28] who highlighted deliberately negotiating with the winning contractor to further reduce their price, and grossly under-priced tenders being awarded as key ethics considerations. For example:

NZIQS [17] clause 17:

> 17. Members must maintain independence and impartiality where the exercise of objective judgement is required. Members must not allow prejudice or bias, bad faith, conflict of interest, or the influence of others to override objectivity.

RAB [19] clauses 47 and 56:

> 47. Honesty and fairness
>
> A registered architect must perform the architect's professional activities with both—
>
> a) honesty; and
>
> b) fairness.
>
> 56. Remuneration and Inducements
>
> A registered architect, in respect of the architect's professional activities,—
>
> (a) must be remunerated solely by the fees and benefits specified in the architect's written terms of appointment or employment agreement; and
>
> (b) must not offer or accept any significant inducement that creates, or may create, a conflict of interest; and
>
> (c) must not offer any significant inducement to procure an agreement for services or gain an unfair advantage.

Engineering NZ [12] clause 5 Behave appropriately:

> In performing, or in connection with, your engineering activities you a. must
>
> i. act with honesty, objectivity, and integrity; and
>
> ii. treat people with respect and courtesy; and disclose and appropriately manage conflicts of interest; and b. must not
>
> i. offer or promise to give to any person anything intended to improperly influence a decision relating to your engineering activities; or
>
> ii. accept from any person anything intended to improperly influence your engineering activities; or iii. otherwise engage in, or support, corrupt practices.

RICS (2021) Rule 1:

> Members and firms must be honest, act with integrity and comply with their professional obligations, including obligations to RICS.

Some of the codes of conduct contained ethics related provisions additional to those recommended by Thornton [26]. As shown in Table 2 below, Written communication is covered by 2/4 codes of conduct (NZIQS, RAB). Confidentiality is covered by 4/4 codes of conduct. Acting within the law is covered by 2/4 codes of conduct (NZIQS, RAB). Acting within institutional rules is covered by 2/4 codes of conduct (NZIQS, RICS). Disciplinary procedures are covered by 4/4 codes of conduct. Health and safety are covered by 1/4 codes of conduct (Engineering NZ). Public Interest is covered by 1/4 codes of conduct (RICS). Interpersonal skills are covered by 2/4 codes of conduct (Engineering NZ, RICS). Environmental is covered by 1/4 codes of conduct (Engineering NZ).

Again, some of these provisions are covered in professional body contracts for services, such as acting within the law, confidentiality, and written communication. Membership agreements would also require members to act within the codes of conduct, being institutional rules. Factors relating to disciplinary procedures tend to focus on not criticising others unless they believe on reasonable grounds that the member has committed a serious breach and complying with any investigation about a member's own conduct. Interpersonal skills focus on treating others with respect. This is most comprehensively covered by RICS. Other professional bodies may wish to consider whether this is something that they also want to request from their members. So too is acting in the public interest:

Engineering NZ [12] clause 5:

> 5. Behave Appropriately
>
> In performing, or in connection with, your engineering activities you
>
> a. must
>
> ii. treat people with respect and courtesy;

RICS (2021) Rule 4:

> Members and firms must treat others with respect and encourage diversity and inclusion.
> Example behaviours

**Table 2** Additional ethics content

| | NZIQS [17] | RAB [19] | Engineering NZ [12] | RICS (2021) |
|---|---|---|---|---|
| Written communication | 14 | 58A | | |
| Confidentiality | 20 | 58C | 7 | Rule 1 |
| Acting within the law | 24 | 46 | | |
| Acting within institutional rules | 8, 22, 25, 26 | | | Appendix A |
| Disciplinary procedures | 23, 27 | 54 | 8 | Rule 5, Appendix A |
| Health and safety | | | 1 | |
| Public interest | | | | |
| Interpersonal skills | | | 5.a | Rule 4 |
| Environmental | | | 2 | |

4.1 Members and Firms Respect the Rights of Others and Treat Others with Courtesy.

4.2 Members and firms treat everyone fairly and do not discriminate against anyone on any improper grounds, including age, disability, gender reassignment, marriage or civil partnership, pregnancy or maternity, race, religion or belief, sex or sexual orientation.

4.3 Members and firms do not bully, victimise or harass anyone.

4.4 Firms check that supply chains do not involve modern slavery or other abuses of the workforce.

4.5 Members and firms report abusive labour practices to proper and recognised authorities if they become aware of, or suspect, them.

4.6 Members and firms work cooperatively with others.

4.7 Members and firms develop an inclusive culture in their workplaces, support equal access and opportunity for all, and identify and address unconscious bias.

Only Engineering NZ [12] clause 2 requires members to consider the environment. This is perhaps an area for other professional bodies to consider, given the national and global focus on reducing emissions to help mitigate the effects of climate change and becoming more climate resilient.

Engineering NZ [12] clause 2:

2. Have regard to effects on environment

You must, in the course of your engineering activities,

i. have regard to reasonably foreseeable effects on the environment from those activities; and

ii. have regard to the need for sustainable management of the environment. In this rule, sustainable management means management that meets the needs of the present without compromising the ability of future generations (including at least the future generations within the anticipated lifetime of the end products and by-products of those activities) to meet their own reasonably foreseeable needs.

Adding requirements for interpersonal communication and the environment should also carefully consider the balance between benefits associated with adding such requirements and the potential to restrict its members' 'freedom of contract' and ability to remain competitive with those practitioners who do long belong as members to their professional bodies. This is because, the more industry practitioners that do not belong to professional bodies means that they are not bound by any ethics requirements in codes of conduct. That said, including ethics requirements for interpersonal communication and the environment could help support the [9]'s objective—'Āta: grow respectful relationships with people and the environment.'

Maximising the number of construction practitioners are included in codes of ethics should help to address findings by previous studies overseas that have found substantial observation of unethical conduct [5, 5, 13]. And the Commerce Commission NZ [7] research that found low industry knowledge about 'cover pricing' an area that could be more specifically focussed on under Honesty related ethics in codes of conduct.

Combining the preferred provisions from each code of conduct into one code of ethics for the NZ construction industry on a project by project opt-in basis could provide a clear and consistent approach to ethics requirements covering both client consultant and contractor sides. Disciplinary procedures would need to be included for breaches, and a publicly available register for those who found to have seriously or repeatedly breached ethics requirements. This would help address one of the concerns raised by Uff [28] that the public often remains unaware of those who breach ethics expectations.

## 5 Conclusions

The ethics related content in construction professional codes of conduct was critically compared in terms of those ethics' requirements recommended by previous literature. These finding can help inform professional bodies of potential areas to improve their ethics coverage in codes of conduct. Findings may also help pave the way towards an industry wide construction code of ethics which may be used on a project by project opt-in basis.

Most ethics provisions were covered by all codes of conduct. However, there was little content related to Integrity (parties should evaluate and manage risks, and assign, eliminate, or share the risk ethically). This is an area that professional bodies may wish to consider including in their codes of conduct or ensuring that this is covered adequately elsewhere within the contracts for services.

Another area that could be improved on is Honesty (avoiding corruption, bribery, claims fraud, collusive tendering, kickbacks, and forged documents to support claims). While all codes of conduct required some form of acting with trustworthiness and honesty, only Engineering New Zealand [12] specifically require its members not to offer or accept bribes. More specific focus in this area could help to address findings by the Commerce Commission [7] that the construction industry lacked knowledge about anti-competitive pricing behaviours. Furthermore, adding ethics requirements covering interpersonal communication and the environment may help support the Construction Sector Accord's [9] objective—'Āta: grow respectful relationships with people and the environment. However, adding new ethics requirements should be considered carefully in terms of professional body members' appetite for such provisions. Or the wider industries' appetite in the case of a construction sector code of ethics. With previous studies highlighting the prevalence of unethical practices in overseas jurisdictions, it would be useful to survey practitioners in NZ about the extent of their observations of unethical practices in NZ.

A roadmap for research towards a construction code of ethics for the NZ construction industry could include first, comparing ethics content within contracts for services used in the professional bodies analysed in this study. Then compile the collective ethics provisions and distribute a survey questionnaire to industry asking participants two rate each for preferred relevance and inviting comments. From this a draft code of ethics may be drafted. One option could be to schedule standard ethics terms (such as anti-corruption) and specific terms (such as sustainability) that parties may select specific to their project. Feedback may then be obtained from the professional bodies, and other relevant stakeholders such as the Construction

Accord. Then case studied to obtain user feedback. There would be less risk in the code of ethics being on an opt-in project-by-project basis with standard and specific terms to choose from. However, if it is intended to replace existing professional body codes of ethics, the industry could equally risk more work done without any code of ethics coverage. There is also the more complex matter of how ethics breaches are investigated and disciplined and by who, and whether a public register should be maintained.

## 6 Ethics Statement

Not applicable. This study is based on publicly available published documentation.

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## References

1. New Zealand Legislation (1986b) Commerce act. Parliamentary counsel office, Retrieved from https://www.legislation.govt.nz/act/public/1986/0005/latest/whole.html#DLM88263. Accessed July 7, 2023
2. Abdul-Rahman H, Wang C, Yap X (2010) How professional ethics impact construction quality: perception and evidence in a fast developing economy. Sci Res Essays 5(23):3742–3749
3. Ameh O, Odusami K (2010) Professionals' ambivalence toward ethics in the Nigerian construction industry. J Prof Issues Eng Educ Pract 136(1):9–16. https://doi.org/10.1061/(ASCE)1052-3928(2010)136:1(9)
4. Bolam v. Friern Hospital Management Committee (1957) 1 WLR 582
5. Bowen P, Pearl R, Akintoye A (2007) Professional ethics in the South African construction industry. Build Res Inf 35(2):189–205. https://doi.org/10.1080/09613210600980267
6. Building Research Authority of New Zealand (BRANZ, n.d.) Contracts and consumer protection. Retrieved from https://www.renovate.org.nz/regulation-compliance/contracts-and-consumer-protection/#:~:text=Building%20contracts%20and%20building%20work,deceptive%20conduct%20and%20false%20representations. Accessed 20 July, 2023
7. Commerce Commission New Zealand (2010) Commerce commission focuses on construction sector. Retrieved from commerce commission—commerce commission focuses on construction sector (comcom.govt.nz). Accessed July, 2023
8. Commerce Commission New Zealand (2019) Detecting bid rigging. Retrieved from https://comcom.govt.nz/news-and-media/feature-articles/detecting-bid-rigging#:~:text=This%20conduct%20can%20occur%20in,substantial%20penalties%20and%20banning%20orders. Accessed July 20, 2023

9. Construction Sector Accord (2022) The accord. Retrieved from https://www.constructionaccord.nz/the-accord/#:~:text=In%20January%202020%2C%20the%20Construction,and%20restoring%20the%20sector's%20confidence%2C. Accessed July 25, 2023
10. Cambridge Dictionary (2023a) Ethics. Retrieved from https://dictionary.cambridge.org/dictionary/english/ethic. Accessed 20 July, 2023
11. Cambridge Dictionary (2023b) Morals. Retrieved from https://dictionary.cambridge.org/dictionary/english/morals. Accessed 20 July, 2023
12. Engineering New Zealand (2016) Code of ethical conduct. Retrieved from Code_of_Ethical_Conduct.pdf (d2rjvl4n5h2b61.cloudfront.net). Accessed July 25, 2023
13. Ho C (2011) Ethics management for the construction industry: a review of ethical decision-making literature. Eng Constr Archit Manag 18(5):516–537. https://doi.org/10.1108/09699981111165194
14. Lavers, P. A. (April 2008). Ethics In construction law—a review of the position in eight European countries. Society of construction law UK
15. MBIE (2023) lbp.govt.nz about us. Retrieved from https://www.lbp.govt.nz/about-us/#:~:text=The%20Licensed%20Building%20Practitioners%20(LBP,to%20the%20Building%20Act%202004. Accessed 21 July, 2023
16. McCarthy SF (2012) Developing an Australian code of construction ethics. Constr Econ Build 12(2):100. https://doi.org/10.5130/AJCEB.v12i2.2536
17. New Zealand Institute of Quantity Surveyors (2017) Code of conduct. Retrieved from NZIQS—code of conduct_3 July 2017.pdf. Accessed July 25, 2023
18. New Zealand Legislation (1986a) Fair trading act. Parliamentary council office. Retrieved from: https://www.legislation.govt.nz/act/public/1986/0121/latest/DLM6410735.html. Accessed July 20, 2023
19. Registered Architect's Board (2018) *Code of minimum standards of ethical conduct for registered architect*. Retrieved from NZRAB_15585_architects code of ethics—A4 version_02.indd. Accessed July 25, 2023
20. Royal Institute of Quantity Surveyors (2021) Rules of conduct. Retrieved from 2021_roc_en (1).pdf. Accessed July 2027, 2023
21. Sinha S, Thomas H, Kulka J (2007) Integrating ethics into the engineered construction curriculum. J Prof Issues Eng Educ Pract 133(4): 291. https://doi.org/10.1061/(ASCE)1052-3928
22. Society of Construction Law (2017) Society of construction law delay and disruption protocol, (2nd edn). Retrieved from https://www.scl.org.uk/sites/default/files/documents/SCL_Delay_Protocol_2nd_Edition_Final.pdf. Accessed July 25, 2023
23. Standards New Zealand (2013) Conditions of contract for building and civil engineering construction. Standards New Zealand
24. Strahorn S, Brewer G, Gajendran T (2015) The influence of trust on project management practice within the construction industry. Constr Econ Build 17:1–19. https://doi.org/10.5130/AJCEB.v17i1.5220
25. Strahorn S, Gajendran T, Brewer G (2015) The influence of trust in traditional contracting: investigating the "lived experience" of stakeholders. Constr Econ Build 15(12). https://doi.org/10.5130/AJCEB.v15i2.4408
26. Thornton A (2004) Ethics and construction law: where to start. Society of construction law UK. Retrieved from https://www.scl.org.uk/papers/ethics-and-construction-law-where-start. Accessed July 20, 2023
27. Uff J (2005) Ethics in construction law—two years on. Society of construction law UK. Retrieved from https://www.scl.org.uk/papers/ethics-construction-law-two-years. Accessed July 20, 2023
28. Uff, J. (2003). Duties at the legal fringe: ethics in construction law. *Society of Construction Law UK*.

29. Vee C, Skitmore C (2003) Professional ethics in the construction industry. Eng Constr Archit Manag 10(2):117–127. https://doi.org/10.1108/09699980310466596
30. The Consumer Guarantees Act (1993) Retrieved from Consumer Guarantees Act 1993 No 91 (as at 29 October 2019), Public Act Contents – New Zealand Legislation. Accessed April 30, 2024

# Mitigating Delay in Construction Contract Payment: A South African Case Study

**Peter Adekunle, Clinton Aigbavboa, Matthew Ikuabe, Kenneth Otasowie, and Ornella Tanga**

## 1 Introduction

Delays in contract payments are common in the construction industry and must be adequately addressed as a result of their frequency [18]. Delays in contract payments are likely to impede the inflow of capital into the construction industry and have a negative impact on the project's net cash flow. As a result, contractors are forced to seek money to ease cash flow problems. The term "cash flow" describes the movement of money into and out of a construction project over a predetermined time frame, usually from the beginning to the end of the project. A faster project delivery process, lower financial risks, and improved working relationships among all stakeholders are all benefits of effective cash flow management [34]. A proactive financial strategy, clear contract terms, effective payment procedures, open communication, and a dedication to fair and on-time payment practices are all necessary to address payment delays in construction contracts. The construction sector may build a more sustainable and collaborative atmosphere, lessening financial strain, and encouraging the completion of successful projects by providing early payment [39]. Payment delays can have a domino impact on the whole supply chain for the construction industry. Payments to their own employees and suppliers may be delayed as a result of subcontractors and suppliers having trouble meeting their own financial commitments. This may cause payments to be late and relationships to become tense all during the project. Payment delays in construction contracts can be caused by a number of circumstances. Poor financial planning by project owners or clients also frequently causes delays in the release of cash for payment [17]. Delays in processing and disbursing payments can also be brought on by bureaucratic procedures, complicated payment approval

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processes, and administrative inefficiencies. The construction industry is susceptible to a system of payment delays, according to a research on payment performance [20]. The vital lifeblood of the building sector is, in reality, payment. During the course of the work, it is necessary to pay for preliminary expenses, supplies, labor, equipment, subcontractors' work, and general overhead. Any economic transaction must include payment; without it, no company can operate successfully [4]. This is important, especially in the construction business since the products are expensive, the building process takes longer, and full payment is provided upon project completion. According to Taghipour et al. [30], the second biggest operational risk that contributes to project delays, after financial failure, is delayed payment. Payment delays frequently lead to delays in material delivery, which reduces worker productivity in the building industry. This has an effect on construction projects' success and, eventually, the industry's viability. Because of this, studies conducted since the 1960s in developed nations like the United Kingdom, the Netherlands, and other nations have shown that construction payment concerns are common and have been a source of concern for many years.

Notably, despite the use of cutting-edge technology and project management practices, building projects still encounter delays [22]. This is the rationale behind the interest that scholars have shown in building project delays over time. Construction projects cannot be completed successfully without the prompt and effective payment of contractors. Both contractors and project owners must be aware of their legal responsibilities and ramifications when payments are delayed [15]. Studying payment delays in construction contracts identifies possible contract gaps or ambiguities, enables the creation of fair and balanced contract conditions, and contributes to the establishment of legislative frameworks that better manage payment-related concerns. To promote a thriving and sustainable construction environment, it is crucial to focus on the reduction of payment delay in construction contracts [27]. The construction industry's biggest cash flow problem, delayed payments, has been recognized by contractors. Additionally, it places financial strain on contractors, puts them under pressure to perform, and has a detrimental domino effect on all other parties involved in construction. It is crucial to design strategies and regulations that improve financial stability, project efficiency, and industry collaboration in order to eventually benefit all stakeholders in the construction sector. This requires recognizing the effects of payment delays. Therefore, the research aims to assess possible mitigation strategies for contract payment delays.

## 2 Literature Review

A recurrent problem that affects the construction sector globally is late payment on contracts [35]. Maintaining cash flow, insuring the continuation of projects, and preserving successful business relationships all depend on contractors, subcontractors, and suppliers being paid promptly and effectively. The efficient execution of building projects is hampered by payment delays, which are caused by a variety of circumstances and put a burden on finances. The goal of this study is to investigate and highlight numerous elements that might successfully reduce payment delays for building contracts.

## 2.1 Bond and Guarantees

One of the most popular types of security utilized in the construction sector is bonds and guarantees. Financial protection against bankruptcy and evidence of the financial soundness of the entity issuing the bond or guarantee are the two goals that bonds and guarantees serve in the industry [32]. A third party, known as a bondsman and typically a bank or insurance firm, guarantees the party's financial responsibilities under the terms of the bond in the event that another party's contractual commitments to the contractor are breached. According to Tang and Zhang [31], a bond is often issued in exchange for a premium paid to the bondsman. In the construction sector, bonds and guarantees are typically used to ensure that parties will fulfill their performance responsibilities, particularly by contractors and subcontractors. These bonds are primarily divided into performance and payment bonds.

## 2.2 Prequalification of Construction Parties

Construction parties' registration and prequalification might be utilized as a safeguard against financial loss. According to Braeckman and Markkanen [21], doing prequalification to evaluate financial capacity and only working with parties that have a strong financial capacity is one of the greatest approaches to reduce the risks of delay, non-payment, and financial collapse. Prior to participating in the bidding process, construction customers generally pre-qualify the contractors for their technical and financial ability [13]. This aids clients in avoiding working with unqualified, underfunded, and inexperienced contractors. It serves as a way for the contractor to get their skills externally audited. Payment to subcontractors is guaranteed if the clients pre-qualify the contractors.

## 2.3 Payment Default Insurance

An insurance cover is a contract that obligates the insurer to bear the financial burden of an obligation or loss covered by the policy [38]. The majority of times, typical contract forms demand that contractors get particular insurance coverage. For instance, New Zealand mandates that contractors have construction equipment, supplies, and contract works insurance [8]. The contractor must also offer insurance protection against third-party liability risks. If the client or contractor fails to offer any security, the contractor might use this to pursue insurance coverage against the owner's risk of payment default or insolvency [12]. An alternative to bonding that could be effective is default insurance. Typically, an insurance provider defends the contractor against any damages and lawsuits asserted against him or her that fall inside the policy's purview. The insurance firm receives a premium in exchange for providing the protection. To protect losses on the value of completed work, the contractor might take up a policy with the insurance provider.

### 2.4 Bankruptcy Notice and Liquidation Proceedings

A bankruptcy notice and liquidation procedures can be used in construction contracts to recoup payments from clients and contractors [14]. While liquidation refers to a scenario where a firm is unable to pay its obligations, bankruptcy refers to a situation where a person is unable to pay his or her debts. The Companies Act of 1993 states that bankruptcy and liquidation procedures may be initiated either voluntarily by the debtor or involuntarily by the creditors following the issuance of a court order [5]. Both voluntary and involuntary bankruptcies and liquidations occur in the construction sector. However, suppliers, subcontractors, and building contractors are unsecured creditors. There won't be any money available for distribution unless they've gotten a security in the form of lien rights, payment bond rights, or trust funds. Additionally, Stef [28] asserted that bankruptcy notification and liquidation procedures are legal tools that may be used to lessen payment delays for building contracts when a party is experiencing financial difficulty or insolvency. These procedures offer a way to deal with unresolved payment concerns and look for solutions when payment delays have grown severe or protracted.

### 2.5 Remedies for Securing Payment Debt

In the construction sector, remedies for obtaining payment debt are the legal steps and actions that can be taken to secure the recovery of unpaid invoices owing to suppliers, subcontractors, or contractors [23]. By giving parties that are having payment issues or non-payment recourse, these remedies help to reduce payment delays in construction contracts. It is significant to highlight that depending on the jurisdiction and the particular contractual arrangements, these remedies may not be available or effective in all cases [33]. When thinking about and pursuing these remedies, it is essential to comprehend the relevant legal requirements and contractual clauses. Contractors, subcontractors, and suppliers are given legal options to ensure payment and manage payment delays thanks to the existence of these remedies. These remedies serve to prevent non-payment and motivate parties to promptly meet their financial responsibilities. In the end, they support fair payment procedures, lessen the effects of payment delays, and build a more equitable and sustainable construction business.

## 2.6 Payment of Stipulated Interest

Payment stipulated interest is the practice of inserting a predetermined interest rate that is applied to past due payments in the construction contract [1]. It is a clause in a contract that imposes financial penalties in the form of interest on the outstanding balance in order to encourage prompt payment. By establishing a cost for late or missed payments, the addition of payment mandated interest helps to reduce payment delays for building contracts. Different legal and regulatory criteria or restrictions may apply to the applicability of paying prescribed interest [19]. In order to ensure compliance, it is crucial to comprehend the local rules and regulations controlling interest charges and to speak with legal experts. According to [29] research, including payment stipulated interest in construction contracts offers a way to reduce payment delays by rewarding prompt payment, making up for late payments, discouraging payment delays, fostering fairness, and assisting cash flow management. Payment specified interest promotes a more equal and effective payment ecosystem within the construction sector by applying financial penalties for late payments.

## 2.7 Suspension of Work

A contractual clause known as suspension of work enables a party, usually the contractor, to temporarily suspend construction activity in reaction to late or non-payment [6]. By putting pressure on the defaulting party to meet their financial responsibilities and maintain the smooth continuation of the project, it helps to alleviate the delay in construction contract payment. The contractor has a strong instrument to influence negotiations and promote prompt payment: the threat of work suspension. The contractor can seriously impede the project's development by stopping construction work, which could result in delays and financial losses for the party in default [3]. The defaulting party is forced to prioritize payment as a result of this financial pressure in order to restart work and prevent future project delays. Work should only be suspended in compliance with contractual requirements, as well as any applicable laws and regulations.

## 2.8 Right to Slow Down Work by the Contractor

A contractual clause known as the "right to slow down work" enables the contractor to purposefully slow down building projects in reaction to late or non-payment of invoices [26]. By exerting pressure on the defaulting party to pay their debts, it helps to alleviate payment delays in construction contracts. The contractor applies financial pressure on the party in default by slowing down work. This purposeful slowdown in building might affect project schedules, which could lead to financial losses and reputational issues for the party defaulting. The financial ramifications of project delays motivate the defaulting party to prioritize payment in order to resume normal construction work and prevent additional financial implications [25]. The choice to halt work should be taken in line with the terms of the contract and any relevant laws and regulations.

## 2.9 Eradication of "Pay When Paid" Clause

By transferring payment responsibilities from one party to another, the elimination of the "pay when paid" provision is a step taken to mitigate payment delays in construction contracts [16]. According to the "pay when paid" rule, the contractor is normally only required to pay suppliers or subcontractors once they have been compensated by the owner or customer. Subcontractors and suppliers are no longer reliant on the contractor receiving money from the owner before they can be paid because to the elimination of the "pay when paid" condition [7]. Instead, payment is required in a reasonable amount of time after the service is finished or as otherwise stated in the contract. This guarantees fast payment to the suppliers and subcontractors, preventing delays in their cash flow and allowing them to successfully handle their financial responsibilities. By guaranteeing fast payment to suppliers and subcontractors, the elimination of the "pay when paid" condition reduces the risk of payment delays in construction contracts.

## 2.10 The Creation of a Right to a Lien

By giving contractors, subcontractors, and suppliers a way to protect their payment rights, the introduction of a right to a lien is a legal mechanism that may be used to alleviate payment delays in construction contracts [20]. An official claim or encumbrance placed on real estate as security for the repayment of a debt is known as a lien. The ability to file for a lien gives contractors, subcontractors, and suppliers a way to legally stake a claim on the real estate where construction is taking place in order to collect their payment. This claim acts as collateral and guarantees that they will get payment for the labor and supplies they have supplied. According to Hitchner et al. [11], the presence of a lien serves as a compelling incentive for landowners or developers to make payments on time in order to avoid any legal repercussions. A significant strategy for reducing payment delays for construction contracts is the development of a right to a lien.

## 3 Methodology

Only one hundred and two (102) people answered to a set of one hundred (120) well-structured questions. This research is thus focused on the 85% of responders. The primary goal of the study presented in this research paper was to investigate the many aspects that the South African construction sector uses to reduce payment delays for building contracts. Primary and secondary data from two sources were used to get the information. According to Adekunle et al. [2], a well-structured questionnaire for the main data was created and distributed to a variety of construction industry experts, including architects, quantity surveyors, construction managers, civil engineers, mechanical, electrical, and industrial engineers. The criteria utilized to gauge the causes reducing payment delays for construction contracts were taken into account using secondary data, which was gathered from a variety of published sources including books, reports, journal articles, and more. The random sampling approach was utilized to conduct this study because it gives every component and group of people an equal chance of being included in the sample. Exploratory factor analysis (EFA), mean item score (MIS), and standard deviation (SD) were used to analyze the factors that reduce payment delays for construction contracts in the South African construction sector. By first establishing their normalcy using the Shapiro–Wilk test and the reliability of the exploration instrument using the Cronbach's alpha test, the gathered data were deconstructed. Cronbach's alpha provides a number between 0 and 1, and the greater the value, the more reliable the data was collected. The instrument's dependability is demonstrated by the 10 mitigation measures' achieved alpha values of 0.890. Kaiser–Meyer–Olkin (KMO) and Bartlett test analyses were also used to assess the structural validity of the estimated scale that was used. Outcome had a KMO value of 0.843 while the Bartlett test had a significant p-value of 0.000 and an estimated chi-square of 1,7004.19 at a degree of freedom of 300. This result implies that the scale used is appropriate for the assessment it was designed to make, given the acceptable range for a KMO value is 0.60 or greater and a p-value for the Bartlett test is less than 0.05.

## 4 Discussion of Findings

According to the data, men, who accounted for 80.2% of the respondents, were the ones who received more replies than women, who made up 19.8% of the respondents. 4.5% of respondents were project managers for construction, 15% were managers of construction, 14.2% of respondents were civil engineers, 13.3% were mechanical and electrical engineers, 24.5% were quantity surveyors. Furthermore, 49.4% of responders were consultants and 38.2% worked for contracting organizations. In total, 12.4% of them were employed by the government as well. Furthermore, while just 18% of the respondents said they had worked on six or fewer projects, over 82% of the respondents stated they had completed seven or more projects. He replies were reliable and credible since, on average, over 85% of respondents had over five years of experience in the South African construction industry, very high percentage.

The strategies ranked by respondents for mitigating payment delays in building contracts in South Africa are presented in Table 1. The first-placed option was "remedies for securing debt payment," with a mean score of 4.11 and a standard deviation of 0.764; the second-place option was "payment of stipulated interest," with a mean score of 4.03 and a standard deviation of 0.695; the third-place option was "the creation of a right to a lien," with a mean score of 3.90 and a standard deviation of 0.797; the fourth-place option was "payment default insurance," with a mean score of 3.87 and a standard deviation of 0.942; the fifth-place option was "eradication of pay when paid clause," with a mean score of 3.86 and a standard deviation of 0.780. Additionally, the least mitigating factor for the delay in construction contract payment was "bonds and guarantees," which ranked sixth with a mean score of 3.81 and a standard deviation of 0.780, "right to slow down work by contractor," which ranked seventh with a mean score of 3.63 and a standard deviation of 1.095, "suspension of work," which ranked eighth with a mean score of 3.59 and a standard deviation of 0.909, "pre-qualification of construction parties," which ranked ninth with a mean score of 3.56 and a standard deviation of 1.147, and "bankruptcy notice and liquidation proceedings," which ranked tenth with a mean score of 3.51 and a standard deviation of 1.091.

According to the report, the most important action that can be taken to reduce payment delays in construction contracts is remedies for securing payment debt. The legal steps and actions that can be taken to secure the recovery of unpaid invoices owing to contractors, subcontractors, or suppliers in the construction sector are referred to as remedies for obtaining payment debt [24]. By giving parties that are having payment issues or non-payment recourse, these remedies help to reduce payment delays in construction contracts. It is significant to note that depending on the jurisdiction and the particular contractual agreements, the accessibility and efficacy of these remedies may differ. When thinking about and pursuing these remedies,

**Table 1** Mitigating measures

| Measures | MIS | SD | R |
|---|---|---|---|
| Remedies for securing payment debt | 4.11 | 0.764 | 1 |
| Payment of stipulated interest | 4.03 | 0.695 | 2 |
| The creation of a right to a lien | 3.90 | 0.797 | 3 |
| Payment default insurance | 3.87 | 0.942 | 4 |
| Eradication of "pay when paid" clause | 3.86 | 0.780 | 5 |
| Bonds and guarantees | 3.81 | 0.780 | 6 |
| Right to slow down work by contractor | 3.63 | 1.112 | 7 |
| Suspension of work | 3.59 | 0.909 | 8 |
| Pre-qualification of construction parties | 3.56 | 1.147 | 9 |
| Bankruptcy notice and liquidation proceedings | 3.51 | 1.091 | 10 |

it is essential to comprehend the relevant legal requirements and contractual clauses. Contractors, subcontractors, and suppliers are given legal options to ensure payment and manage payment delays thanks to the existence of these remedies as observed by Oseni [19]. These remedies serve to prevent non-payment and motivate parties to promptly meet their financial responsibilities. In the end, they support fair payment procedures, lessen the effects of payment delays, and build a more equitable and sustainable construction business.

Using exploratory factor analysis, the ten (10) variables identified from the literature were factored into two (2) clusters that are thus interpreted based on the observed inherent relationship among the variables in the cluster. A total of six (6) variables were loaded onto cluster 1, as shown in Table 2. These variables include "Payment Default Insurance" (82.4%), "Bonds and Guarantees" (71.5%), "Remedies for securing debt" (68.8%), "Eradication of 'pay when paid' clause" (67.3%), "Payment of Stipulated Interest" (64.5%) and "Bankruptcy notice and liquidation proceedings" (61.5%). Therefore, this factor cluster can be termed "Payment Related Factors" with an Eigen value (E.V) of 7.341 and percentage variance (%V) of 39.348%, making it a major factor mitigating delay in construction contract payment. In cluster 2, there are four (4) variables loaded onto it. These variables include "Right to slow down work by contractor" (72.5%), "Suspension of Work" (68.0%), "Pre-qualification of construction parties" (62.8%), and "The creation of a right to a lien" (53.9%). The cluster is therefore labeled "Work-Related Factors" with an Eigen value (E.V) of 3.703 and percentage variance (%V) of 9.364%, making the second major factor mitigating delay in construction contract payment behind the variables in cluster 1.

The study's exploratory factor analysis (EFA) found that the best way to prevent delays in building contract payment is to secure debt payments. [37] assert that

**Table 2** Exploratory factor analysis of the mitigating measures

| Measures | 1 | 2 | |
|---|---|---|---|
| Factor 1—payment-related factors | | | E.V = 7.341, %V = 39.348 |
| Payment default insurance | 0.824 | | |
| Bonds and guarantees | 0.715 | | |
| Remedies for securing debt | 0.688 | | |
| Eradication of "pay when paid" clause | 0.673 | – | |
| Payment of stipulated interest | 0.645 | * | |
| Bankruptcy notice and liquidation proceedings | 0.615 | / | |
| Factor 1—work-related factors | | | E.V – 3.703, %V = 19.34 |
| Right to slow down work by contractor | | 0.725 | |
| Suspension of work | | 0.680 | |
| Pre-qualification of construction parties | | 0.628 | |
| The creation of a right to a lien | | 0.539 | |

looking for alternative financial sources to sponsor contract payment is one way to handle late or non-payment issues between customers and contractors that will benefit both sides. The contractor should fully understand any payment terms or stipulations in the contract, particularly for certain projects where customers may have specific requirements that contractors must adhere to in order to be paid. According to Hasmori et al. [10], contractors must ensure that documentation for payment claims is comprehensive with sufficient papers before presenting it to clients in order to prevent payment delays. Additionally, contractors must maintain continuous communication with clients on payment in order to keep them updated on the status of their payments [37]. A timely approval of compensation events and variation orders guarantees that any modifications to the initial contract are completed quickly, reducing hiccups and delays. This supports the conclusions made by Gambo et al. [9] that setting a minimum number of days to sign payment certificates creates a defined timeframe for payment processing, lowering uncertainty and facilitating on-time payments. By establishing a deadline for contractors to file claims, you can keep projects on schedule and avoid the buildup of backdated claims that might stymie development. By establishing financial penalties for delays and encouraging prompt payments, the payment of specified interest encourages timely payments. By reducing human paperwork and facilitating quicker processing and payment of bills, using an electronic invoicing system accelerates payment procedures [36]. This would ensure prompt decision-making and administration by enforcing responsibility and resulting in disciplinary actions for officials who fail to sign or submit papers on time.

In addition, the study found that giving suppliers and contractors a legal claim on the property through the formation of a lien promotes fast payment for services rendered or materials provided, hence reducing payment delays. According to Ramachandra and Rotimi [24], payment default insurance gives contractors and subcontractors financial protection by shielding them against non-payment or default by project owners or other parties. The “Pay When Paid” phrase must be eliminated to guarantee contractors’ prompt payment regardless of their higher-tier payment status. Bonds and guarantees, such as payment and performance guarantees, give project owners and subcontractors financial protection while reducing risks and payment delays. By giving the contractor the freedom to slow down work, you may help them deal with problems like late payments, changes in the design, or unresolved disagreements, reducing the impact of such problems on the project’s overall timetable. Work suspension allows for the temporary halting of construction works in the case of non-payment, disagreements, or unanticipated circumstances, allowing for the resolution of problems before moving forward. Pre-qualifying construction partners reduces the possibility of performance problems and delays by ensuring that reputable and competent parties are hired. In order to resolve insolvency or financial issues experienced by construction parties and minimize delays brought on by such situations, bankruptcy notification and liquidation processes are needed. The payment process is also accelerated by running payments daily rather than weekly, shortening the period between invoice submission and payment and minimizing payment delays. Together, these actions encourage accountability, openness, and efficiency in the payment procedures for construction contracts, greatly decreasing delays and assisting in the timely completion of projects.

## 5 Conclusion

Payment delays for building contracts are a recurring problem that affects the construction sector globally. Maintaining cash flow, insuring the continuation of projects, and preserving successful business relationships all depend on contractors, subcontractors, and suppliers being paid promptly and effectively. The efficient execution of building projects is hampered by payment delays, which are caused by a variety of circumstances and put a burden on finances. The effective completion of construction projects and the general health of the construction sector depend critically on mitigating payment delay under construction contracts. This essay has examined a number of strategies that may be used to solve this problem and advance prompt and equitable payment processes. Contractors, subcontractors, and suppliers have a legal framework to pursue their just reimbursement through the remedies for securing payment debt, ensuring that their financial interests are safeguarded. Stipulated interest acts as a financial inducement for timely payment, discouraging payment delays by placing additional expenses on defaulting parties. Eliminating the "pay when paid" provision creates fair and timely payment responsibilities while removing the uncertainty and risk brought on by payment delays. All parties participating in the building project are given financial protection and assurance via bonds and guarantees, which lowers the possibility of payment failures. Contractors have the ability to apply pressure to parties who are in default, encourage payment compliance, and assist dialogue and settlement of payment concerns through the authority to slow down work and the right to suspend work. Pre-qualifying construction partners reduces the danger of payment delays brought on by unstable finances by ensuring that only respectable and financially stable companies are involved in the project. In situations when the party in default risks financial insolvency, bankruptcy notice and liquidation procedures offer a way to manage payment concerns. These procedures allow suppliers, subcontractors, and contractors to recover unpaid fees via the use of legal procedures while also assisting in the protection of their rights. Contractors, subcontractors, and suppliers can protect their payment rights, order their claims, and offer a legal defense in the event of payment delays by establishing a right to a lien. It encourages property owners and developers to swiftly meet their financial responsibilities and acts as a disincentive against non-payment. By putting these strategies into practice, parties participating in the construction sector may strive toward a more equitable and effective payment system, cutting down on payment delays and maintaining the stability of everyone concerned's finances. However, it is essential to understand that each measure has its own unique legal and practical implications. As a result, each measure must be implemented carefully and must conform to all applicable laws and regulations. Therefore, the results of this study will have substantial ramifications for project stakeholders, politicians, and professionals working in the

South African construction industry. This study aims to contribute to the development of comprehensive and useful solutions that can improve the efficiency, transparency, and financial sustainability of construction contracts in South Africa by illuminating the underlying causes of payment delays and highlighting effective mitigation strategies. In the end, it is hoped that the research findings will contribute to the creation of wise regulations, legal frameworks, and business procedures that may successfully reduce payment delays for building contracts. By doing this, this research hopes to strengthen the South African construction sector as a whole and promote an atmosphere that is more suited for project completion, economic expansion, and sustainable development.

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## References

1. Abdul-Rahman H, Takim R, Min WS (2009) Financial-related causes contributing to project delays. J Retail Leis Prop 8(3):225–238. https://doi.org/10.1057/rlp.2009.11
2. Adekunle P, Aigabvboa C, Thwala W, Akinradewo O, Oke A (2022) Challenges confronting construction information management. Front Built Environ 8(December). https://doi.org/10.3389/fbuil.2022.1075674
3. Ansah SK (2011) Causes and effects of delayed payments by clients on construction projects in Ghana. J Constr Project Manag Innov 1(1):27–45
4. Arner DW, Buckley RP, Zetzsche DA, Veidt R (2020) Sustainability, FinTech and financial inclusion. Eur Bus Organ Law Rev 21(1):7–35. https://doi.org/10.1007/s40804-020-00183-y
5. Branch B, Khizer A (2016) Bankruptcy practice in India. Int Rev Financ Anal 47(March 2004):1–6. https://doi.org/10.1016/j.irfa.2016.06.004
6. Cunningham T (2013) Will the construction contracts bill improve subcontractor cash flow ? Technol Univ Dublin 3(1):0–39. https://doi.org/10.21427/gygy-8k71
7. Elazouni A, Gajpal Y, Fares A (2023) Negotiating win-win payment terms between construction contractors and subcontractors. Autom Constr 146(June 2022):104676. https://doi.org/10.1016/j.autcon.2022.104676
8. Finnie D, Ali NA, Park K (2018) Enhancing off-site manufacturing through early contractor involvement (ECI) in New Zealand. Proc Inst Civil Eng: Manag, Procurement Law 171(4):176–185. https://doi.org/10.1680/jmapl.17.00029
9. Gambo N, Said I, Ismail R (2017) Mediation model for improving cost factors that affect performance of small-scale building construction contract business in Nigeria: a PLS-SEM approach. Int J Constr Educ Res 13(1):24–46. https://doi.org/10.1080/15578771.2016.1208309

10. Hasmori MF, Ismail I, Said I (2012) Issues of late and non-payment among contractors in Malaysia. In: 3rd international conference on business and economic research 2012, 12–13 March 2012, vol 2, pp 82–93. www.internationalconference.com.my
11. Hitchner S, Schelhas J, Gaither CJ (2017) A privilege and a challenge: valuation of Heirs property by African American landowners and implications for forest management in the Southeastern U.S. Small-Scale For 16(3):395–417. https://doi.org/10.1007/s11842-017-9362-5
12. Husein AT (2014) Construction and projects in Saudi Arabia: overview. Practice Law 1–11
13. Johnson DM (2004) Adaptation of organizational change models to the implementation of quality standard requirements. Int J Qual Reliab Manage 21(2):154–174. https://doi.org/10.1108/02656710410516961
14. Kenyatta M, Kenyatta MO, Alkizim AO, Kivaa Mbiti T (2015) Recapitulating the payment default effects to contractors in The Kenyan construction industry. Int J Soft Comput Eng (IJSCE) 4:2231–2307. https://www.researchgate.net/publication/320426776
15. Khalef R, El-adaway IH, Assaad R, Kieta N (2021) Contract risk management: a comparative study of risk allocation in exculpatory clauses and their legal treatment. J Legal Aff Dispute Resolut Eng Constr 13(1). https://doi.org/10.1061/(asce)la.1943-4170.0000430
16. Manu E, Ankrah N, Chinyio E, Proverbs D (2015) Trust influencing factors in main contractor and subcontractor relationships during projects. Int J Project Manage 33(7):1495–1508. https://doi.org/10.1016/j.ijproman.2015.06.006
17. Marzouk MM, El-Rasas TI (2014) Analyzing delay causes in Egyptian construction projects. J Adv Res 5(1):49–55. https://doi.org/10.1016/j.jare.2012.11.005
18. Mohamad N, Suman AS, Harun H, Hashim H (2018) Mitigating delay and non-payment in the Malaysian construction industry. IOP Conf Ser: Earth Environ Sci 117(1). https://doi.org/10.1088/1755-1315/117/1/012037
19. Oseni U (2013) Towards restructuring the legal framework for payment system in international Islamic trade finance. J Int Trade Law Policy 12(2):108–129. https://doi.org/10.1108/JITLP-10-2012-0016
20. Peters E, Subar K, Martin H (2019) Late payment and nonpayment within the construction industry: causes, effects, and solutions. J Leg Aff Disput Resolut Eng Constr 11(3):1–12. https://doi.org/10.1061/(asce)la.1943-4170.0000314
21. Plummer Braeckman J, Markkanen S (2022) Perceptions of risk in relation to large hydropower projects: a finance perspective. SSRN Electron J. https://doi.org/10.2139/ssrn.4011266
22. Prasad KV, Vasugi V, Venkatesan R, Bhat N (2019) Analysis of causes of delay in Indian construction projects and mitigation measures. J Financ Manag Prop Constr 24(1):58–78. https://doi.org/10.1108/JFMPC-04-2018-0020
23. Ramachandra T, Rotimi JO (2011) The nature of payment problems in the New Zealand construction industry. Australas J Constr Econ Build 11(2):22–33. https://doi.org/10.5130/ajceb.v11i2.2171
24. Ramachandra T, Rotimi JOB (2015) Mitigating payment problems in the construction industry through analysis of construction payment disputes. J Legal Aff Dispute Resolut Eng Constr 7(1). https://doi.org/10.1061/(asce)la.1943-4170.0000156
25. Roe MJ, Tung F (2013) Breaking bankruptcy priority: how rent-seeking upends the creditors' bargain. Virginia Law Rev 99(6):1235–1290. https://doi.org/10.2139/ssrn.2224035
26. Samaraweera PDP, Perera BAKS, Dewagoda KG (2019) Management of payment delays in government funded construction projects in Sri Lanka. World construction symposium, November, pp 411–421. https://doi.org/10.31705/WCS.2019.41
27. Shi Q, Zuo J, Huang R, Huang J, Pullen S (2013) Identifying the critical factors for green construction—an empirical study in China. Habitat Int 40:1–8. https://doi.org/10.1016/j.habitatint.2013.01.003
28. Stef N (2018) Bankruptcy and the difficulty of firing. Int Rev Law Econ 54:85–94. https://doi.org/10.1016/j.irle.2017.11.002
29. Stout LA (2014) Killing conscience: the unintended behavioral consequences of pay for performance. J Corporation Law 39(3):524–561. http://scholarship.law.cornell.edu/facpub

30. Taghipour M, Seraj F, Amir Hassani M, Farahani Kheirabadi S (2015) Risk analysis in the management of urban construction projects from the perspective of the employer and the contractor. Int J Organ Leadersh 4(4):356–373. https://doi.org/10.33844/ijol.2015.60284
31. Tang DY, Zhang Y (2020) Do shareholders benefit from green bonds? J Corp Finan 61(March 2018):101427. https://doi.org/10.1016/j.jcorpfin.2018.12.001
32. Thompson BS (2023) Impact investing in biodiversity conservation with bonds: an analysis of financial and environmental risk. Bus Strateg Environ 32(1):353–368. https://doi.org/10.1002/bse.3135
33. Truby J (2018) Decarbonizing bitcoin: law and policy choices for reducing the energy consumption of blockchain technologies and digital currencies. Energy Res Soc Sci 44(July):399–410. https://doi.org/10.1016/j.erss.2018.06.009
34. Wuttke DA, Blome C, Henke M (2013) Focusing the financial flow of supply chains: an empirical investigation of financial supply chain management. Int J Prod Econ 145(2):773–789. https://doi.org/10.1016/j.ijpe.2013.05.031
35. Yap JBH, Chow IN, Shavarebi K (2019) Criticality of construction industry problems in developing countries: analyzing Malaysian projects. J Manage Eng 35(5). https://doi.org/10.1061/(asce)me.1943-5479.0000709
36. Yaqoob I, Salah K, Jayaraman R, Al-Hammadi Y (2022) Blockchain for healthcare data management: opportunities, challenges, and future recommendations. Neural Comput Appl 34(14):11475–11490. https://doi.org/10.1007/s00521-020-05519-w
37. Ye KM, Rahman HA (2010) Risk of late payment in the Malaysian construction industry. World Acad Sci, Eng Technol 65(5):538–546
38. Yu H (2015) Universal health insurance coverage for 1.3 billion people: what accounts for China's success? Health Policy 119(9):1145–1152. https://doi.org/10.1016/j.healthpol.2015.07.008
39. Zainal Abidin NA, Ingirige B (2018) The dynamics of vulnerabilities and capabilities in improving resilience within Malaysian construction supply chain. Constr Innov 18(4):412–432. https://doi.org/10.1108/CI-09-2017-0079

# Mental Health Interventions and the Productivity of Construction Workforce

**Merly Grace (Meg) Manago Carillo and Funmilayo Ebun Rotimi**

## 1 Introduction

The mental well-being of New Zealanders is a matter of great importance. Unfortunately, the construction industry has high suicide rates, with one worker taking their own life every week. Research carried out by McArthur in 2020, shows that mental health conditions account for 53 out of every 100,000 construction workers' deaths. Shockingly, almost 75% of all suicides in 2019 were committed by men, as reported by the Coroner's Office and presented to MATES in Construction, New Zealand. These statistics are concerning, and it is worth noting that New Zealand ranked 69th out of 168 countries in suicide rates in 2022 [44]. Therefore, it is important to prioritise mental health awareness and support in all industries to prevent further tragic loss of life. Mental health problems are a significant public health concern that affects a considerable proportion of the population across all age groups and cultural backgrounds. Approximately one in four young people in New Zealand are estimated to be affected by mental illness annually. Mental health problems result in significant social and economic costs, such as reduced productivity, increased healthcare expenses, and a decreased quality of life for individuals and their families [42]. Mental health interventions aim to prevent, treat, or manage mental health disorders and enhance individuals' quality of life.

According to recent statistics, the construction industry in New Zealand has been struggling with a high rate of suicide cases. Despite receiving a funding boost in 2019, concerns have been raised about the effectiveness of mental health interventions since then (The Guardian 2021). While various measures have been put in place to improve the well-being of industry members, their impact on mental health has not been adequately assessed. In 2016, New Zealand prioritised mental health as part of

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employer health and safety measures to ensure a safe workplace. However, despite being aware of the high suicide rates in the industry, programs and actions aimed at addressing this issue have not been thoroughly evaluated for effectiveness [27]. Consequently, it is imperative to perform a new evaluation of present treatments for mental health.

MATES in construction is a program established in Australia to provide support for employers and employees struggling with the high suicide rate in the construction industry [22]. Despite the program's launch in 2008, the number of suicide cases has continued to increase, and the industry has the highest number of suicide cases. It is projected that the suicide rate will increase by 42% in 2022 [38]. The COVID-19 pandemic has exacerbated the situation, leading to burnout among workers who are 10–20 times more likely to be at risk, pushing every worker to the brink of mental health [11].

Despite the government's efforts to improve mental health services, accessing effective mental health interventions remains a challenge. The shortage of mental health professionals, coupled with high demand of their services, and inadequate funding create significant obstacles. It is imperative to address these challenges to provide effective mental health interventions to construction workers and prevent further loss of life. To this end, this study aims to investigate the effectiveness of current mental health interventions in New Zealand. The objective of this study is to set a benchmark for measuring progress by prioritising mental health.

## 2 Literature Review

The mental health of construction workers is significantly influenced by substance abuse, such as drugs and alcohol, often used as a coping mechanism for stress and personal issues [21]. This maladaptive behaviour exacerbates their mental health problems and poses serious safety risks on construction sites. Moreover, conflicts arising from generational differences within the industry further impact mental well-being. Research conducted in some countries, like the United States and Canada highlights the challenges faced by different generations working together, including communication breakdowns, clashes of work values, and resistance to change [41]. All these conflicts can contribute to heightened stress levels and emotional strain, ultimately affecting mental health outcomes. Gaining access to suitable mental health care is a challenge faced by many people across various industries around the world. This includes stigma that discourages workers from seeking help and support. According to a study conducted in the United Kingdom, construction workers' poor mental health can be attributed to shame associated with masculinity and lack of self-compassion. This is further complicated by the fact that construction workers are often unaware of the resources available to them and face financial constraints. The physically demanding nature of construction work, with long hours, intense pressure, and exertion, leaves little time and energy for workers to focus on their mental well-being. Numerous measures have been taken worldwide to tackle these difficulties. Construction companies in New Zealand, Australia, Sweden, and Singapore have established confidential counselling and support services for their employees through employee assistance programs [19]. Additionally, partnerships with mental health organisations have been formed to promote early intervention and provide personalised services for construction workers. Awareness campaigns are also being conducted to raise awareness about mental health issues in the industry. New Zealand has specifically tailored interventions for construction workers, focussing on mental health literacy, early intervention, and customised services [29]. A healthier and more supportive work environment can be established by understanding the factors, removing barriers, and implementing suitable interventions. This review section will explore the research and evidence related to mental health challenges and interventions in the construction industry.

## 2.1 *Factors Affecting the Mental Health of Construction Workers*

The mental well-being of construction workers is a significant concern, and substance abuse is a key factor that affects their health. A report by WorkSafe in 2014 indicates that as many as one in five employees in the construction industry were found to be under the influence of drugs and alcohol [4]. This alarming statistic reveals the prevalence of substance abuse in the field and its potential impact on the safety of workers and the general public. Further analysis of coroner's files shows that individuals who were intoxicated at the time of their deaths accounted for 37.3% of suicide cases among workers in the industry, with 9.3% under the influence. These findings suggest that substance abuse and mental health issues are closely linked, and it highlights the need for intervention and support for workers in the construction industry. Research by Bryson and Duncan [2] indicates that substance abuse may be a form of self-medication for construction workers dealing with stress and personal issues. The high-pressure environment of the construction industry, coupled with long hours and physical demands, can lead to stress, anxiety, and depression. Without proper support and resources to manage these mental health issues, workers may turn to substance abuse as a coping mechanism. Ensuring the well-being and safety of construction workers and the public is of utmost importance, and addressing substance abuse and mental health within the industry is a step towards achieving this. By providing accessible resources and support, it is possible to empower workers to manage personal issues and stress in healthy ways, thus reducing the risk of substance abuse and its associated dangers.

Another factor contributing to the mental health challenges is the generation gap, which leads to differences in opinions and expectations within the field. Reference stated that intergenerational issues affect the relationship between older and younger workers, potentially causing conflicts or problems in the workplace. Bryson and Duncan [2] further explained that younger generations tend to be more sensitive, seeking positive feedback, while older workers are more receptive to direct feedback. Substance abuse, including drugs and alcohol, significantly affects the mental health of young Australian workers in the construction industry, with higher levels of psychological distress and drug use compared to the norms for their age and gender in the general Australian population. In the Hong Kong construction industry, tradespeople experience high-stress levels, which can negatively impact mental health, organisational efficiency, and safety compliance. Therefore, it becomes crucial to learn effective stress management techniques to prevent mental health issues.

Construction apprentices face various challenges, including workplace bullying, suicidal behaviour, and suicidal thoughts [36]. The demands associated with construction work can have detrimental effects on the psychological well-being of professionals in the field, according to. The construction industry in the United States has a higher risk of suicides than other industries, with 53.2 suicides per 100,000 construction workers, the highest recorded among all industries, according to Schultz [37] and the Centers for Disease Control and Prevention. Hashem [12] revealed that construction workers in the USA experience four times the average suicide rate of the general population [12]. Recently found that 49.4% of male construction workers surveyed expressed suicidal ideation, significantly higher than combined reports from other industries. It is crucial to address these mental health challenges and learn effective stress management techniques to prevent mental health issues in the construction industry.

### *2.2 Barriers to Access to Mental Health*

In order to establish good mental health intervention, there are a number of obstacles to overcome in the country, including insufficient funding, lack of staff, negative attitudes, and cultural dissimilarities [17]. One of the primary hindrances to effective mental health intervention in New Zealand is the lack of funding. The mental health system in the country has historically been underfunded, resulting in a scarcity of resources and limited access to services for those who require them. While the government vowed to increase funding for mental health services in 2018, many experts believe that more needs to be done. Due to inadequate funding, mental health services frequently lack the resources to provide timely and appropriate care, which can result in poor patient outcomes.

Another significant barrier to good mental health intervention in New Zealand is workforce shortages [5]. There is a shortage of mental health professionals in the country, including psychiatrists, psychologists, and other mental health practitioners [25]. This shortage can result in long appointment wait times and difficulty accessing appropriate care. The shortage is particularly acute in rural areas, where fewer mental health professionals are available to serve the population.

Some individuals may lack proper education and awareness to recognise the signs and symptoms of mental health issues, which can result in the delayed or absent seeking of assistance until the condition worsens [21]. Insufficient knowledge can lead to misunderstandings about mental health, such as the belief that it signifies weakness or that it cannot be treated [24]. Such misunderstandings can hinder people from obtaining assistance despite it being available.

In New Zealand, mental illness stigma remains a significant obstacle to effective mental health intervention [26]. Despite efforts to reduce stigma, many people still hesitate to seek help for mental health issues due to shame or embarrassment. This reluctance to seek treatment can lead to worsening symptoms and poorer outcomes. Moreover, stigma can make it more challenging for mental health professionals to provide care, as patients may be less likely to disclose their symptoms or seek help. To create a supportive work environment, it is important to reduce the stigma around mental health, which has been identified as an effective way to lower suicide rates in the workplace [24]. A study conducted by Harvard Business Review revealed that mental health concerns have led to a significant increase in attrition rates, with 50% of voluntary or involuntary resignations occurring due to mental health-related issues. This highlights the importance of addressing mental health issues in the workplace, as they can impact various aspects of work and lead to significant financial and project delays. Construction workers, in particular, are vulnerable to the effects of stigma in the workplace, as it is a major factor affecting their mental health, according to a study by Eyllon et al. [7]. Therefore, it is essential for both employees and employers to understand how to address mental health issues in the workplace. Finally, cultural differences can also be a barrier to good mental health intervention in New Zealand. The country has a diverse population, and mental health professionals must be able to provide care that is sensitive to the needs and beliefs of different cultural groups. This can be challenging, as mental health professionals may not always have the necessary cultural competence to provide effective care.

### *2.3 Addressing Mental Health Challenges in the Construction Industry: Initiatives and Interventions*

In New Zealand, BRANZ is an organisation that focuses on creating innovative solutions for building performance. One concern that they addressed was the high rates of suicide within the construction industry, leading them to conduct a study to determine the factors that contribute to employees' mental health. Bryson and Duncan [2] found that a toxic belief in masculinity, or a "macho" culture, resulted in bullying, alcohol and drug abuse, and differing ages, all of which negatively impacted the employees' mental health. Currently, BRANZ is conducting further research to identify the demographics in the statistics.

Remote work locations can cause difficulties for construction workers seeking mental health support services, potentially contributing to mental health problems [19]. Strategies such as promoting a healthy work–life balance, increasing access to support services, and improving communication between workers and managers have been shown to reduce mental health issues among construction workers and improve their overall well-being.

MATES program targets mental health issues among construction workers. The program provides on-site training and management support to workers, helping them identify and manage risks to their mental health. These activities aim to build stronger relationships within construction companies and improve employees' mental health, despite the industry being male-dominated. Additionally, Site Safe offers health and safety programs for construction workers, providing at least 40 credits in Site Safe programs and recognition from the New Zealand Qualification Authority. Reference [15] recommends implementing practices such as mental health first aid training, daily work in the company and community, and access to employee assistance programs (EAPs) to improve mental health interventions in the construction industry. Mental health first aid training is crucial in the construction industry to recognise symptoms of mental health issues and address them promptly. Kime [15] also suggests offering insurance policies that cover mental health. EAPs provide workers with easy access to the right resources to address their concerns or problems and manage their mental health issues.

In the construction industry, the L.E.A.R.N., Look for signs, Empathise and listen, Ask directly about suicide and Reduce the dangers, and Next Steps, is an approach can be a valuable tool for suicide prevention [43]. According to Kime [15], this approach helps workers prepare for personal challenges. The University of Washington [43] provides information on identifying warning signs of suicidal behaviour and offers a toolkit for prevention. Also, Kime [15] emphasises the importance of mental health assessment resources for construction employers to identify areas where employees may need support. The Mental Health Assessment Program offers diagnoses and evaluations, enabling employers to provide appropriate assistance to industry workers called the light program in 2017.

### *2.4 Common Mental Health Interventions in New Zealand [27]*

In New Zealand, various interventions are available to help individuals improve their mental and emotional well-being. These interventions are commonly used to treat different mental health conditions. Here are some details about each intervention (Georgetown Behavioural Hospital 2023):

1. Cognitive-Behavioural Therapy (CBT): This talk therapy helps individuals identify negative thought patterns and behaviours and replace them with positive ones. It is often used as a first-line treatment for anxiety and depression.

2. Acceptance and Commitment Therapy (ACT): This intervention focuses on helping individuals accept their thoughts and feelings while also committing to making positive changes in their behaviour. It is commonly used to treat anxiety and depression in New Zealand.
3. Mindfulness-Based Stress Reduction (MBSR): This program teaches individuals to focus on the present moment, reduce stress, and promote relaxation. It is often used to help individuals manage chronic pain and other physical and mental health conditions.
4. Dialectical Behaviour Therapy (DBT): This intervention helps individuals manage their emotions and improve their interpersonal relationships. It is commonly used to treat borderline personality disorder and other mental health conditions.
5. Family-Based Therapy (FBT): This intervention involves family members in the treatment process to help individuals recover from mental health conditions. It is commonly used to treat eating disorders and other conditions that affect family dynamics.

Effective and evidence-based treatments are available for different mental health conditions through these interventions. To identify the most suitable intervention for individual needs, it is important to seek the guidance of a mental health expert, keeping in mind that everyone's mental health journey is distinct, and the most effective approach will vary based on their situation and requirements. It is always recommended to consult with a qualified mental health professional to determine the best intervention.

## 3 Research Method

The objective of this study is to evaluate the efficacy of existing mental health interventions in New Zealand. It aims to examine the strengths and weaknesses of these interventions, with a particular emphasis on their impact on an individual's mental health and well-being. The goal is to raise awareness and encourage the development of better intervention strategies. To accomplish this, an extensive literature review was first conducted to identify various intervention approaches and the barriers that hinder their success. Subsequently, in the research process, we conducted a pilot survey employing a semi-structured questionnaire. This survey targeted a diverse group of professionals in the construction industry, encompassing architects, site managers, project managers, quantity surveyors, designers, office managers, and workers. The participants were selected through a randomised process facilitated by MS Excel. The pool of potential respondents was drawn from a comprehensive database of individuals who had either undergone mental health interventions or had direct experiences with and observations of mental health issues in New Zealand from 2018 to 2023.

In total, eight (8) questionnaires were deemed usable and formed the basis of our pilot survey. This preliminary investigation aimed to refine and validate our survey instrument, ensuring its effectiveness in capturing valuable insights from a broader sample in subsequent phases of the study. The small initial sample size allowed for critical adjustments to be made to the survey tool, enhancing its suitability for the larger-scale data collection that followed.

A mixed-method approach that employed both quantitative and qualitative techniques was adopted. This aimed to understand the experiences of individuals with mental health issues and the effectiveness of the interventions they received. Statistical methods were used to identify any significant differences in outcomes between different types of interventions, barriers to good mental health, and thoughts on mental health. Both descriptive and statistical analyses were employed.

Descriptive analysis was used to better understand the characteristics and distribution of data and describe datasets, such as identifying anomalies. This study collected data on the participants' height and thoughts, with measures of central tendency, measure variability, frequency distribution, and percentiles. Statistical analysis was used to summarise the data and offer a clear presentation of essential elements, creating a diagram that represented components and the relationships between them. This was then used to analyse the behaviour of the system to identify any potential problems or inefficiencies and to design improvements or modifications to the system. The data were coded and entered into Excel accordingly [39]. This study aims to determine the level of awareness of mental health intervention in New Zealand. By doing so, it seeks to educate the public and enhance their understanding of the availability, barriers, and effectiveness of mental health interventions.

## 4 Data Analysis

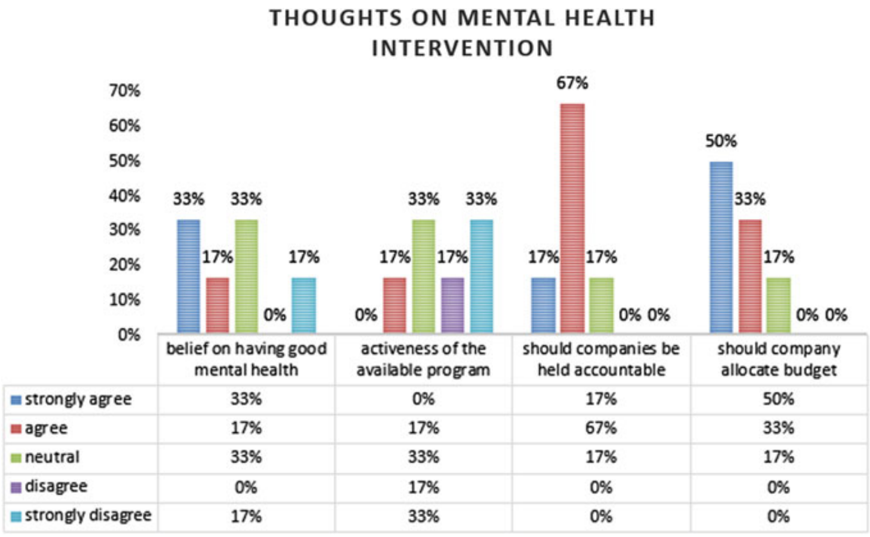
The semi-structured survey questionnaire contained five sections, with four being the main sections. These sections covered demographic information, identifying current mental health interventions, identifying the effectiveness of mental health interventions, barriers to good mental health treatment, and recommendations for improvement. The questionnaire also touched on other topics that are not relevant to the current paper. Respondents were asked to rate their responses on a Likert scale ranging from strongly disagree (5) to agree (1) strongly.

**Demographic Data**

Demographic data were collected from survey participants, including age, identity, years of experience in the New Zealand construction industry, employment status, location, highest qualification, and the job title. From this data, participant profiles were created. The survey results showed that feedback was provided by project engineers (25%), quantity surveyors (12.5%), office managers (25%), and construction workers (37.5%). The majority of participants (62.5%) had 6–10 years of experience in the industry, while 37.5% had less than five years of experience. All of them are currently staying and working in full-time employment in Auckland. The majority of the participants (62.5%) are male and 37.5% are female. Lastly, the majority of the participants (62.5%) have a degree level of education, while 25% are diploma holders and 12.5% have the highest level of education (postgraduate).

### *4.1 Thoughts on Mental Health Intervention*

Participants were presented with four mental health interventions identified from the literature and indicated their agreement on a five-point scale (1 being strongly agree and 5 being strongly disagree). The survey found that the belief of the respondents to the mental health intervention and the activeness of the currently available intervention are both sitting in the median. It shows that people are just relying on what they are aware to be available in their environment. While more people agree that companies should be held accountable and allocate a budget for mental health interventions for their employees as part of their responsibilities and to protect employee's well-being (Fig. 1).




| | belief on having good mental health | activeness of the available program | should companies be held accountable | should company allocate budget |
|---|---|---|---|---|
| strongly agree | 33% | 0% | 17% | 50% |
| agree | 17% | 17% | 67% | 33% |
| neutral | 33% | 33% | 17% | 17% |
| disagree | 0% | 17% | 0% | 0% |
| strongly disagree | 17% | 33% | 0% | 0% |

**Fig. 1** Survey on thoughts on the mental health intervention

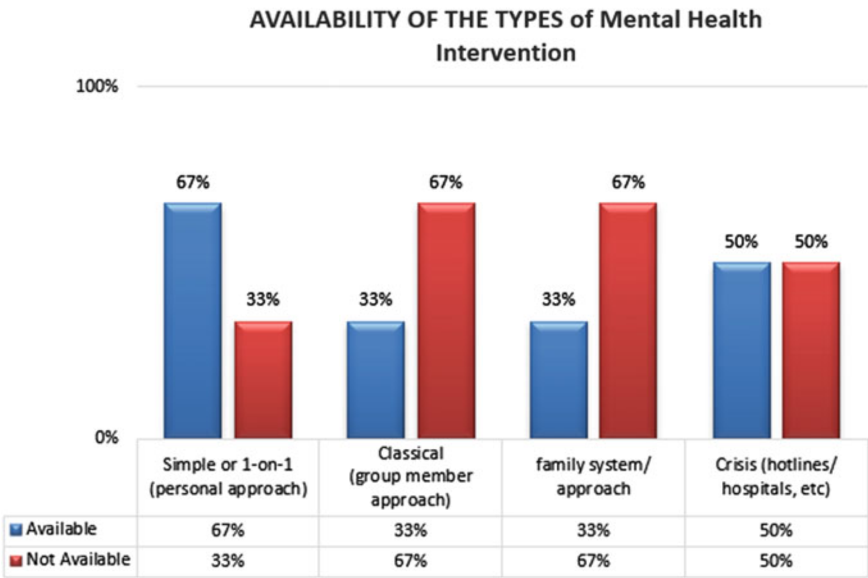


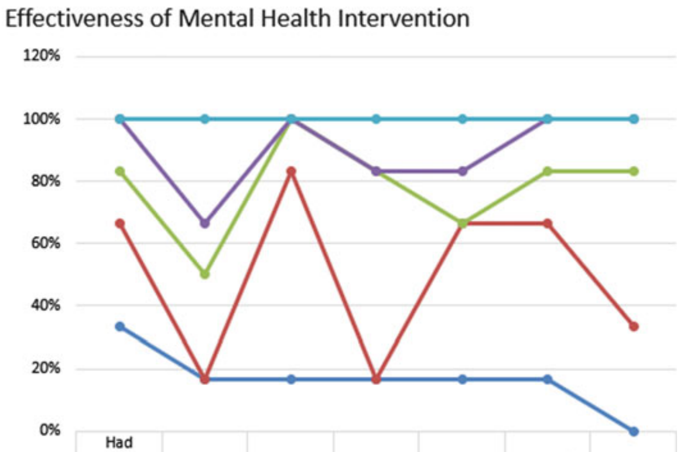

**Fig. 2** Survey on the availability of the types of mental health intervention

## *4.2 Availability of the Types of Mental Health Intervention*

According to this survey, many common types of mental health interventions are not readily available or openly discussed within the community. This is problematic, as these interventions can become a waste of resources and funding if they are not accessible to those who need them (Fig. 2).

## *4.3 Effectiveness of Mental Health Intervention*

According to this graph, a growing number of individuals are facing mental health challenges, and their recovery process is slow. As a result, there is a general consensus that mental health interventions are helpful, but currently available interventions are only moderately effective. This indicates that there is still a long way to go if we want to make significant progress in addressing mental health concerns (Fig. 3).




| | Had Mental Health issues | resolve speed | beneficial | effective | access | prevent/cu-re | improvem-ent |
|---|---|---|---|---|---|---|---|
| strongly disagree/very unlikely | | 33% | | 17% | 17% | | |
| disagree/unlikely | 17% | 17% | | | 17% | 17% | 17% |
| neutral | 17% | 33% | 17% | 67% | | 17% | 50% |
| agree/ Likely | 33% | | 67% | | 50% | 50% | 33% |
| strongly agree/ very likely | 33% | 17% | 17% | 17% | 17% | 17% | |

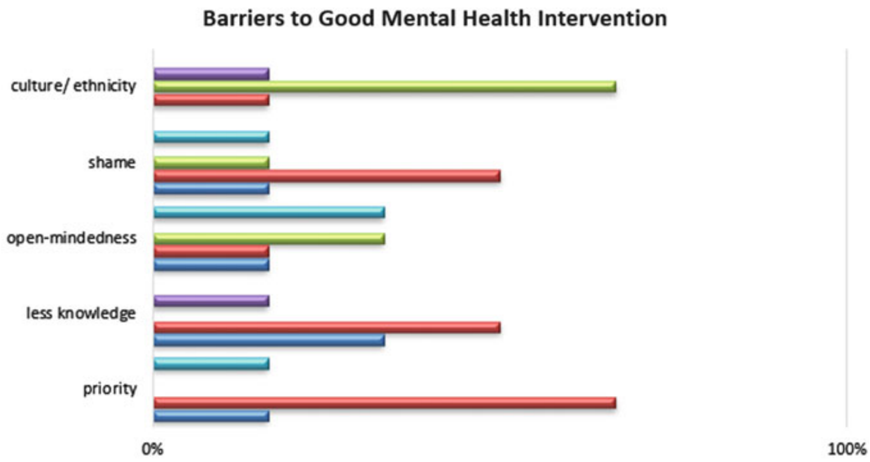
**Fig. 3** Survey on the effectiveness of mental health intervention

### *4.4 Barriers to Having Good Mental Health Intervention*

The results indicate that most people believe mental health interventions should be prioritised despite many individuals having limited knowledge or feeling ashamed to discuss the topic, particularly within culturally diverse communities (Fig. 4).

### *4.5 Improvement of Mental Health Intervention*

This graph illustrates the eight factors that can enhance mental health interventions. These factors include opportunities for improvement, raising awareness, mandating employee education, reviewing government policies and implementation, providing government support, promoting better employment, creating a healthy environment, and tailoring interventions to meet individual needs (Fig. 5).




| | priority | less knowledge | open-mindedness | shame | culture/ethnicity |
|---|---|---|---|---|---|
| strongly disagree | 17% | | 33% | 17% | |
| disagree | | 17% | | | 17% |
| neutral | | | 33% | 17% | 67% |
| agree | 67% | 50% | 17% | 50% | 17% |
| strongly agree | 17% | 33% | 17% | 17% | |

**Fig. 4** Survey on the barriers on having good mental health intervention

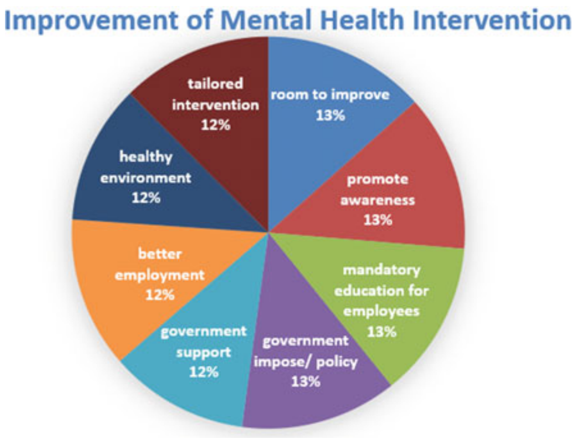



**Fig. 5** Graph on the factors that help to improve mental health intervention

## 5 Discussion

This research is valuable in identifying the specific requirements of the community and proposing solutions to enhance mental health and well-being. By tackling factors that cause poor mental health or even suicide in workplaces and environments, it aims to improve the quality of life for individuals. Previous literature has also stressed the significance of addressing cultural and social aspects that contribute to mental health issues [31]. This study supports the previous research by emphasising the importance of enhancing existing interventions and implementing targeted solutions backed by empirical evidence [31].

There are several cultural and social factors that contribute to poor mental health in the industry. These include excessive workload, cultural norms of working overtime, tight deadlines, work superiors' communication styles, sexism, discrimination, lack of freedom, language barriers, misjudgement, suicidal thoughts, ignorance, fear, and the influence of religion or family background. However, effective mental health support services in New Zealand have been identified. These include internet portals or websites, government promotion of work–life balance, government hotlines, companies offering flexible working hours and events, private organisations offering mental health support, local GPs or clinics, employee assistance professional services (EAP), non-government campaigns on mental health awareness, and school-based mental health programs.

In addition, several factors were discovered that hinder people from accessing mental health support or services. These include budget constraints, reluctance to acknowledge personal issues, conflicting thoughts and emotions, time constraints due to work and personal obligations, communication difficulties, negative outlook on life, and difficulty in identifying or expressing concerns. These hindrances have consistently been reported as obstacles to mental health services and are in line with the existing literature on the subject. This study provides empirical evidence that reinforces the need for targeted interventions to address these issues.

Furthermore, this study aligns with most of the existing literature, highlighting the importance of creating supportive environments and empowering individuals to take an active role in their mental well-being. The research confirms and extends the current knowledge on mental health interventions in New Zealand, identifying cultural and social factors that affect the effectiveness of support services. Recommended strategies include increased government funding, comprehensive implementation of interventions in various aspects of society, encouraging open communication, team-building activities, regular talks that provide confidence or support, problem-focused solutions, root cause analysis, education on time and emotional management, lifestyle changes, and fostering a caring environment for self-recovery or self-care.

## 6 Conclusion

This research contributes to the current knowledge on mental health interventions in New Zealand by providing valuable insights into the cultural and social factors that affect mental health, due to the country's diversity. Effective support services, such as internet portals and work–life balance campaigns, are available to promote awareness of mental health from families, companies, and the government. The study identifies several barriers that prevent access to good mental health interventions, including inadequate funding, cultural differences, and a shortage of mental health professionals, resulting in long waiting times for services. This lack of awareness disrupts the continuity of care for individuals with mental health disorders. Despite government efforts to improve mental health services, many individuals still struggle to access effective interventions.

Mental health interventions are essential for improving the well-being of individuals with mental health problems, but addressing these barriers requires a collaborative effort from policymakers, mental health professionals, and the public. Therefore, this research will help inform policies and practices that enhance the efficiency and effectiveness of the mental health system, with recommendations for improving mental health in New Zealand. The findings highlight the need for up-to-date evaluations of existing mental health interventions to ensure their validity and meet the needs of those who require them. Future interventions should focus on increasing accessibility, implementing evidence-based interventions, addressing cultural considerations, and prioritising prevention. By doing so, mental health services in New Zealand can effectively provide inclusive care to those in need.

Although this research provides valuable insights into potential barriers to mental health interventions, the small sample size limits its ability to generalise the effectiveness of these interventions in the construction industry without further investigation in other regions. However, the study's findings shed light on the effectiveness of current interventions and their impact on work and well-being. To ensure more robust generalisations, it may be beneficial to explore other fields of research, such as health and psychology, which offer more diagnostic approaches than survey data.

To enhance the study's rigour, future research could include a more extensive and diverse sample, encompassing construction workers from various ethnic and cultural backgrounds. Additionally, incorporating open-ended questions to gather more profound qualitative data and exploring alternative data collection methods like in-person interviews or focus groups could be considered. Despite its limitations, this study serves as a significant starting point for investigating the effectiveness of mental health interventions in New Zealand.

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## References


1. BRANZ (n.d.) About BRANZ. Retrieved from https://www.branz.co.nz/about/#:~:text=It%20is%20an%20independent%20and,built%20environment%20in%20New%20Zealand. Accessed 29 April, 2022
2. Bryson K, Duncan A (2018) Mental health in the construction industry scoping study. Retrieved from https://d39d3mj7qio96p.cloudfront.net/media/documents/SR411_Mental_health_in_the_construction_industry.pdf. Accessed 29 April, 2022
3. Building Mental Health (n.d.) Building mental health is an initiative led by industry experts, providing support and advice to increase awareness of mental health. Retrieved from https://www.buildingmentalhealth.net/about-us.html. Accessed 29 April, 2022
4. Burt D (2016) Cracking down on drink and drugs. Retrieved from https://www.buildmagazine.org.nz/assets/PDF/Build-156-100-Health-And-Safety-Cracking-Down-On-Drink-And-Drugs.pdf?. Accessed 29 April, 2022
5. Emmett T (2019) New Zealand construction: few barriers, many opportunities. Retrieved from https://www.turnerandtownsend.com/en/perspectives/new-zealand-construction-few-barriers-many-opportunities/. Accessed 29 April, 2022
6. Engineers Australia (2020) Building mental health into the construction industry. Retrieved from https://www.engineersaustralia.org.au/news-and-media/2022/07/building-mental-health-construction-industry. Accessed 29 April, 2022
7. Eyllon M et al (2020) Mental health stigma and wellbeing among commercial construction workers: a mixed methods study. Retrieved from https://www.researchgate.net/publication/342173141_Mental_Health_Stigma_and_Wellbeing_Among_Commercial_Construction_Workers_A_Mixed_Methods_Study. Accessed 29 April, 2022
8. George A (2022) Why is the construction sector so male-dominated? Retrieved from https://www.businessleader.co.uk/why-is-the-construction-sector-so-male-dominated/. Accessed 29 April, 2022
9. Georgetown Behavioral Hospital (2023) Examples of specific mental health treatment methods. Retrieved from https://www.gbhoh.com/services/adult-mental-health-program/. Accessed 20 March, 2023
10. Gullestrup J, Lequertier B, Martin G (2011) MATES in construction: impact of a multimodal, community-based program for suicide prevention in the construction industry. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3228565/. Accessed 29 April, 2022
11. Haar J, Kane C (2022) A post-lockdown study of burnout risk amongst New Zealand essential workers. Retrieved from https://pubmed.ncbi.nlm.nih.gov/35738197/. Accessed 08 July, 2023
12. Hashem S (2021) Surge in construction worker suicide rates leads to U.S. department of labor, industry leaders and stakeholders to take action. Retrieved from https://ohsonline.com/articles/2021/08/27/surge-in-construction-worker-suicide.aspx. Accessed 29 April, 2022
13. Independent research association of New Zealand, 2018, BRANZ scopes mental health in the construction industry. Retrieved from https://www.iranz.org.nz/news/2018/branz_mental_health_in_construction_industry. Accessed 29 April, 2022
14. Kier (2019) The importance of mental health first aid training in the construction industry. Retrieved from https://www.kier.co.uk/media/blog-posts/the-importance-of-mental-health-first-aid-training-in-the-construction-industry/. Accessed 29 April, 2022
15. Kime M (2022) Best practices guide for mental-health intervention in construction. Retrieved from https://www.agcwa.com/wp-content/uploads/2021/08/Mental-Health-Best-Practices-Guide-Construction-FINAL.pdf. Accessed 29 April, 2022
16. Kotera Y, Green P, Sheffield D (2019) Mental health shame of UK construction workers: relationship with masculinity, work motivation, and self-compassion. Retrieved from https://journals.copmadrid.org/jwop/art/jwop2019a15. Accessed 29 April, 2022
17. Kulshrestha V, Shahid S (2022) Barriers and drivers in mental health services in New Zealand: current status and future direction. Retrieved from https://pubmed.ncbi.nlm.nih.gov/35722983/. Accessed 8 July, 2023

18. Lewis L (2021) Suicide prevention programme mates in construction seeks government funding as number of young tradies taking their lives rises. Retrieved from https://www.newshub.co.nz/home/new-zealand/2021/02/suicide-prevention-programme-mates-in-construction-seeks-government-funding-as-number-of-young-tradies-taking-their-lives-rises.html. Accessed 29 April, 2022
19. Life in Mind (2022) Report examines suicides in the Australian construction industry. Retrieved from https://lifeinmind.org.au/news/report-examines-suicides-in-the-australian-construction-industry. Accessed 29 April, 2022
20. LivingWorks (n.d.) The world's leading suicide intervention training program. Retrieved from https://www.livingworks.net/asist#:~:text=LivingWorks%20ASIST%20is%20a%20two,plan%20to%20keep%20someone%20alive. Accessed 29 April, 2022
21. Lorek S (2023) Mental health and suicide prevention in construction. Retrieved from https://constructible.trimble.com/construction-industry/mental-health-in-construction-stats. Accessed 08 July, 2023
22. MATES in Construction (2022) Connector training. Retrieved from https://mates.org.au/training-support#:~:text=Connector%20Training%20is%20provided%20to,connecting%20them%20to%20professional%20help. Accessed 29 April, 2022
23. Master Builders Association (2022) Suicide in the construction industry: 2001–2019. Retrieved from https://www.mbansw.asn.au/media/industry-news/suicide-construction-industry-2001-2019. Accessed 29 April, 2022
24. Mayo Clinic (2017) Mental health: overcoming the stigma of mental illness. Retrieved from https://www.mayoclinic.org/diseases-conditions/mental-illness/in-depth/mental-health/art-20046477. Accessed 30 June, 2023
25. McConnell G (2022) Retrieved from https://www.stuff.co.nz/national/politics/300715555/health-nz-needs-650-mental-health-staff-to-fill-gaps. Accessed 08 July, 2023
26. Mental Health Foundation (2016) Addressing issues in our mental health system. Retrieved from https://mentalhealth.org.nz/news/post/addressing-issues-in-our-mental-health-system. Accessed 29 April, 2022
27. Mental Health Foundation (2023) Statistics on suicide in New Zealand. Retrieved from https://mentalhealth.org.nz/suicide-prevention/statistics-on-suicide-in-new-zealand. Accessed 03 July, 2023
28. Milner A, King T (2018) Men's work, women's work, and suicide: a retrospective mortality study in Australia. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1111/1753-6405.12859. Accessed 29 April, 2022
29. Ministry of Health (2018) Mental health and addiction. Retrieved from https://www.health.govt.nz/our-work/mental-health-and-addiction. Accessed 29 April, 2022
30. Ministry for Women (2019) Industry. Retrieved from https://women.govt.nz/gpg/industry. Accessed 29 April, 2022
31. National Health Committee (1998) The social, cultural and economic determinants of health in New Zealand: action to improve health. Retrieved from https://www.health.govt.nz/system/files/documents/publications/det-health.pdf. Accessed 30 June, 2023
32. Nwaogu JM, Chan APC, Mershack Opoku T (2022) Staff resilience and coping behavior as protective factors for mental health among construction tradesmen. J Eng, Des Technol 20(3):671–695. Retrieved from https://doi.org/10.1108/JEDT-11-2020-0464. Accessed 29 April, 2022
33. Pamidimukka A, Kermanschachi S (2019) Impact of CoVid-19 on field and offer workforce in construction industry. Retrieved from https://www.sciencedirect.com/science/article/pii/S2666721521000120. Accessed 29 April, 2022
34. Pricewaterhouse Coopers International Limited (2016) Valuing the role of construction in the New Zealand economy. Retrieved from https://www.pwc.co.nz/pdfs/CSG-PwC-Value-of-Construction-Sector-NZ.pdf. Accessed 29 April, 2022
35. Rice-Oxley M (2021) Why do so many construction workers kill themselves?. Retrieved from https://www.theguardian.com/society/2019/aug/13/why-do-so-many-construction-workers-kill-themselves. Accessed April 29, 2022

36. Ross V, Mathieu SL, Wardhani R, Gullestrup J, Kõlves K (2021) Factors associated with workplace bullying and the mental health of construction industry apprentices: a mixed methods study. Front Psych 12(629262–629262):2022. https://doi.org/10.3389/fpsyt.2021.629262onApril29
37. Schultz B (2021) Study examines why construction workers have such high suicide rates. Retrieved from https://www.forconstructionpros.com/business/construction-safety/news/21734804/study-examines-why-construction-workers-have-such-high-suicide-rates. Accessed 29 April, 2022
38. Scoop Independent News (2021) MATES in construction programme profiled in world health organization guidance. Accessed 29 April, 2022
39. Simplilearn (2023) What is statistical analysis? Types, methods and examples. Retrieved from https://www.simplilearn.com/what-is-statistical-analysis-article. Accessed 30 June, 2023
40. Social Solutions (2022) Barriers to mental health treatment and access to care. Retrieved from https://www.socialsolutions.com/blog/barriers-to-mental-healthcare-access/. Accessed 29 April, 2022
41. Swartz H (2011) Managing the benefits and challenges of the multi-generational workforce. Retrieved from https://irc.queensu.ca/managing-the-benefits-and-challenges-of-the-multi-generational-workforce/. Accessed 03 July, 2023
42. Trautmann S, Rehm J, Wittchen H (2016) The economic costs of mental disorders. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5007565/. Accessed 29 April, 2022
43. University of Washington (n.d.) Forefront suicide prevention LEARN skills. Retrieved from https://intheforefront.org/learn-saves-lives/. Accessed 29 April, 2022
44. World Health Rankings (2022) Retrieved from https://www.worldlifeexpectancy.com/oceania/suicide-cause-of-death. Accessed 29 April, 2022

# Traditional Architecture: A Natural Disaster Resilient Alternative

**Naomaan Riyaz, Mohamed Elkharboutly, and Suzanne Wilkinson**

## 1 Introduction

Post-disaster reconstruction initiatives face some common hurdles around the world. Hurdles such as scarcity of materials and financial constraints have been highlighted in scholarly work [50]. Another critical hurdle arises from the shortage of skilled labour [43]. Also, other challenges that emerge in post disaster reconstruction are the neglect and non-involvement of the affected communities. These collective challenges invariably result in constructing houses that do not fit the geographical or cultural requirements of the affected communities and these inadequacies lead to abandonment of these houses [16].

Traditional building methods have been used for thousands of years; the building system varies according to its surrounding environment, even in the different regions of a country. The house features, design, material used, and construction techniques are all influenced by the nature of the surrounding area and the resources available [32]. Throughout the years, the traditional building methods were subjected to continuous modifications and improvements to make them adaptable to different environmental conditions and socio-cultural and livelihood changes, for example, the traditional Malay house in Malaysia has been progressively changed to create a modern energy-efficient housing and the traditional house has been entirely replaced [29].

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Some of the traditionally built houses sustained and showed impressive performance, surviving natural hazards with either minor or no damages like the Dhajji-Dewari and Bhatar houses during the Pakistan 2005 earthquake [32], the Himis house in the Turkey 2011 earthquake [51] and the Rajbanshi & Ghumauro house, the Nepal earthquake 2015 [22].

However, the traditional houses did not resist natural disasters in other cases, like the destruction of traditional adobe houses in Iran after the Bam earthquake [38]. But, it is not always the traditional method of building that was to blame. In some cases, the housing damages were due to a poorly built version of the original design due to several factors, some of which are the infrequent disasters and poor economic situations like the case of traditional houses in Alto Mayo, Peru [53].

To achieve the objective of this study, an extensive review has been done of various traditional building methods in different areas and locations subjected to different varieties of natural hazards.

## 2 Traditional Building Methods

As Langenbach [34] described, traditional architecture has evolved from human observation and experience over hundreds of years. Traditional architecture always incorporates construction using natural materials that exist in the local area, ensuring the sustainability of the building [32]. It is also distinguished by reflecting the local community's requirements in the housing interior and exterior features and its structural ability to withstand the most prevalent natural hazard in its geographic location [53]. After the Kashmir earthquake of 2005, the performance of the traditional houses, locally known as "Dhajji-Dewari", was outstanding compared to the modern ones [34] and other traditional houses in Kashmir, known as the "Bhatar" performed well during the earthquake [47]. During the 2015 Nepal earthquake, traditional houses' performance was the same as in Kashmir [8]. In Turkey, after the earthquake in 2006, the traditional house called the "Himis" survived the earthquake with minor damages compared to the modern concrete houses destroyed in the area affected by the earthquake [2].

## 3 Research Method

This paper is about traditional disaster-resilient architecture, which has passed the test of time worldwide. Previously published research related to traditional architecture in different parts of the world was reviewed to build the case for this paper. Published literature on traditional houses representing a specific type of sustainability was analysed. These research papers on different types of construction were studied for composition, the material used, technology and the sustainability of the construction.

Published literature on different construction methods was assessed for the performance of the construction during disasters like earthquakes, cyclones, and floods.

## 4 Findings and Discussion

In this section, traditional houses that have survived different natural hazards will be discussed with a focus on the building material, the construction method used and the houses' unique features that enhanced their performance during the natural hazard.

### *4.1 Dhajji-Dewari, Kashmir*

On the 8th of October 2005, a 7.6 magnitude earthquake struck Northern Pakistan and the Kashmir valley, causing widespread havoc and damaging and destroying over 400,000 houses [18]. The Dhajji-Dewari traditional houses, as shown in Fig. 1, survived the earthquake with minor or no damages [34]. The houses all are typically single-storeyed houses with pitched roofs, but also in some areas, the Dhajji-Dewari would go up to six-storey houses [4].

#### 4.1.1 House Features

The Dhajji-Dewari has unique construction features that make it an earthquake-resistant house. The Dhajji-Dewari is a timber-brick masonry construction that consists of a timber frame with diagonal bracing members. The frame is infilled with brick and mud mortar to create a patchwork masonry that divides the wall into small panels instead of one large unit, which has performed better in earthquakes [32].

The construction and relevance of individual components of the construction are defined below.

Roofs

The roofing system comprises timber trusses enveloped by metal, asbestos, cement, or plastic corrugated roof sheets. Typically, the roofing system is constructed with timber A-frame trusses spanning across primary timber columns, although there are exceptions to this pattern. At times, the timber trusses extend between primary beams rather than columns. These timber trusses are commonly arranged in a gable roof configuration. In contrast, hipped roofs are considered even more favourable

**Fig. 1** Dhajji-Dewari house in Srinagar Kashmir, India [34]

due to their superior overall rigidity compared to roofs with gable ends, avoiding the masonry for gable ends. In the traditional approach, rough-cut purlins were employed to bridge the gaps between the roof trusses, upon which wooden roof tiles known as shingles were placed as weather-resistant surfaces. However, in more recent times, the roof covering has transitioned to a variety of sheeting materials such as metal, asbestos, cement, or plastic corrugated sheets [25, 26].

Dhajji-Dewari roofs are designed to withstand the challenging weather of the region of Kashmir, especially snowfall. The slanting design of the roof allows the snow in winter to slide off, preventing excessive accumulation and potential structural damage [26].

Walls

The most significant feature of the construction method is the walls. These are mainly responsible for earthquake resistance. The walls are timber braced with stone or brick masonry infilled with mud as the binding Material [26]. The walls comprise a timber frame with cross bracings, helping resist the shear force. The cross-bracings provide triangular stability to the structure, which means that at the time of the earthquake, the three forces of compression, tension and shear are distributed evenly by the frame [3], fulfilling the functional requirements of enclosing and partitioning and the structural requirements. The gaps in between the timber bracings are filled by mud mortar with brick or stone. And then, the whole wall is plastered with mud to give it a finished look [23].

The joints of the wooden frame are created with interlocking joints, creating a stable and cohesive structure.

Foundation

Typically, Dhajji-Dewari buildings have a shallow foundation as a strip footing just around the base of the timber frame [26]. This base is made mainly of semi-dressed or rubble stones. Sometimes, the foundation can be a few feet high, depending on the slope of the land or the amount of snow that the area receives during winter [26]. The stones used in the foundation also provide damp proofing from the groundwater seepage, which could make the timber damp, compromising the structural integrity of the timber frame. Traditionally, no anchorage was used between the foundation, helping to provide base isolation. But if the building is on a slope, the building is fixed to the foundation to stop rolling over in case of a seismic event [26].

### 4.1.2 Building Material

The materials used in the Dhajji-Dewari construction are available locally and quickly. In the Indian side of Kashmir, the infill is brick because of the abundance of clay. The mud mortar is sometimes strengthened by adding lime, shredded grass, or pine needles. This also helps in avoiding shrinkage. The timber for the frame is traditionally made of the fine-grained wood of the deodar (cedar wood) available locally. It has a reputation for being resistant to rotting and has tremendous strength. The longevity of the Dhajji-Dewari construction is based primarily on the strength and health of the timber, and deodar has been proven to be successful in lasting longer and healthier [26].

The same destructive earthquake of 2005 also affected the Pakistani-administered part of Kashmir province. The Pakistani government reported destroying over 80% of houses in rural areas. According to the report on the Kashmir earthquake by Earthquake Reconstruction and Rehabilitation Authority, the EERI, in 2005. The collapsed structures consisted mainly of earthen walls, unreinforced stone or concrete blocks, masonry and concrete frames with masonry infills. Among the surviving structures was the Taq or Bhatar vernacular [28]. The Bhatar, as it is called in Pakistan, is known as Taq in Kashmir [33]. It is a traditional construction system adopted in some parts of the Northern Pakistani Areas, including Kashmir. The Bhattar construction is a different type of Dhajji-Dewari, and it was used in some high-profile heritage sites in

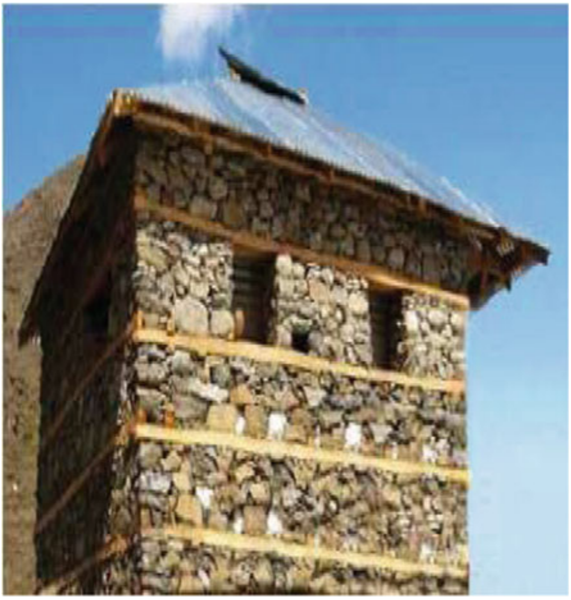

**Fig. 2** Bhatar House in Pakistan [45]

North Pakistan, like the Baltit and Besham Fort, as well as many other historic houses and temples that survived the devastating October 2005 earthquake [47] (Fig. 2).

#### 4.1.3 House Features

The Taq or the Bhattar construction has hefty and load-bearing masonry walls divided horizontally by wood runners that look like ladders. These ladder like structures serve to connect the walls seamlessly to the floors and the entire structure is bonded together by the substantial weight of the stone masonry [32].

The construction and relevance of individual components of the construction are defined below.

Roofs

The Taq has a heavy, pitched roof built on top of the walls, with wooden rafters and purlins, initially covered with slates or wooden shingles. The trusses used are heavy and not sawn to add to make the house heavy and hold the walls together. The roof sits on a timber ring on all the walls around the building, the same as the rest of the house. The roof in the houses is an individual and isolated element of the construction that acts as a diaphragm under seismic loads [14].

**Fig. 3** Ghumauro Dhi construction in Nepal [21]

Walls

Its construction involves thick stone walls reinforced by horizontal timber runner beams that look like ladders, and in some structures, weak mud mortar is used to bind the stone [47]. The horizontal timber beams are equally spaced vertically, providing a solid corner connection and forms with the timber lacing a stable structure that is capable of withstanding seismic activities. The timber beams used in that construction do not form complete frames like Dhajji-Dewari, instead, these runner beams rest all along the stone or brick masonry of the house. The weight of the masonry on the runner beams helps to prestress the walls making them ready for resistance to the lateral forces of an earthquake [35]. The masonry of the walls is usually limestone, found in the northern regions of Pakistan. These rocks of different sizes are compacted together [35].

Foundation

The foundation in the Taq house is the same as Dhajji-Dewari. These houses are generally built on a shallow strip foundation by hand digging the ground about 100 mm deep [10]. The base of the foundation is made mainly of semi-dressed or rubble stones, as in Fig. 3. Sometimes the foundation can be a few feet high, depending on the slope of the land or the amount of snow that the area receives during winter [26].

#### 4.1.4 Building Material

All the materials used for constructing the house are collected from the surrounding local environment. The material used involves timber and stone, and the properties and strengths of these materials differ depending on the location of the house. The most commonly used timber is Deodar or Cedar, widely acknowledged for its quality, strength, and durability. This timber is readily available in the region. The stone commonly used for the construction are limestone and sandstone [10].

### *4.2 Ghumauro Dhi, Nepal*

In April 2015, a devastating earthquake struck central, eastern and western Nepal. Around 500,000 houses either collapsed or were partially damaged. According to the Post Disaster Need Assessment, most of these houses were low-strength masonry structures, reinforced concrete framed structures [5].

In the Midwestern hills of Nepal, the Kaski area, the traditional housing system of Ghumaro dhi was founded and developed by the locals. It was reported that during 1934, 1988 and finally the 2015 earthquakes, the houses did not collapse, and damages were very minute in these locally developed dwellings [48]. The earthquake resistance of these house is ensured by the use of struts, timber bands, low ceiling heights in stories with fewer and small openings in walls [22].

Nepal lies on the boundary of the subduction of the Indian and the Tibetan tectonic plates, which results in frequent high-intensity earthquakes striking Nepal. The location of Nepal on the boundary of these plates puts Nepal in the 11$^{th}$ position on the list of countries most prone to frequent earthquakes [31].

#### 4.2.1 House Features

The Ghumauro Dhi houses are structures that are rounded with heavy stone masonry. These houses have vertical timber members that are placed in the masonry on intervals. These houses are usually two stories where the floors are divided by timber members. Timber is also used for supporting window and door openings [21].

The construction and relevance of individual components of the construction is defined below:

Roof

Roof in the Ghumauro Dhi houses depends on the availability of materials. Most of the roofs are made from locally available mud, followed by galvanised iron sheet and a minority of houses use slate tiles for roofs [22]. Dipendra Gautam in his research found about 15 houses with stones tied with iron wires to the purlins to keep them from falling. Wooden pegs were tied to the rafters [22].

Walls

The Ghumauro Dhi houses are traditionally rounded structures. These rounded structures are made from stone masonry and have Agrakh (Shorea Robusta) timber members derived from local forests. These timber members are used as vertical posts or pegs between stone masonry. The construction of the walls is symmetrical, and the timber is used as a lintel for openings. The slabs between floors are made of timber as well. The stone masonry is usually mud bonded, but newer constructions sometimes use cement [22].

Foundation

The foundation in the Ghumauro Dhi houses is made of stone plinths. These stone plinths constitute a strapped foundation. These stone plinths are always levelled on top even if the house is on a slope which is a characteristic practise of building houses in the hills [22].

#### 4.2.2 Building Material

The materials used in construction come from the surrounding environment. That includes stone masonry for walls and timber elements for posts and rafters from local trees. The house has a unique feature: a symmetrically rounded circular structure with one or two storeys. The roof mainly consisted of slates tied with wires to the wooden purlins.

As per Gautam, D. et al., the regular circular feature of the house and the lightweight roofing provided a significant influence in avoiding structural failure during earthquakes.

### *4.3 Rajbanshi House, Nepal*

Terai is a lowland region in the southern part of Nepal. Due to its low altitude topography, the area has recursive flooding seasons. In response to this topographic nature, the locals developed a unique vernacular dwelling with a unique feature. The houses are built on stilts with an elevated platform supported by stilts, usually ranging from one to three meters in height [22]. According to [22], the construction of such a housing system goes back more than 40 years. It was also mentioned that

**Fig. 4** Rajbanshi flood and earthquake resistant house in Nepal [22]

during floods in this area, the inhabitants would stay safe from epidemics and snake attacks, which are common in the flooding season.

Often referred to as the country's breadbasket, the Terai region is renowned for its predominantly flat landscape, gently sloping to the south. Its altitude fluctuates between 65 and 300 m above sea level, and its breadth ranges between 20 and 45 km. A characteristic subtropical climate graces the Terai, with an average ambient temperature of 25 °C. The annual precipitation in this area varies, ranging from 1200 mm to 3000 mm, including sporadic rainfall and sudden downpours. The Terai serves as the endpoint for all Nepalese rivers, originating from the Churia and Siwalik foothills, providing the region's water supply for sustenance. The monsoon season, extending from June to September, often sees these rivers at their maximum capacity, leading to floods and submergence in various parts of the Terai. Changes in climate, particularly alterations in rainfall frequency and intensity, exacerbate the flood and submergence issues in the Terai region [1] (Fig. 4).

### 4.3.1 House Features

The Rajbanshi houses are built on wooden pillars that prevent flood water from entering the houses. This helps in creating a sound earthquake-resistant structure as well. The house's living quarters begin from the first floor, which is reachable by stairs.

The construction and relevance of individual components of the construction are defined below.

Roof

Most of the roofs in Rajbanshi houses have tapered mud roofs, followed by galvanised iron sheets and wooden planks. The rafters and purlins are made from timber. Using mud as the primary roofing material has traditional roots, which serve the purpose of passive cooling during the burning heat of summers and passive heating during cold winters. The gable of the roof is isolated from the house by wooden slabs or bamboo sticks [22].

Walls

The walls mainly consist of bricks or stones bound together with mud. After this, the second most common practice is making walls made of wood planks. Also, in some places, walls are made of hand-weaved bamboo ikra nets, This type of wall provides ventilation for air circulation to regulate heat in the houses during summer and also to keep the construction of a low weight [22].

Foundation

The Rajbanshi houses are built on a 1–3 m high foundation platform. This platform is open and has stairs that lead to the first floor, where the families live. The foundation platform is on wooden pillars that are piled into the ground. This helps to keep the houses dry in case of floods. Since these timber posts have constant contact with water, the locally available dampness-resistant wood Shorea Robusta is used [22].

### 4.3.2 Building Material

The wood used in the construction of Rajbanshi House is Shorea Robusta, derived from the local Sal forest. The local availability of timber for houses makes the construction of Rajbanshi house very economical. Dependra Gautam et al. in their research in 2016 found out that majority of Rajbanshi houses were constructed in less than $500 [22].

## *4.4 Himis, Turkey*

It has been observed during the major earthquakes that struck Turkey from the year 1960 till 2001 that the Himis vernacular houses have survived the incidents with minor or no damages. However, most of the damaged homes in the same area were masonry, adobe, timber, or concrete framed buildings [2].

Turkey is in a seismically active region known as the Alpide Belt, which is prone to earthquakes due to the convergence of several tectonic plates. It is the second most seismically active region of the world after the Pacific Ring of Fire [6].

The country has a long history of seismic activity. The North Anatolian Fault (NAF) is a major fault line that extends across northern Turkey. It has been responsible for several large earthquakes, including the 1999 Izmit and 2011 Van earthquakes. The NAF remains a significant source of seismic activity in the country [55] (Fig. 5).

### 4.4.1 House Features

The Himis houses fall in the traditional timber-laced masonry. The house is a half-timbered construction known by different names worldwide. It is a timber-laced construction with brick-and-mortar infills between the timber members. Timber is the most critical component of the construction. The walls are 10–12 cms thick [23].

The construction and relevance of individual components of the construction is defined below:

**Fig. 5** Traditional Himis building standing while modern reinforced concrete building collapsed during 1999 Druze earthquake [15]

Roof

The roof of the Himis is intentionally made to be a lightweight timbered roof. Traditionally the roofs had no trusses and had a “post and beam” system [44]. Rafter systems, spaced closely together with or without a central ridge beam, were laid over horizontal beams that ran longitudinally at approximately the midpoint or a third down the length of the rafter. These intermediate beams were supported by angled posts, or struts, that terminated at a central horizontal beam, known as bedding, which sat atop the tie beams of the roof. The ridge beam was sustained by vertical posts arising from the central beam. To bolster the structure further, collar beams were occasionally employed. Although the resultant configuration mimics a truss-like appearance, it does not reflect the true structural purpose of the roofing system. Finally, the entirety of the roof was overlaid with clay or natural stone tiles on boards directly fastened to the rafters [44].

Walls

Turkey has an abundance of timber available locally, because of which the use of timber in housing grew [49]. The Himis vernacular is a composite construction system using timber, adobe, stone, or brick. The upper floor is usually constructed as timber-framed, with bricks, mud bricks or stones as infills. The walls of the timber framing consist of vertical posts bound together externally with horizontal timber lathes called the Baghdadi, all connected through nailed joints. All of those features provided an outstanding resistance to the lateral stresses that the structure is subjected to as a result of the seismic loads [51].

Foundation

The foundation of the Himis house is shallow and made of stone masonry [44].

### 4.4.2 Building Material

The main material used for the construction is Timber and fired bricks. The houses also include stone masonry for the foundation. The masonry is held together by clay. All of the material for the houses is available locally [44].

## *4.5 Bure Houses, Fiji*

Fiji experiences recurring seasons of tropical cyclones. In February 2016, Tropical cyclone Winston, categorised as level 5, struck Fiji, resulting in destruction of nearly

**Fig. 6** Navala village, Fiji [17]

30,000 homes affecting 62% of the Fijian population [42]. Most of the destroyed houses were made with timber frames and had pitched roofs with steel sheets on top. The damage primarily resulted from powerful wind gusts destroying the roof.

The Traditional Village of Navala is located on the Viti Levu island of Fiji. The Village consisted of 130 houses, 99 of which were constructed as traditional bures. After the cyclone, 26 dwellings were reported to be damaged, with no fatalities [20].

Fiji, located in the South Pacific, faces a significant threat from tropical cyclones. The country experiences an average of two to three cyclones yearly, with the peak season typically occurring between December and March. These cyclones bring powerful winds, heavy rainfall, storm surges, and potential flooding, posing a considerable risk to the islands. The impact of cyclones can be devastating, resulting in infrastructure damage and, most importantly, damage to houses (Fig. 6)

### 4.5.1 House Features

According to Fujieda [41] Bure house is of a rectangular plan constructed over an elevated rubble foundation. The Bure is mainly a timber-framed structure with two main designs. One design has a middle king post, with wall posts spaced equally, the other model is smaller without the king post. Bamboo mats are used for the external walls. The roof rafters are made from timber, and bamboo is used for purlins. The roofing material consists of a thick layer of thatching tied down to the purlins. All the structural components are tied together using ropes with tap joints. All the materials used for constructing the Bure house are from the surrounding environment, making it easy to build, repair and maintain.

The construction and relevance of individual components of the construction is defined below:

#### Roofs

The hipped roof provides an outstanding dispersion of wind loads on the roof framework. Extensive research spanning decades has substantiated that a hipped roof surpasses a gabled roof in the event of hurricanes. The critical negative pressure exerted on the roofs diminishes as the inclination angle increases. Regarding the roof support system, reports indicate the pressure exerted on the entire span of the gabled roof structure is twice as substantial as that experienced by the span of a hip roof when subjected to comparable wind velocities. Consequently, hipped roofs are deemed superior to gabled roofs in withstanding high wind conditions [17].

#### Walls

The walls in the Bure houses are short and have a low centre of gravity achieved by making the bottom part of the walls heavier than the top part. As the cyclone blows against a wall and exerts positive pressure on the face wall and negative pressure on the leeward side, the short walls mean the wind has a smaller area to act upon. The location of the building also governs the regulation of wind pressure with respect to valleys and hills. The openings on the walls are kept to a minimum with wooden shutters on top [17].

#### Foundation

Continuous foundation under the houses was found to be problematic, causing uplifting, and overturning in some cases. Elevated stone foundations proved to be effective, along with timber posts that are treated with preservatives and piled deep into the ground [17].

### 4.5.2 Building Material

In Fiji, traditional Bure houses are typically constructed using natural and locally sourced materials. The primary Material used for the framework is wood, often obtained from indigenous timber species such as vesi (Intsia bijuga) or dakua (Dysoxylum richii). These timbers are known for their strength and durability. The walls of Bure houses are commonly made from woven or woven bamboo panels, which provide ventilation while maintaining structural integrity. The roofs are traditionally thatched with sago palm leaves or sugarcane leaves [17].

## *4.6 Gaiola Pombalina, Lisbon Portugal*

Portugal is an earthquake-prone country. One of the biggest earthquakes in the history of Portugal was in November 1755, registering 8.7 on the Richter scale, destroying Lisbon city almost entirely [39].

The earthquake was followed by a tsunami which in turn was followed by a massive fire that kept burning for weeks [39], causing havoc to an already destroyed city. Downtown Lisbon was most affected by the earthquake.

Immediately after those incidents, a new urban policy was established, which led to the enforcement of new construction rules aimed at making the new construction resistant to hazards like earthquakes, fire, and flood [39].

The new construction that was done based on this newly established urban policy is called "Pombalino" construction which enforced a maximum of three stories per construction.

The floors are made of timber boards on timber joists, which act as diaphragms [7]. The roof has a timber truss covered by ceramic tiles. Another necessary provision is a thick masonry wall between adjacent buildings higher than the roof to stop a fire from propagating.

Lisbon is an area where tectonic plates meet, making it prone to seismic activity. The region lies on the boundary between the Eurasian Plate and the African Plate, known as the Azores–Gibraltar Transform Fault. This fault line is responsible for the movement and interaction between these two plates, leading to frequent seismic events. The other threat to Lisbon is the presence of the Tagus River, which has caused a lot of flooding in Lisbon and keeps the water table high, making moisture another threat to the housing (Fig. 7).

### 4.6.1 House Features

The Gaiola construction is called the cage construction [23]. It is a three-dimensional timber-framed construction with horizontal and vertical members forming small squares with internal x-shaped braces. The frame is wrapped in masonry which is made of stone rubble and broken bricks [23]. The timber frame is only above the ground frame to prevent fire from the fire places in the ground floor [7]. Another feature is a wall that goes over the roof surface to prevent fires from propagating between buildings [7, 12]

The construction and relevance of individual components of the construction are defined below.

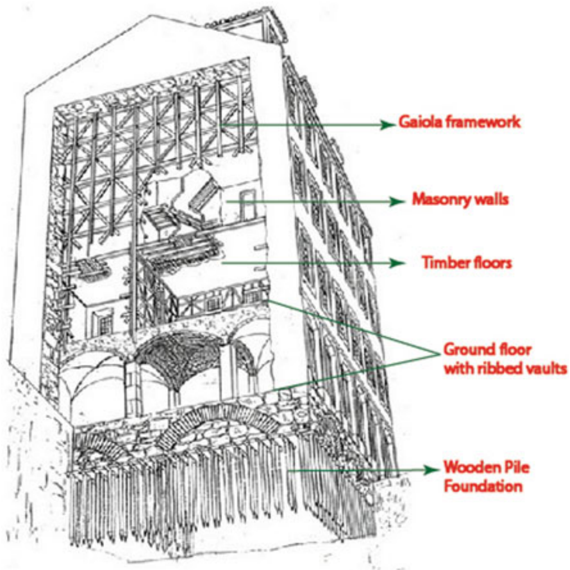


**Fig. 7** Gaiola Pombalina framework [36]

Roofs

Roofs are constructed using wooden frameworks and clay tiles and might incorporate window openings. The Roofing consists of timber trusses that work as a diaphragm. One of the measures involves incorporating substantial stone walls that surpass the height of the roof's wooden framework between adjacent structures. This precautionary step aims to impede the spread of fire between buildings. This masonry wall has no opening. A steel ring beam is attached to the roof along the eves as a measure for seismic strengthening. The roof typically has openings that can be both doors and windows to the attic under the roof.

Walls

The most critical feature of these Pombalina housing is the 3-dimensional interior wall timber structure known as Gaiola, which looks like a cage with horizontal and vertical members laced together by diagonals (called Gaiola; hence the name Pombalina Gaiola) which resists the horizontal force during an earthquake.

The timber members are usually notched together or braced with nails. The masonry infills on these interior walls are usually stone rubble (initially taken from the earthquake rubble) [7].

The other walls, including façade and partition walls, are single-leaf masonry and can be distinguished from the Gaiola walls by the thickness, which is between

18–25 cm on Gaiola walls and 10–15 cms on the others. These walls do not have any structural function [12].

Foundation

This construction developed has short and small dimension timber piles in the foundation laced together by a timber frame. The ground floor had ribbed ceramic vaults with stone masonry arches. These served multiple purposes. The ground floor was mails used for commercial establishments like shops which often had fireplaces. The stone masonry would prevent that fire from reaching to the upper floors in case of a breakout. These masonry vaults also prevented the damping of the timber in the upper floors in case of a flood or the moisture from the high water table due to the Tagus river [7].

### 4.6.2 Building Material

The materials used in the construction include wooden panels for internal walls. The roofs are made from timber, and the tiles are made from ceramic. The ground floor is made of masonry of ceramic and stone. The exterior walls are made of calcareous stone and lime mortar. The infill is usually stone rubble or clay bricks and broken roman bricks [7].

## *4.7 Taquezal and Bahareque, South America*

In several countries of Central America, there exists a distinct variation of the infilled timber-frame system. This system, known as Taquezal in Nicaragua and Bahareque in El Salvador, is believed to have originated from a combination of indigenous Native American construction techniques and the incorporation of timber and masonry infill-frame practices observed in parts of Europe, including Spain. These types of buildings, once predominant in the Nicaraguan capital of Managua, constituted around 85% of the city's structures in 1932. Following the earthquake of 1931, American engineer J. R. Freeman noted the similarity between Taquezal construction and the Baraccata style developed in Southern Italy a century ago, highlighting its resilience against collapse and the protection it provides to occupants [19] (Fig. 8).

In the 1971, earthquake there was a substantial transformation. More than half of the Taquezal buildings in and around Managua either collapsed or sustained heavy damages contributing significantly to the elevated mortality rates and as a result the Earthquake Engineering Research Institute (EERI) advocated for the prohibition of Taquezal construction [30].

A crucial observation was made while examining damage caused by the October 10, 1986, earthquake in El Salvador. The analysis revealed that structural failures in


**Fig. 8** Plaster shaken off a Bahreque house [27]

bahareque buildings were predominantly due to wood decay or termite infestation. The structures with the most significant damage exhibited the highest level of rot or infestation.

Interestingly, as early as 1932, Freeman had foreseen the challenge of wood decay expressing concern about the climate of Managgua progressively weakening the structures and the infiltration of termites [19]. By 1972, the Taquezal buildings in Managua were considerably older than in 1931. Less resilient softwoods from North America had replaced the tropical hardwoods used initially. Therefore the indications imply that the predominant factor contributing to the failures in this system was not an inherent flaw within the structure but rather environmental influences and inadequate maintenance [32].

### 4.7.1 House Features

In these houses, a sturdy timber frame featuring post-and-beam construction is assembled, with the walls positioned within this frame made up of studs roughly 25 inches apart. This solid timber framework comprises hardwood posts positioned at wall intersections and corners. Wood lath or bamboo is subsequently fastened across these studs, creating a basket-like formation and filling pockets with multiple layers of small stones. The wall is typically completed with a finishing coat of either mud or lime plaster [32].

The construction and relevance of individual components of the construction are defined below.

Roof

Typically, the roof is made of palm tree strands, laying on top of wood frames. This practice was changed in the colonial period by replacing the palm tree fronds with clay tiles on wooden frames, but this resulted in lessening the seismic resistance capability of the structure because the clay tiles made the roof heavier and thus resulted in it digging into the mud on the walls thereby making the structure rigid and compromising the earthquake resistance capability [46].

Walls

Taquezal and Bahareque structures are characterised by the assembly of a robust post-and-beam timber frame, wherein the walls are comprised of uniformly spaced studs. This substantial timber framework incorporates hardwood posts strategically placed at corners and intersections of walls. Over the studs, a lattice-like structure is fashioned by affixing wood lath or bamboo. The ensuring spaces are subsequently filled with layers of small stones, identified as Taquezal con piedra, or adobe, known as Taquezal con barro terra. To complete the wall surface, a final layer of mud or lime plaster is typically applied [32, 37].

Foundation

One of the essential features of earthen earthquake-resistant housing is the foundation, which is true for Bahareque and Taquezal. In the case of Bahareque, shallow ditches are dug around the boundary walls, and the posts are placed in them; the ditches are filled with rocks. Although low cost, This type of foundation helps keep the structure dry by not allowing surface water to seep up [46].

### 4.7.2 Building Materials

The material used for the construction is readily available in the dry forests of South America [40]. All the timber for frames and roofs, stones for foundations, bamboo for the walls, clay for the adobe and the palm tree branches are all obtained from locally available resources.

### 4.8 Quincha Houses, Peru

Peru is yet another dangerously earthquake-prone country. With at least 10 seismic events causing minor damages and one major seismic event causing destruction every 10 years. In 1912, Earthquake in Peru destroyed 99% of the building in Piura in Peru [9].

So a variation of Taquezal and Bahareque was developed in Peru called Quincha, a form of Wattle and daub construction. This construction method is very common in the south American belt of earthquake-vulnerable countries with proof of its traditional existence [9] and development in Peru by the Portuguese architect Constantino de Vasconcelos. But the construction method varies with each country in the region depending mainly on the types of local Material available. But the fundamental principals of the construction remain primarily the same [9] (Fig. 9).

#### 4.8.1 House Features

The construction features of the Quincha house are the same as other construction methods in Central and South America, like Taquezal and Bhareque. The construction process is different in all countries depending on locally available materials.

**Fig. 9** Under construction Quincha house with wood and clay walls [11]

The fundamental construction method has bamboo or tree branches set up into a mesh of horizontal and vertical members, plastered on top with mud. The plaster on top varies with the location [11].

Roof

The roofing framework of the quincha house is crafted from the branches of the locally available carob trees. These branches, that are used as beams, provide the foundation for a covering on top made from slender branches and twigs of the same tree. This structure is then enveloped by a composite material of clay and straw, cut into small pieces. Sometimes, people use baked clay tiles or corrugated metal sheets instead of the clay and straw mat [9].

Walls

Quincha walls have a foundational framework. Wooden posts, that are made of trunks of locally available carob or cherry trees are embedded in to the ground. Beams made of the branches of the same tress with smaller diameters tied on top of the posts using wire, ropes or nails depending on availability in the region. The open space is filled vertically with small branches that are tied to the horizontal beams in the frame. The wall frame is then covered with a mixture of mud and straw called daub [11].

Foundation

Traditional Quincha foundation did not have a specially prepared foundation and it does not require a foundation because of the light weight of the structure. Recently, a shallow concrete slab has been put in place for a foundation [11].

### 4.8.2 Building Material

The material used in Quincha houses varies from region to region based on what materials are locally available but, the basic idea behind using materials remains constant. A mesh with horizontal and vertical members made of cane, tree limbs or small branches. This mesh is plastered with mud in a combination of earth and water. The mesh and the plaster have different variants depending on the location in Central America, but the principle remains the same [11].

**Fig. 10** Traditional Bhunga house [56]

## *4.9 Bhunga Houses, Gujrat*

Bhunga houses are traditional homes made of clay and bamboo, which are prevalent in the Kutch region of India. These houses have been in use for several centuries and have proven to be highly resistant to natural disasters such as earthquakes and high-speed winds [54].

The design of the Bhunga house is unique. It is a perfect example of how traditional construction methods can be used to build sustainable and disaster-resistant homes.

The Bhunga house's natural hazard resistance capabilities have been tested several times and emerged unscathed every time. In 2001, a massive earthquake measuring 7.7 on the Richter scale hit the Kutch region, and many modern concrete houses collapsed. However, the traditional Bhunga houses remained standing with minimal damage [13] (Fig. 10).

### 4.9.1 House Features

The Bhunga house is an excellent example of how traditional construction methods can be used to build sustainable, eco-friendly homes resistant to natural hazards. The circular shape, dome-like structure, mud and clay walls, bamboo framework, thatched or tiled roofs, natural ventilation system, raised platform foundation, and proper door and window placement make it a highly resilient and durable structure.

These houses are an excellent alternative to modern concrete structures that are expensive, environmentally harmful, and prone to collapse during natural disasters.

The construction and relevance of individual components of the construction are defined below.

The roof of the Bhunga house is the most crucial part of the structure, as it must bear the brunt of the strong winds and rain. The traditional Bhunga house's roof is made of thatch, a natural material that can withstand strong winds. However, modern Bhunga houses now have tiled roofs, which offer better protection against cyclones and heavy rain. The roofs of the Bhunga house have a conical shape making the ceiling high, and the roof is low at the periphery. Its made of thatch, making it lightweight and helps against the lateral forces of earthquakes [13].

Walls

The Bhunga house's circular shape and dome-like structure are the primary reasons for its durability and resistance to natural hazards. No stones or aggregates are available in this region; therefore, the main material for the construction of the walls is mud and thatch, both of which are available locally, along with bamboo for the framework [24]. The mud walls are made of rammed earth put on a bamboo framework plastered by lime and painted on top with decorative cultural patterns [49].

The height of the walls in a Bhunga house is low to help it stay stable during an earthquake. The Bhunga house walls are made without any connection to any other adjacent structures and have no common wall system, so no transfer of load from one wall to another occurs during an earthquake [13].

Foundation

The Bhunga house's foundation is built on a raised platform made of mud, which keeps the house above ground level, reducing the risk of waterlogging during floods [24].

### 4.9.2 Building Material

The area in Gujarat where the Bhunga house is found is an arid desert, and no stones and aggregates are available in this region for the construction of houses; therefore, only thatch, mud, and bamboo are used for construction because of being readily available [24].

## 5 Discussion

All the reviewed traditional architectures comprise composite structures that utilise different materials to construct the house. Timber was the most commonly used material among all the different architectures. Timber frames in the walls and roofing were used in constructing the Dhajji-Dewari [4], the Bhatar [43], for the roofing structure in the Ghumauro Dhi, and the stilts and the whole structure of the Rajbanshi house [22]. Furthermore, the traditional Bure houses used different types of timber for the walls and the roof structures [20]. Timber framing was the most common practice in the natural hazard-resilient vernaculars discussed above. The use of timber framing in most of the above-discussed vernaculars indicates that timber-framed construction subdivides the walls into smaller units with horizontal and vertical members mixed with weak mud mortar, preventing large cracks from happening under seismic loads. The essential idea behind this frail yet adaptive construction is its lack of rigid, robust components that would otherwise draw the complete brunt of the earthquake. Hence, these buildings endure seismic events by not interacting with them entirely. Put differently, even though the brickwork and mortar used in some structures are prone to breaking, the overall system exhibits ductile behaviour.

The quality and safety of traditional structures are not solely determined by technical expertise but rather by factors such as the local economy, availability of labour and materials, accessibility to specialised traditional knowledge, and the meticulousness of inspections. This holds especially true for traditional timber frame structures requiring frequent and scrutinised inspections to prevent collapse from concealed defects. In most cities affected by earthquakes implementing stricter engineering standards won't suffice. In numerous developing nations, advanced engineering techniques and consistent material quality are beyond reach for most ongoing construction projects. We can foster a more durable and sustainable link with our cultural heritage by appreciating the strengths of simpler, hand-built structures that were more resilient even before modern machinery and materials. This is a more valuable perspective than viewing these pre-modern examples simply as outdated remnants.

The vernaculars were subjected to different types of hazards; however, timber was still the commonly used construction material, which points out the importance of timber as a versatile construction material. Another common aspect for all the reviewed vernaculars was that all used resources were locally available.

The locally available Material was mixed with the indigenous house-building knowledge to form houses that responded to local hazards. In the Dhajji-Dewari [4] and the Bhatar [47], the timber lacings used for either adobe or stone walls provided seismic resistance. In the Ghumauro dhi, the cylindrical feature of the house provided the required seismic resistance in addition to the light weighted roofing structure. The Rajbanshi vernacular, located in a flood-prone area, was built on stilts up to three meters high, preventing the house from floods [22]. The Himis vernaculars with the vertical timber wall posts interconnected horizontally and diagonally provided a unique seismic resistance in addition to the stone foundation and the light, superstructure and roofing Material [2]. As mentioned by the residents of the Navala village

[17], the Fijian Bures are designed to provide slight movement when subjected to strong wind gusts resulting from tropical cyclones. This feature was implemented using rope-tied connections. Also, these are designed to facilitate house rebuilding using the same material in case of being damaged by a cyclone.

## 6 Conclusion and Further Research

Traditional building methods are being developed and used over a long period. Throughout the years, the traditional buildings were constructed in a way that made them adaptable to different environmental conditions. To create resilient communities, we must use locally available materials best and adopt traditional knowledge that has stood the proof of time and its concept's validity.

The study reviewed traditionally built houses that showed impressible performance, surviving different natural hazards with either minor or no damages. The Dhajji-Dewari and Bhatar vernaculars that survived the Pakistan 2005 earthquake. The Himis traditional house construction survived many earthquakes, and the Fijian Bure showed resiliency after the TC Winston of 2016.

As per the review, most of the traditional houses in this study were constructed using indigenous knowledge to respond to the typical natural hazard in its area; all of the vernaculars have survived over the years with minor or no damage. Also, most of the construction materials used were provided locally as naturally available materials, which proves the sustainability of the concept.

The study suggests considering the indigenous knowledge existing in the disastrous areas and adopting or incorporating the traditional local expertise in the post-disaster reconstruction projects as a superior option to the contemporary designs.

Further investigation will be carried out to study post-disaster reconstruction projects that used traditional building methods, analyse the material used for any structural modifications, and measure its resilience compared to reconstruction using modern construction methods.

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## References

1. Adhakari BR (2013) Flooding and inundation in Nepal Terai: issues and concerns. Hydro Nepal: J Water, Energy Environ 12:59–65
2. Aktaş YD (2017) Seismic resistance of traditional timber-frame hımış structures in Turkey: a brief overview. Int Wood Prod J 1–8. https://doi.org/10.1080/20426445.2016.1273683

3. Ali Q, Ahmad N, Ashraf M, Rashid M, Schacher T (2017) Shake table tests on single-story Dhajji-Dewari traditional buildings. Int J Architectural Heritage 11(7):1046–1059
4. Ali Q, Schacher T, Ashraf M, Alam B, Naeem A, Ahmad N, Umar M (2012) In-plane behavior of the Dhajji-Dewari structural system (wooden braced frame with masonry infill). Earthq Spectra 28(3):835–858. https://doi.org/10.1193/1.4000051
5. Bank W (2015) Nepal—earthquake post disaster needs assessment: sector reports (No. 97501)
6. Basu M (2023) All about the Alpide belt that makes Turkey a hotbed for devastating earthquakes News magazine. The Print. Retrieved from https://theprint.in/world/all-about-the-alpide-belt-that-makes-turkey-a-hotbed-for-devastating-earthquakes/1357347/
7. Bento R, Cardoso R, Lopes M (2004) Earthquake resistant structures of Portuguese old 'pombalino' buildings. Paper presented at the 13th world conference on earthquake engineering, paper
8. Bodach S, Lang W, Hamhaber J (2014) Climate responsive building design strategies of vernacular housing in Nepal. Energy Build 81. https://doi.org/10.1016/j.enbuild.2014.06.022
9. Camilloni HR (2003) Quincha architecture: The development of an antiseismic structural system in seventeenth century Lima. Paper presented at the proceedings of the first international congress on construction history, Madrid, 20th–24th Jan, 2003
10. Carabbio R, Pieraccini L, Silvestri S, Schildkamp M (2018) How can vernacular construction techniques sustain earthquakes: the case of the Bhatar buildings. Front Built Environ 4:18
11. Carbajal F, Ruiz G, Schexnayder CJ (2005) Quincha construction in Perú. Pract Period Struct Des Constr 10(1):56–62
12. Cardoso R, Lopes M, Bento R, D'Ayala D (2003) Housing report historic, braced frame timber buildings with masonry infill ('Pombalino' buildings)
13. Choudhary ATSA (2016) Approach to sustainable architecture through vernacular practices: a case study of dwelling in village of Madhya Pradesh and Gujarat
14. Dhandapany D, Menon A (2019) Seismic behavior of timber-laced masonry structures in the Himalayan belt. Structural analysis of historical constructions: an interdisciplinary approach, pp 605–613
15. Doğangün A, Tuluk Ö.İ, Acar R, Livaoğlu R (2005) Traditional wooden buildings and their damages during earthquakes in Turkey
16. Dy GA, Naces MLP (2016) Rebuilding with a heart: architecture roles in post-disaster psychosocial interventions. J Archit Urban 40(1):2–7. https://doi.org/10.3846/20297955.2016.1159533
17. Elkharboutly M, Wilkinson S (2022) Cyclone resistant housing in Fiji: the forgotten features of traditional housing. Int J Disaster Risk Reduction 82:103301
18. ERRA (2006) Rebuild, Revive with Dignity and hope. Retrieved from Pakistan http://erra.gov.pk/Reports/ERRA-Review-200506.pdf
19. Freeman JR (1932) Earthquake damage and earthquake insurance: studies of a rational basis for earthquake insurance, also studies of engineering data for earthquake-resisting construction. McGraw-Hill book company
20. Fujieda A, Kobayashi H (2013) The potential of Fijian traditional housing to cope with natural disasters in rural Fiji. J Disaster Res 8(1):18–27
21. Gautam D, Prajapati J, Paterno KV, Bhetwal KK, Neupane P (2016) Disaster resilient vernacular housing technology in Nepal. Geoenvironmental Disasters 3(1):1. https://doi.org/10.1186/s40677-016-0036-y
22. Gautam D, Prajapati J, Paterno KV, Bhetwal KK, Neupane P (2016) Disaster resilient vernacular housing technology in Nepal. Geoenvironmental disasters
23. Gülkan P, Langenbach R (2004) The earthquake resistance of traditional timber and masonry dwellings in Turkey. Paper presented at the 13th world conference on earthquake engineering
24. Gupta J, Mazumdar S (2016) Study of local bhunga houses in Kutch adapting to desert climates in a sustainable way, with reference to modern green building norms followed in India. Arch Time Space People 34–40
25. Hicyilmaz TWK (2011) Seismic performance assessment of Dhajji-Dewari building system. ARUP

26. Hicyilmaz K, Bothara JK, Stephenson M (2011). Dhajji-Dewari. Housing report. World housing encyclopaedia available at: http://www.world-housing.net/asia/india/report-146-dhajji-dewari
27. Holliday L, Kang THK, Mish KD (2011) Taquezal Buildings in Nicaragua and Their Earthquake Performance
28. Hughes R (2005) Vernacular architecture and construction techniques in the Karakoram. *Karakoram: Hidden Treasures in the Northern Areas of Pakistan*, 99–132
29. Ibrahim SH, Liew AAH, Nawi MNM, Yusoff MN (2015) Reinventing traditional Malay house for sustainable housing design: obstacle and proposed solution. J Teknologi 72(1):97–102. https://doi.org/10.11113/jt.v72.3134
30. Institute EER, Públicas NMDFYO (1973) Managua, Nicaragua earthquake of December 23, 1972: earthquake engineering research institute conference proceedings, vol 1. Earthquake Engineering Research Institute
31. Khadka B, Shakya M (2021) Seismic characteristics of unreinforced mud masonry houses in Nepal: a miserable scenario before and after 2015 Gorkha (Nepal) earthquake. Eng Fail Anal 124:105308
32. Langenbach R (2007) From Opus craticium to the Chicago Frame: earthquake-resistant traditional construction. Int J Architectural Heritage 1(1):29–59
33. Langenbach R (2010) Earthquake resistant traditional construction is not an oxymoron. Paper presented at the proceedings the royal government of Bhutan international conference on disaster management and cultural heritage: living in harmony with the four elements, Thimphu, Bhutan
34. Langenbach R (2016) 1—what we learn from vernacular construction. In: Nonconventional and vernacular construction materials. Woodhead Publishing, pp 3–36. https://doi.org/10.1016/B978-0-08-100038-0.00001-9
35. Langenbach R (1992) Of Taq and Dhajji Dwari: the earthquake resistant mud and brick architecture of Kashmir. Paper presented at the international conference on earthen architecture, Las Cruces, New Mexico
36. Lopes M, Meireles H, Cattari S, Bento R, Lagomarsino S (2013) Pombalino Constructions: Description and Seismic Assessment
37. López M, Bommer J, Méndez P (2004) The seismic performance of bahareque dwellings in El Salvador. Paper presented at the proceedings of the thirteenth world conference on earthquake engineering, Vancouver, paper
38. Manafpour A (2008) Bam earthquake, Iran: lessons on the seismic behaviour of building structures. Paper presented at the 14th world conference on earthquake engineering, Beijing, China
39. Mendonça P (2005) Habitar sob uma segunda pele: estratégias para a redução do impacto ambiental de construções solares passivas em climas temperados. Retrieved from https://repositorium.sdum.uminho.pt/handle/1822/4250
40. Mite-Anastacio F, Tello-Ayala K, García-Troncoso N, Silva CE, Malaga-Chuquitaype C, Arévalo K, Villao D (2022) Structural behavior of cemented bahareque for social housing: a case study in Guayaquil city, Ecuador. Front Built Environ 8:922397
41. Miyaji M, Fujieda A, Veitata S, Kobayashi H (2021) Field research on cyclone damage and housing reconstruction in Fijian village—case study of Navala village after tropical cyclone Winston. Jpn Architectural Rev 4(3):504–514
42. Miyaji M, Fujieda A, Waqalevu SV, Kobayashi H (2017) Challenges for self-recovery from cyclone disasters in a traditional Fijian village: the case of Navala village after tropical cyclone Winston. WIT Trans Built Environ 173:161–172. https://doi.org/10.2495/DMAN170161
43. Mumtaz H, Mughal SH, Stephenson M, Bothara JK (2008) The challenges of reconstruction after the October 2005 Kashmir earthquake. Bull NZ Soc Earthq Eng 41(2):68–82
44. Panoutsopoulou L, Mouzakis C, Tsakanika E (2022) Timber-framed wall construction in mansions of Mainland Greece during the Ottoman period. Int J Architectural Heritage 1–16. https://doi.org/10.1080/15583058.2022.2065223
45. Parajuli H, Kiyono J, Ono Y (2008) Effectiveness of wooden bond beams in dry stone masonry houses. J appl mech 11:615–623

46. Peñalba CU (1981) A review of the seismic behavior of earthen housing in Nicaragua. Paper presented at the conference proceedings
47. Pere DDAP-Y (2007) Build back better—Bhatar background and rationale June 2007
48. Rana BSJB (1935) The great earthquake of Nepal (Nepalko Mahabhukampa) [in Nepali]. Jorganesh Press, Kathmandu
49. Rawool P, Motorwala HF (2019) Proposed collaboration centre for trading of arts and craft, in Kutch-Hujrat
50. Şahin Güçhan N (2007) Observations on earthquake resistance of traditional timber-framed houses in Turkey. Build Environ 42(2):840–851. https://doi.org/10.1016/j.buildenv.2005.09.027
51. Sarwar AR (2006) Reconstruction and rehabilitation planning: Pakistan earthquake experience. Pakistan Horizon 59(4):109–125
52. Schilderman T (2004) Adapting traditional shelter for disaster mitigation and reconstruction: experiences with community-based approaches. Build Res Inform 32(5):414–426. https://doi.org/10.1080/0961321042000250979
53. Stades (2021) Bhunga: the 200-year-old earthquake-resistant mud houses of Kutch society. Retrieved from https://30stades.com/2021/10/17/bhunga-200-year-old-earthquake-resistant-mud-houses-rann-of-kutch-gujarat/
54. Steinberg F (2007) Housing reconstruction and rehabilitation in Aceh and Nias, Indonesia—Rebuilding lives. Habitat Int 31(1):150–166. https://doi.org/10.1016/j.habitatint.2006.11.002
55. The Earthquake- Proof Huts of Kutch
56. Vasconcelos G, Poletti E (2015) Traditional timber frame walls: mechanical behavior analysis and retrofitting. In: Handbook of research on seismic assessment and rehabilitation of historic structures. IGI Global, pp 30–59

# A Bibliometric Analysis of Early Contractor Involvement (ECI) Research in the Construction Industry

**Iresha Dilhani Jayasinghe, Niluka Domingo, An Le, and Regan Potangaroa**

## 1 Introduction

The procurement method plays a significant role in construction projects and entitles over 80% of the contract value [17]. Naoum and Egbu [19] explained that procurement systematically links and coordinates the construction team members, including contractual and functional elements. Therefore, selecting the appropriate procurement method has contributed to the project's success [3, 24]. Boton and Forgues [4] mentioned that the outstanding characteristics of a construction project are the involvement of diverse stakeholders from different organizations and working together for a common goal. There is a developing trend in the construction industry to move toward collaborative approaches and engage the parties early to identify the most impactful solutions in the preconstruction stage [18]. According to [6], the key advantages of increased collaboration are reduced project costs and schedules and better buildability. Moreover, a similar study by Atkinson et al. [3] has proven that cost and time savings, enhanced innovation, stakeholder satisfaction and the prospect of pipeline projects/long-standing relationships are the most cited benefits of collaborative working in construction as in selected studies by the author. Thus, both Bresnen and Mashall [6] and Atkinson et al. [3] studies agreed that there is

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a relationship between the benefits of collaboration and the selected procurement method.

As a result of this scenario, ECI has been introduced to procure construction projects, which have become more prevalent in infrastructure projects [24]. It allows the utilization of the contractor's knowledge of construction and experience in design [28] and establishes long-term relationships among participants. However, Scheepbouwer and Humphries [26] argued that ECI is a hybrid of traditional and collaborative delivery methods. Thus, ECI is a relatively new technique in the construction sector, and it has been introduced as the best alternative with minimal study or testing, with decisions on selecting ECI for a project mainly being judgmental and dependent on decision-makers biases [24]. Therefore, this paper focused on the latest comprehensive literature review in ECI for existing projects to investigate worldwide development, knowledge structure, and research gaps in the ECI in order to gain a comprehensive understanding of various ECI models and their applications. ECI could effectively manage the uncertainty and risk challenges in the construction industry [23], thus, it is worth doing a literature review to identify how ECI helps solve these issues. Accordingly, the following research questions are the focus of this study.

1. What are ECI and ECI approaches?
2. What are the benefits and challenges of the use of ECI?
3. What are the future research trends and implications?

This study is conducting bibliometric analysis in evaluating the ECI research area. Therefore, it follows a structured approach to investigate ECI. The introduction provides a broader picture with scientific context, practical application, existing research contributions, and the paper's objectives. Section 2 then details the research methodology used, which focused on the selection of the literature. Section 3 presents results obtained through science mapping and the key findings are further analyzed in Sect. 4 to identify the leading research focuses. Existing gaps in the literature, together with the potential future directions, conclude in Sect. 5.

## 2 Method

Uncovering the depth of knowledge within any research topic is very important. Therefore, a bibliometric analysis offers a great opportunity to look at the research front and reveal the intricate connections within the research community [11]. Oraee et al. [22] recommended bibliometric analysis for construction industry-related research in order to recognize certain construction-related concepts. As a result, science mapping was used for visualization and analysis of bibliometric networks, while findings were discussed in detail, and interpretation of the research topic was done using qualitative analysis [5]. To construct and visualize the bibliometric networks, VOS viewer, where VOS stands for "Visualization of Similarities", is a

**Table 1** Keywords list used in the literature search

| String | Group | Keyword |
|---|---|---|
| 1 | Obligatory (O) | "Early contractor involvement" OR "early involvement" OR "early contractor" |
| 2 | People | "Contractor*" |
| 3 | Civil construction | "Construct*" OR "building" OR "infrastructure" |

free text mining software that offers basic operations [29]. Further, it has the characteristic of clustering similar and related knowledge from different disciplines [8], thus mapping the knowledge acceptably [29].

While many databases offer comprehensive literature analysis of the literature, focusing on simple reproduction of the findings tends to use a single database [7]. Scopus, a well-established, multi-disciplinary citation repository [36], has been chosen to include more recently published articles in this regard than other online resources, such as the Web of Science. The literature search was conducted on 31 July 2023. Table 1 shows the three separated search strings connected by the Boolean connector, "AND", which are complete enough to provide a comprehensive overview of the topic of the study.

Considered publications on this subject were from the last decade to demonstrate the latest trends of the ECI. The terms were applied across titles, abstracts and keywords to achieve the maximum amount of literature in the database. Figure 1 illustrates the application of the exclusion criteria to the initial retrieved 165 publications. This process enables the review process to focus on the most relevant literature and ultimately enhance the quality of the analysis, as shown in Fig. 1. The snowball approach was applied to extend the search from the references and key authors of the already found literature and to avoid omitting the relevant studies.

# 3 Result

## *3.1 Keywords Co-Occurrence Analysis*

A keywords network was generated to illustrate the facts and rationale of the research studies. In order to acquire a holistic view of the existing research in VOSviewer, "All keyword" and "Full counting" options were selected. The co-occurrence analysis of keywords is done using the 85 selected papers, and the minimum number of occurrences of a keyword selected was 4, and 35 out of 714 keywords with 308 links were generated after adjusting the duplicates such as "early involvement", "early contractor involvement", "integrated project deliveries", and "integrated project delivery". Further, in VOSviewer, the network is divided into clusters where the same studies might fall in the same cluster. Each keyword stands as a circular node and different clusters of words, each marked by a distinct color. The biggest nodes

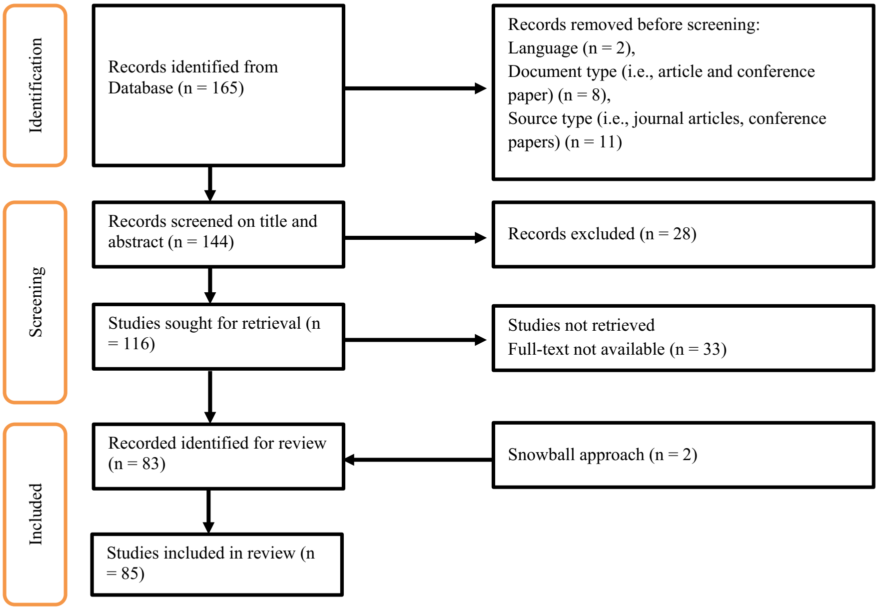


**Fig. 1** Methodology approach

are the most frequent keywords of the research area and the arcs represent the relationship between the keywords. The thickness of each arc indicates the strength of the relationship between connected words.

The network is divided into five clusters. Most studies have been focused on project management, early contractor involvement, contractors, the construction industry (invisible yellow node) and integrated project delivery. Cluster 1 contained 10 items focusing on decision-making, cost–benefit analysis, supply chain, project performance and project delivery. Cluster 2 (9 items) focuses on early contractor involvement, design and construction, collaboration, lean production, and contractors. Next, cluster 3 included eight items relating to buildings, construction management, procurement and critical success factors. Cluster 4 comprised six items addressing the construction industry and ECI models, including integrated project delivery (IPD) and partnering. Finally, cluster 5 (2 items) focused on architectural design and building information modeling (BIM). Figure 2 indicates the connection of keywords and their co-relationship.

## 3.2 *Country Analysis*

The world collaboration map is a way to measure the global influence on scientific research. Commenting on Fig. 3, Australia and the United Kingdom are the countries

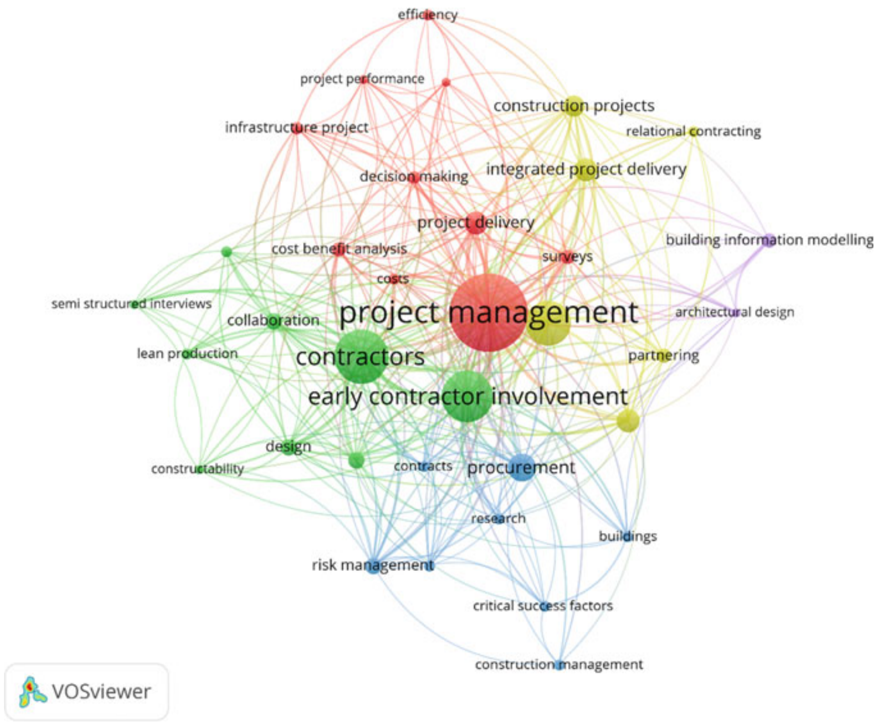


**Fig. 2** Keyword analysis

that contributed the most. Next, the United States, Norway, and Sweden contributed potently to the research. Sweden and Finland are the next-level countries passionate about this field. Finally, as per the results, there is a trend in Hong Kong, China, Malaysia, New Zealand, and the Netherlands on ECI. This graph summarizes that most publications are distributed among developed countries with the capacities and capabilities to adapt to the new challenges faced by their construction industries.

### *3.3 Time Series Analysis*

Figure 4 timeline shows the number of Articles between 2013 and 2022. The most significant factor that emerges from the graph is that between 2016 and 2018, there was a boom in the number of publications. Moving to a more detailed analysis, despite the fluctuations, since 2013, there has been a gradual increment, followed by a peak of 15 journals in 2018. This increase implies that researchers have been more interested in this subject during the last decade. During the COVID-19 pandemic, in 2020 and 2021, there was a slight fall in publications. The year 2022 could be

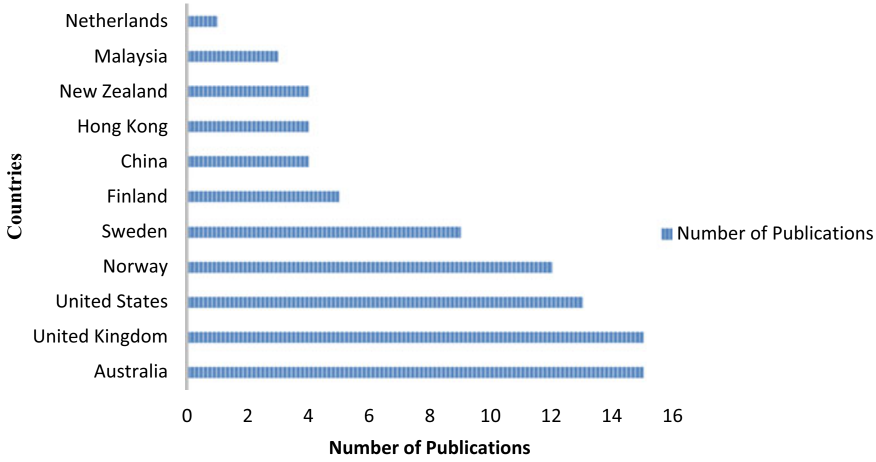


**Fig. 3** Country analysis

identified as a year of scientific rehabilitation as the number of publications has again hit 14; thus, 2023 has a trend to increase.

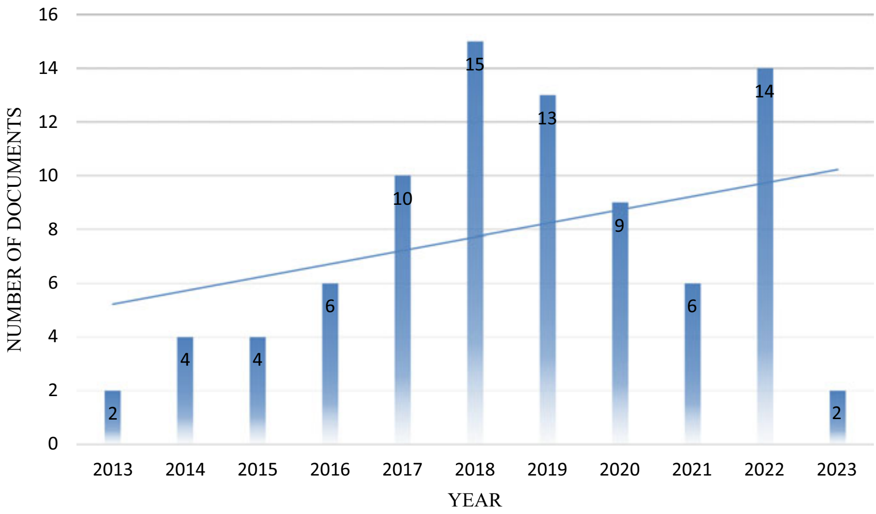


**Fig. 4** Number of relevant papers published in each year

**Table 2** Sources of the journal papers

| Journal title | Number of selected papers |
|---|---|
| Journal of construction engineering and management | 4 |
| Architectural engineering and design management | 4 |
| Buildings | 4 |
| International journal of construction management | 4 |
| International journal of managing projects in business | 4 |
| Engineering construction and architectural management | 3 |
| Construction management and economics | 3 |
| Journal of management in engineering | 2 |
| Procedia engineering | 2 |
| Construction innovation | 2 |
| International journal of construction education and research | 2 |
| International journal of project management | 2 |
| Journal of facilities management | 2 |
| Journal of financial management of property and construction | 2 |
| Proceedings of the institution of civil engineers municipal engineer | 2 |
| Other journals (One article published in each journal) | 21 |

### *3.4 Journal Analysis*

Table 2 includes the sources of research publications on early contractor involvement published in various journals, disregarding conference papers. The journals span various fields, including construction management, economics, civil engineering, design management, innovation, and facilities management. This concludes that the ECI has extended over the facilities management and innovation other than as a project delivery method.

### *3.5 ECI Approaches*

Wondimu et al. [33] conducted a study that identified and classified twenty-five ECI approaches in infrastructure projects. The study found seven groups for infrastructure projects in Norwegian public projects, as in Table 3. Many countries have adopted ECI differently according to their regulations and cultural aspects. For instance, in 2012, the United Kingdom's (UK) construction industry was encouraged by the UK government to use novel approaches by introducing new models of construction procurement (NMCP) [3]. Cost-led procurement (CLP) and two-stage open book are the two models introduced in order to engage supply teams at an early phase of the project and integrated project insurance (IPI) is a pain/gain sharing mechanism

**Table 3** ECI approaches in infrastructure projects

| Classification | ECI Method |
|---|---|
| Basic approaches to ECI | Indirect approaches, information meetings, workshops, direct contracts with specialist contractors, contractors promoting their ideas and front-end partnering |
| Project delivery arrangements | The framework agreement, public–private–partnership (PPP), partnering, integrated project delivery (IPD) and alliance |
| Selection method | Based on qualifications and prices and based on only qualifications |
| Procurement procedures | The negotiated procedure, competitive dialogue (CD) and innovation partnership |
| Alternative solutions | Announced with alternative technical solutions, allowing variant solutions and Idea competition |
| Target cost contracts | Single-stage, two-stage and multiple-stage |
| Contract structures | Design-bid-build (DBB), construction management at risk (CMR), design-build (DB) and novated design and construct contract |

where the proposal developed by the alliance team insured under a single insurance product [3]. The integrated project delivery (IPD) approach is a solution for rapidly developing complex and large infrastructure projects that reduce engineering changes [35]. Moreover, Salim and Mahjoob [25] described that clients' demands had generated the use of IPD with BIM, facilitating the substantial benefits of BIM.

Furthermore, best value procurement (BVP) practices in complex projects where the complex parameters defined by the European (EU) public procurement rules in the European and it has been described as an ECI approach to select the suitable vendor for construction projects in the Norwegian construction industry [21]. Public–private partnerships (PPP) have been combined with ECI to promote risk sharing and build long-term relationships within a trustworthy environment [27]. Another procurement procedure introduced by the EU parliament in 2004 was competitive dialogue (CD) to engage retailers in the early stage of a construction project to stimulate innovations [34]. Project partnering (PP) is another concept that brings relationship-based procurement into the design phases of high-risk construction projects by involving the contractor in the early stages [32].

Figure 5 summarizes how ECI has been demonstrated in different countries. From the graph, Norway has practiced many alternative ECI methods more than other countries. Despite involving the contractor in the early stages, in the workshop procedure, the contractor is involved before the plan approval stage but after the design stage in Germany [33]. Alliance was initially established in Australia and named a pure alliance because selecting the contractors was only based on non-price criteria. However, due to the influence of the EU public regulations, it changed to a competitive alliance where the procurement is done through the CD approach and the most economically advantageous tender (MEAT) is used for selecting the contractors.

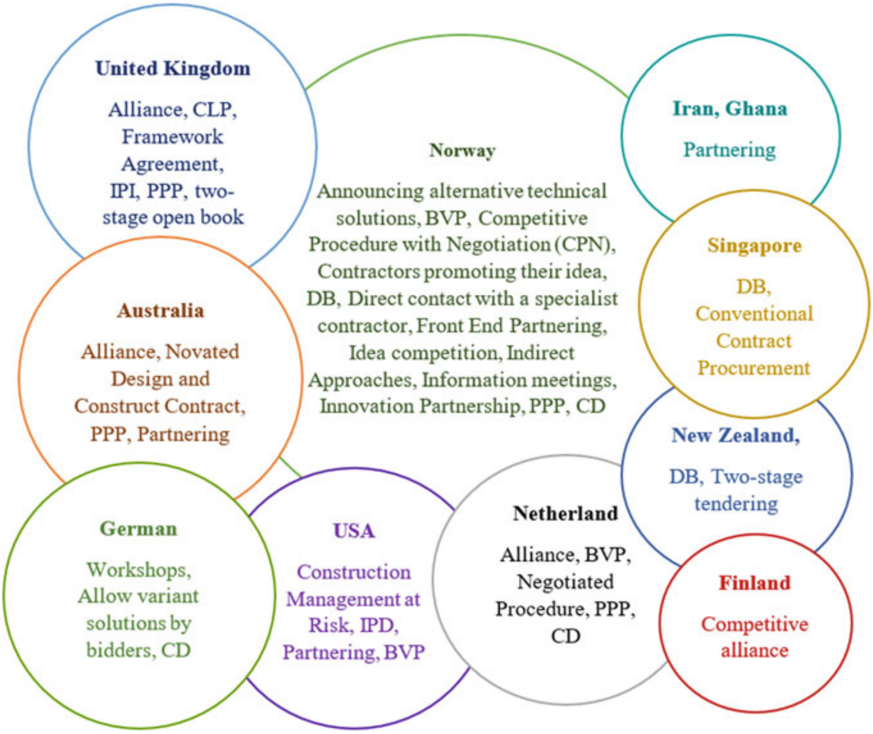


**Fig. 5** Distribution of ECI Worldwide based on [15, 16, 18, 32, 33]

ECI has been introduced to procure construction projects, which have become more prevalent in infrastructure projects [23]. For instance, as per the findings, alliance, BVP, DB, indirect approach, information meetings, partnering and PPP have been used in building projects [33], and other balance approaches have been used in infrastructure projects.

# 4 Discussion

## *4.1 Usage of ECI*

Most studies have evidence that the collaborative environment of the ECI has been adopted mainly on infrastructure projects [10, 14, 31, 34]. This is due to the opportunity to develop design and construction methods early to minimize the cost and delivery risks [12]. The innovative solutions also shed the complexity of infrastructure projects [35]. Notwithstanding the trends of using ECI on complex projects, Nigeria has practiced ECI as an effective cost management tool on low-cost housing projects (LHPs) to enhance the pre-design, design and construction phases of LHPs.

Recently, emerging research areas such as green buildings (GBs), BIM, digital fabrication (DFAB), waste management and off-site manufacturing (OSM) have driven the attention of ECI. A study by ref. [9] identified the early involvement of project participants as a critical success factor for promoting GBs. Green construction projects necessitate collaboration and early participant engagement because of the several designs, extensive simulation and analysis, and novel materials [30]. Next, when considering the DFAB, ECI enables the incorporation of design information for fabrication on the BIM platform in the design stage [20]. Further, ECI is a significant BIM implementation factor recognized by ref. [2]. Ajayi and Oyedele [1] clarified that ECI is not only a procurement method but also a tool for waste management. Freezing the design before execution starts and developing flexible and adaptable designs assist in reducing waste generated from the replacing materials, refurbishment and maintenance activities, respectively [1]. In addition, ECI shrinks the design failures and helps to overcome the cultural confrontation of unfamiliar OSM technologies [13].

There are discrepancies in using the ECI in the construction industry. It challenges scholars to understand the reality of the ECI, as there are discrepancies in using the ECI in the construction industry [23]. Furthermore, ECI is an emerging method in the construction sector, so it has been chosen as a favored alternative without any research or examination. Decisions to use ECI for a project have primarily been based on judgment and decision-maker biases [24].

## *4.2 Benefits of ECI*

ECI has become more prominent due to its benefits throughout the life cycle of the projects. For example, Farrell and Sunindijo [12] state that a competent contractor could positively influence the quality of the outcomes of the construction projects as the contractor gets involved in the early stage. Laryea and Watermeyer [16] express that through ECI, there are opportunities to integrate the design and the construction, leading to an improved schedule. However, the authors argue that this success will depend on the knowledge of the ECI client, the contract type, the flexibility of the team and the contractor's commitment. Adding this, Rahmani [23] mentioned that the joint risk management mechanism helps to improve certainty in the price and the scope of the construction project. Furthermore, ECI enables the primary contractor and sub-contractors to collaborate directly with other stakeholders to ensure the project's success [18].

Further, the integration process of the design and the construction leads to a step up in the collaboration between the project participants as they have to achieve common goals [16]. Rahmani et al. [24] stated that the high certainty and good understanding of the risks positively influenced the relationships, trust, and reliability, reducing mindreading and inaccurate assumptions of the project participants. The collaboration environment enables constructability and innovation as the team players can develop the design and planning together [24].

### *4.3 Challenges of ECI*

However, the contracting practice and teamwork changes make ECI challenging for the construction sector. Rahmani [23] has identified cultural barriers as the most significant challenge because implementing ECI is affected by the contractors' and clients' different cultural expectations. Moreover, the main barriers are the lack of knowledge regarding the ECI and guidance for managing the client–contractor relationship [12]. The result of a study conducted by Rahmani [23] has identified that ensuring value for money, altering the relationship parameters, and inadequate contractor compensation for early-phase involvement were experienced by the stakeholders in the majority of their ECI contracts. Furthermore, Rahmani [23] indicated that negative attitudes spread broadly due to difficulty developing good relationships and trust without previous work relations. In addition, the lack of adequate training for the ECI creates a misunderstanding of critical strategic decisions and degrades the confidence and knowledge of the delivery team in adopting ECI [23]. It is also important to highlight that behaviors and communication protocol in the first stage are inappropriate for the second stage of the ECI process [12].

## 5 Conclusion

The study contributes a niche contribution to an updated systematic literature review in ECI for existing infrastructure projects and little on buildings. The science mapping reveals that ECI is mainly focused on utilizing ECI on infrastructure projects, public clients and characteristics of ECI. For the last five years, the industry has experienced growth in the ECI approaches as little research has covered the studied area. The United States has taken the lead in the research while the UK and Australia have the growth trend, but other countries are on their way to the ECI research. Studies highlighted that the contractor's local regulations and selection method significantly impact the ECI approaches and result in many directions with other aspects. ECI is not a procurement method and plays vital roles in GB, BIM, DFAB, waste management, and OSM.

There are no further studies on these approaches to define the best process for each project. Significantly, there is a lack of studies on utilizing ECI in building construction projects, which will be more challenging than infrastructure projects. In addition, the right time to enter the ECI contracts and the clearly defined responsibilities of ECI parties are little discussed in the selected articles. Finally, a few recent studies discussed mitigating risks in construction projects by involving the contractor early.

Therefore, these findings suggest the need for a decision-making framework for ECI projects for infrastructure and building projects. Moreover, future studies could be done to identify the trends of ECI around the world and conduct more case studies on each approach to define how ECI has been supporting construction projects to overcome risks and achieve the goals of each construction project. As the construction industry's future is under pressure to act effectively with modern technologies, the green building concept has been becoming a trend in the era; therefore, ECI could change with these approaches timely. Further research would also support the industry by effectively studying the adoption of ECI on building projects. These trends accommodate researchers to identify and make ECI more effective. As a result, the study's criteria for selection limit its capacity to offer a new light on future ECI advancements.

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## References

1. Ajayi SO, Oyedele LO (2018) Critical design factors for minimizing waste in construction projects: a structural equation modelling approach. Resour Conserv Recycl 137:302–313. https://doi.org/10.1016/j.resconrec.2018.06.005
2. Al-Ashmori YY, Othman I, Rahmawati Y, Amran YHM, Sabah SHA, Rafindadi ADU, Mikić M (2020) BIM benefits and its influence on the BIM implementation in Malaysia. Ain Shams Eng J 11(4):1013–1019. https://doi.org/10.1016/j.asej.2020.02.002
3. Atkinson RJ, Tennakoon M, Wedawatta G (2022) Use of new models of construction procurement to enhance collaboration in construction projects: the UK construction industry perspective. J Financ Manag Prop Constr 28(1):45–63. https://doi.org/10.1108/JFMPC-02-2021-0016
4. Boton C, Forgues D (2017) The need for a new systemic approach to study collaboration in the construction industry. Procedia Eng 196:1043–1050. https://doi.org/10.1016/j.proeng.2017.08.060
5. Braun V, Clarke V (2022) Thematic analysis: a practical guide. SAGE Publications Ltd., London
6. Bresnen M, Marshall N (2000) Partnering in construction: a critical review of issues, problems and dilemmas. Constr Manag Econ 18(2):229–237. https://doi.org/10.1080/014461900370852

7. Bryman A, Buchanan DA (2009) The Sage handbook of organizational research methods. SAGE Publications Ltd., London
8. Bui T, Domingo N, MacGregor C, Wilkinson S (2022) Zero carbon refurbishment for existing buildings: a literature review. IOP Conf Ser: Earth Environ Sci 1101(2):022017. https://doi.org/10.1088/1755-1315/1101/2/022017
9. Chen L, Chan APC, Owusu EK, Gao X (2022) Critical success factors for green building promotion: a systematic review and meta-analysis. Build Environ 207:108452. https://doi.org/10.1016/J.BUILDENV.2021.108452
10. Chen L, Manley K, Lewis J, Helfer F, Widen K (2018) Procurement and governance choices for collaborative infrastructure projects. J Constr Eng Manage 144(8):10, 04018071. https://doi.org/10.1061/(asce)co.1943-7862.0001525
11. El Baz J, Iddik S (2022) Green supply chain management and organizational culture: a bibliometric analysis based on scopus data. Int J Organ Anal 30(1):156–179. https://doi.org/10.1108/IJOA-07-2020-2307
12. Farrell A, Sunindijo RY (2022) Overcoming challenges of early contractor involvement in local government projects. Int J Constr Manag 22(10):1902–1909. https://doi.org/10.1080/15623599.2020.1744216
13. Finnie D, Ali NA, Park K (2018) Enhancing off-site manufacturing through early contractor involvement (ECI) in New Zealand. Proc Inst Civil Eng: Manage, Procurement Law 171(4):176–185. https://doi.org/10.1680/jmapl.17.00029
14. Hällström AA, Bosch-Sijtsema P (2020) Collaboration and relationships in Nordic infrastructure project networks. Proceedings of the 36th annual ARCOM 2020, UK, pp 245–254
15. Högnason GO, Wondimu P, Lædre O (2019) Best value procurement (BVP) in Norwegian construction projects. Periodica Polytech Archit 50(1):12–20. https://doi.org/10.3311/PPar.12862
16. Laryea S, Watermeyer R (2016) Early contractor involvement in framework contracts. Proc Inst Civil Eng-Manage, Procurement Law 169(1):4–16
17. Lester A (2021) Project management, planning and control: managing engineering, construction and manufacturing projects to PMI, APM and BSI standards, 8th edn. Elsevier, pp 295–337
18. Malvik TO, Wondimu P, Kalsaas BT, Johansen A (2021) Various approaches to early contractor involvement in relational contracts. Procedia Comput Sci 181:1162–1170
19. Naoum S, Egbu C (2015) Critical review of procurement method research in construction journals. Procedia Econ Finan 21:6–13. https://doi.org/10.1016/S2212-5671(15)00144-6
20. Ng MS, Graser K, Hall DM (2023) Digital fabrication, BIM and early contractor involvement in design in construction projects: a comparative case study. Architectural Eng Des Manage 19(1):39–55. https://doi.org/10.1080/17452007.2021.1956417
21. Nygård EF, Wondimu P, Lædre O (2019) Best value procurement—experiences from the execution phase. In: Annual conference of the international group for lean construction, pp 109–120. https://doi.org/10.24928/2019/0170
22. Oraee M, Hosseini MR, Palliyaguru R, Tivendale L (2018) Bibliometric analysis of published studies in ASCE construction research congress, USA. Proceedings of the construction research congress, pp 13–23. https://doi.org/10.1061/9780784481301.002
23. Rahmani F (2021) Challenges and opportunities in adopting early contractor involvement (ECI): client's perception. Architectural Eng Des Manage 17(1–2):67–76. https://doi.org/10.1080/17452007.2020.1811079
24. Rahmani F, Khalfan M, Maqsood T (2022) A conceptual model for selecting early contractor involvement (ECI) for a project. Buildings 12(6). https://doi.org/10.3390/buildings12060786
25. Salim MS, Mahjoob AMR (2020) Integrated project delivery (IPD) method with BIM to improve the project performance: a case study in the Republic of Iraq. Asian J Civil Eng 21(6):947–957. https://doi.org/10.1007/s42107-020-00251-1
26. Scheepbouwer E, Humphries AB (2011) Transition in adopting project delivery method with early contractor involvement. Transp Res Rec 2228(1):44–50. https://doi.org/10.3141/2228-06

27. Solheim-Kile E, Wald A (2019) Extending the transactional view on public-private partnership projects: role of relational and motivational aspects in goal alignment. J Constr Eng Manag 145(5):04019030. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001643
28. Song L, Mohamed Y, Abourizk SM (2009) Early contractor involvement in design and its impact on construction schedule performance. J Manag Eng 25(1):12–20. https://doi.org/10.1061/(ASCE)0742-597X(2009)25:1(12)
29. Van Eck NJ, Waltman L (2014) Visualizing bibliometric networks, measuring scholarly impact: methods and practice. Springer International Publishing, pp 285–320. https://doi.org/10.1007/978-3-319-10377-8_13
30. Venkataraman V, Cheng JCP (2018) Critical success and failure factors for managing green building projects. J Archit Eng 24(4):04018025. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000327
31. Wang R, Samarasinghe DAS, Skelton L, Rotimi JOB (2022) A study of design change management for infrastructure development projects in New Zealand. Buildings 12(9):1486. https://doi.org/10.3390/buildings12091486
32. Wondimu PA, Hosseini A, Lohne J, Laedre O (2018) Early contractor involvement approaches in public project procurement. J Public Procurement 18(4):355–378. https://doi.org/10.1108/JOPP-11-2018-021
33. Wondimu PA, Klakegg OJ, Lædre O (2020) Early contractor involvement (ECI): ways to do it in public projects. J Public Procurement 20(1):62–87. https://doi.org/10.1108/JOPP-03-2019-0015
34. Wondimu PA, Lohne J, Lædre O (2018) Competitive dialogue in Norwegian public infrastructure projects. J Constr Eng Manag 144(10):05018011. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001540
35. Zhang Y, Hu H (2020) Data envelopment analysis based efficiency measurement of engineering change controlling for infrastructure construction under integrated project delivery mode. IET Intel Transport Syst 14(11):1433–1439. https://doi.org/10.1049/iet-its.2019.0779
36. Zhu J, Liu W (2020) A tale of two databases: the use of web of science and Scopus in academic papers. Scientometrics 123(1):321–335. https://doi.org/10.1007/s11192-020-03387-8

# A Review of Barriers to Safety Incentives Design and Implementation in the Construction Industry

**Kunle E. Ogundipe, Babatunde F. Ogunbayo, and Clinton O. Aigbavboa**

## 1 Introduction

The construction industry has notably contributed to economic growth in developed and developing countries due to increased demand for infrastructural development [36, 43, 44, 48]. The involvement of government and private clients in construction activities has increased worker recruitment within the construction industry with little or no implementation of health and safety practices [38, 40, 42, 51]. Unfortunately, construction industry activities harm the lives and safety of the employees due to the complexities of its operations [2, 4, 51]. As a result, thousands of reported and unreported work-related fatalities, deaths, and injuries occur in construction operations annually [3, 27, 30]. The problems of health and safety practices in the construction industry are attributed to unsafe acts and working conditions. Nonetheless, existing studies attributed the problem of health and safety practices in developing countries, including Nigeria, Ghana, and South Africa, to ineffective safety policies, weak enforcement frameworks, skills shortage of the enforcement personnel, inadequate incentives, lack of safety incentives regulations and policies, ineffective sanctions of offenders, and delay justice delivery [12, 13, 20, 41, 45].

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Moreover, stakeholders in the construction industry use different motivations, including safety incentives to align the construction workforce with performance-related goals such as safety, quality, cost, and productivity [9, 18, 19, 47]. Nordgren-Selar [39] maintained that human beings require social, economic, and psychological measures of safety incentives to stimulate performance and productivity in the workplace. Shui et al. [54] described safety incentives as a strategy to improve existing safety management systems, eliminate the possibility of occupational accidents, improve productivity, and ensure smooth construction activities. Gerhart [21] mentioned that safety incentives are used to induce safe behaviours that can improve performance among workers and check destructive behaviours that are detrimental to attaining projects, clients and organisational goals. Alfandi and Alkahsawney [9] described safety incentive schemes as organisational tools to promote team spirit and increase morale due to external persuading factors that motivate individuals to work harder to meet organisational goals and get rewarded. Safety incentive payments are made to workers outside their wages or salary in line with the organisation's set standards for group or individual workers, allowing them to accomplish extra output [11, 60]. Hence, safety incentives drive workers beyond their actual performance to earn extra pay or recognition in meeting organisation goals and personal actualisation [49].

Despite efforts made by construction firms to design and implement safety incentives to improve HandS practices in the construction industry, the process faced different issues and challenges. Nonetheless, there is continuous research on the effective design and implementation of safety incentives in the construction industry. Zulkefli et al. [64] contend that the safety incentive scheme is becoming standard practice among construction firms in motivating contractors and workers to achieve project goals and improve workplace safety and performance. Unfortunately, this is not without various barriers, as described by Choi et al. [16] and Aina and Akinyemi [8], the success of safety incentive schemes largely depends on construction managers choosing an appropriate scheme for the right situation. Also, fewer studies have established the barriers to designing and implementing safety incentive schemes within the construction industry, especially in developing countries like Nigeria, Ghana, and South Africa. However, the knowledge of barriers to safety incentive schemes design and implementation in the construction industry is in fragments and does not seem to provide consolidated information [7, 14, 28, 53, 62]. Hence, in addressing this gap in knowledge in designing and implementing safety incentives in the construction industry, this study aims to identify and understand barriers to the design and implementation of safety incentive schemes to abate the problems encountered in project delivery. This study seeks to answer the following research questions:

- What concept underpins safety incentives design and implementation in the construction industry?
- What barriers influence safety incentives design and implementation in the construction industry?

Hence, through critical reviews of the extant literature, this study reviewed barriers to safety incentives design and implementation in the delivery of construction projects to enrich further the knowledge gap about its application in the construction industry.

## 2 Material and Methods

In addressing and understanding the concept underpinning safety incentives and the likely barriers to safety incentive schemes design and implementation in the construction industry. This was achieved by carefully reviewing peer-reviewed journal articles and conference papers on safety incentives applicable in construction contracts and organisations within the construction industry. Figure 1 explains two stages in this study's search and selection of peer-reviewed academic publications. Determination of the relevant online databases was identified and established in the first stage. These include Scopus, Emerald, PubMed, Google Scholar, Science Direct, ASCE Library and JSTOR because of their wider coverage of quality peer-reviewed academic publications in the research field of the construction industry, particularly in the safety incentives. The literature search process was conducted in the second stage using the following keywords: ("safety incentives, "incentive concept", "incentive schemes design", "incentives implementation", "barriers to safety incentives", and "construction industry"). Keywords are engaged to search in the aforementioned online databases, while the retrieved literature was restricted to peer-reviewed journal articles and conference papers written in English. Additionally, the abstracts of the papers retrieved were read through to determine their relevance to this study. The preliminary search identified one hundred and twenty-two papers from various online databases. However, the exclusion criteria for this study ensure that sixty-three invalid papers were excluded due to overlapping literature coverage, author(s) details absence, missing year of publications and papers written in language order than English on safety incentives within the online databases. Nonetheless, fifty-nine articles related to the study were retrieved and retained for further analysis. Thus, the fifty-nine articles were found relevant to the study theme, justifying a representative sampling of existing studies on the safety incentives for the construction industry. The selected papers were further discussed under the theme of the safety incentives concept, barriers to safety incentives design and implementation in the construction industry, the implication of the study, and conclusions and recommendations. The reviewed papers are used to understand the literature gap on barriers to safety incentive design and implementation in the construction industry.

### *2.1 Safety Incentives Concept in the Construction Industry*

The term "incentives" could be traced to the Latin word "incentivus", meaning the act of singing and enchanting [15]. Bruni et al. [15], citing Pianigiani [65], noted that

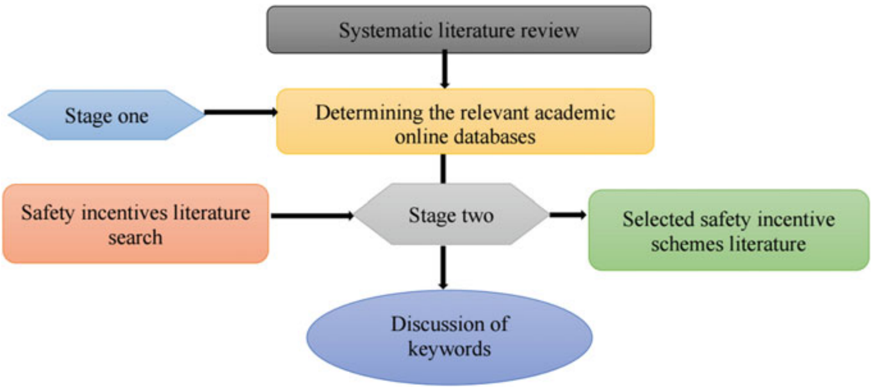


**Fig. 1** Systematic research design adopted for the study

the modern meaning of stimulate or arouse comes from a musical instrument called incentivus, like flute and pitch pipes used to conduct orchestras and choirs, and also to dictate the running pace of soldiers in battle. Nonetheless, as described by Singh [55], citing Taylor [58], the incentives concept could be credited to the scientific management principles by applying the division of work and responsibility. Singh [55], citing Taylor [57], and Taylor [58], found that scientific management principles significantly improve employees' productivity, performance, motivation and sense of active participation and involvement. Scientific management principles contributions have become organisational incentivisation tools for improving productivity and performance. Hence, Taylor [58] noted that scientific management paved the way for the "initiatives and incentives" concept based on four principles, namely:

(i) Development of science for workers to replace the rule of thumb;
(ii) Scientifically selection and training of workers based on their job needs;
(iii) Support workers and managers to facilitate and improve work in line with the principles of sciences developed;
(iv) Division of work and responsibility between workers and management.

The competitive business conditions in the twenty-first century make employee safety incentives/motivation in the construction industry more crucial than before. This is due to stiff competition and economic uncertainties, which require organisations to establish and maintain a motivated workforce [6]. Ahiabor [6] maintained that the principal objective of the safety incentive concept is to incite or intend to incite more outstanding efforts from employees by the manager, giving employees what they want (improved wages and working conditions) to achieve what employers want (low labour cost, accidents, death, and productive output). The scientific management principles propound that workers respond to inducement, especially money when the employers want them to perform more than the expected target. The use of money for motivation has been criticised by social scientists starting from Hawthorne's studies till today. Thus, criticism of the scientific management principles led to different approaches, theories, and models to design and implement safety incentive schemes in the construction industry [55].

According to the Australian Constructors Association. (ACA), [10], Hughes et al. [26], and Tang et al. 56], the safety incentives concept in construction contracts aims to transfer or share the project's risks with contractors. The safety incentive schemes in construction contracts involve rewards and penalties on the contracting firms to ensure the safe completion of projects to prevent all barriers that affect safety, schedule, technical and cost performance, among others [23–25]. Contracting firms are incentivised when such projects are completed within the set scopes of quality, safety performance, productivity, technological progress, innovation, and management [47, 56]. Mohammadfam et al. [37] and Saracino et al. [53] affirmed that safety incentives significantly improve the construction industry's communication systems and workplace safety conditions. Rose and Manley [52] posited that the practical application of safety incentive schemes in construction contracts could stimulate contractors to align with the client's objectives. Using safety incentive schemes in construction projects aligns the client's project goals with the motivations of contractors to ensure the safe completion of projects by including penalties for any unsafe or accidents on sites, and incentives for excellent safety and project performance [24]. Safety incentives concept in construction contracts could also lead to excellent safety practices, reduced accident rates, and improved project performance [24]. Appropriately applying safety incentives in construction contracts can stimulate contractors to align with client objectives and improve project performance [36, 46, 47].

## *2.2 Barriers to Designing and Implementing Safety Incentives in the Construction Industry*

Researchers expressed different views on the effectiveness of safety incentive schemes and how they improve health and safety practices and performance-related goals in the construction industry [7, 14, 28, 53, 62]. Choi et al. [16] argued that the construction industry might face three significant barriers in designing and implementing safety incentive schemes. These are (i) barriers associated with workers, (ii) barriers associated with organisations or contracting firms, and (iii) the prevailing barriers to subcontracting practices. The barriers associated with workers, as described by Choi et al. [16], citing Koehn et al. [33], include the difficulty of training illiterate workers and the low safety attitude of front-line construction workers to understand safety incentive schemes. According to Kheni [32], Poon et al. [ 50], and Choi et al. [16], the construction industry has difficulty in designing and implementing effective safety incentive schemes because of the high turnover rate of workers, high mobility of workers, and workers are less familiar with the workplace environment. Thus, Abas et al. [1] added that inadequate communication between workers and managers and unsatisfactory safety awareness are barriers to safety incentive implementation in the construction industry. It is noteworthy to state that the execution of construction projects requires the input of professional, skilled, semi-skilled and unskilled employees with or without formal education. This makes communication barriers peculiar to the success of safety incentive scheme implementation [1, 16]. Jiang et al. [29] showed that setting unclear goals, low awareness, complex manual operations, and inconsistent performance indicators standards are barriers to safety incentives in the construction industry. Moreover, Karakhan and Gambatese [31] highlighted that safety incentives should design rewards with the magnitude and importance of workers' incentive drives. Safety incentive schemes could become ineffective if the performance goals conflict with workplace safety and create tension in organisational profitability [14]. Thus, Brandhorst and Kluge [14] contend that employees will make a choice between safe and mandatory activities (less productive) procedure and unsafe and forbidden activities (more productive).

Consequently, Aina and Akinyemi [8] study showed that construction firms use safety incentives to motivate workers to be more productive. However, the study shows that the methods and process of selecting appropriate safety incentive schemes constitute a significant barrier to its effectiveness for construction operations [8]. Cox et al. [17] postulated that most selection processes and methods of designing and implementing safety incentive schemes in the construction industry neglected psychological factors. Aina and Akinyemi [8] maintained that the construction industry often based safety incentive scheme selection methods majorly on discretion, tradition, study-based, and performance-based measurement. Aina and Akinyemi [8], citing Kohn [34], maintained that construction organisations often select safety incentive schemes without investigating the relationship between job performance and employee incentive drives. Nonetheless, the traditional methods of selecting safety incentive schemes are influenced by the construction firms' safety culture, job complexities, and the capacity to pay. Also, the discretional method of selecting a safety incentive scheme is influenced by fluctuation in production, timing, and system of governance. Performance-based selection of safety incentive schemes is influenced by the availability of standardised work measurement techniques, adequacy of work and cost–benefit analysis [8]. The study-based selection was influenced by the system of governance and strategy, cost and benefit analysis and adequacy of work-study. Nevertheless, Goodrum and Gangwar [22] posited that construction managers' focus on the selection process and methods of designing safety incentive schemes should avoid employees' loss of confidence and inequity perception towards the safety incentive schemes. Ahassan [5] and Choi et al. [16] added that most contracting firms in the construction industry operate as small and medium enterprises in SMEs, making it challenging to implement safety incentives. Contracting firms in this category have limited budgets, human resources, poor design and implementation of safety incentive schemes, and inadequate attitude of top managers towards safety practices [16]. Goodrum and Gangwar [22], and Shui et al. [54] attributed the barriers to safety incentive schemes among construction firms to the lack of existing health and safety policies that address training, culture, financial plan safety incentives, inadequate record-keeping, and other critical elements.

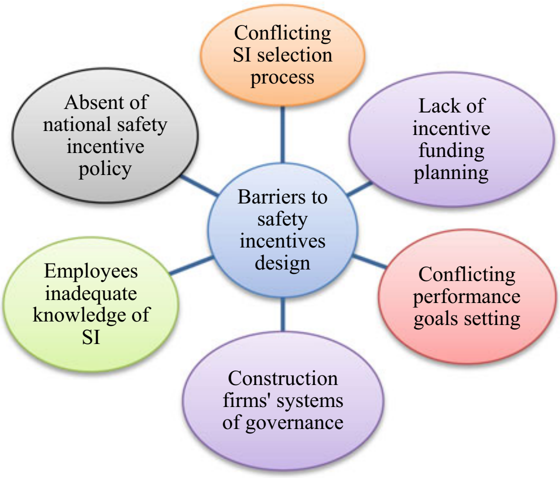


**Fig. 2** Barriers to safety incentives design and implementation in the construction industry. Source: Authors Review 2023

The prevailing barriers to subcontracting practices in the construction industry, according to Choi et al. [16], Wong and So [61], Yik and Lai [63], are due to the absence of regulatory systems for standardised subcontracting practices. Choi et al. [16] added that ineffective communication between clients, contracting and subcontracting firms, and implementation of safety measures are prevailing barriers to subcontracting practice in the construction industry. Therefore, the success of safety incentive schemes largely depends on construction firms choosing an appropriate scheme for the right situation [8, 35]. Ji et al. [28] concurred that while the safety incentive scheme greatly benefits construction organisations, poorly designed and implemented could deteriorate the quality of production output, affect organisational goals, and increase clerical work calculating incentive earnings. Hence, overcoming the barriers of perceived fairness preference, risk preference, and the ability of safety incentive schemes to motivate safety behaviours and meet organisational goals is critical to the safety incentives success in the construction industry [28] (Fig. 2).

## 3 Implication of the Study

Designing and implementing safety incentive schemes in the construction industry generates controversial and divisive opinions among safety professionals and stakeholders on how effectively it improves construction health and safety practices. This is due to different barriers affecting the construction industry's design and implementation of effective safety incentives. Nonetheless, construction firms face many difficulties with the types of safety incentives, period of the schemes, management commitment, worker's willingness, and process and selection methods of designing and implementing safety incentive schemes. The significant barriers to safety incentives scheme design and implementation are linked to workers' factors, organisation or construction firms' factors, and prevailing subcontracting practices in the construction industry. Understanding these barriers informs construction with various performance indicators to design and implement safety incentive schemes towards improving construction industry health and safety practices. Therefore, in developing effective safety incentive schemes, models, and policies for the construction industry, it is essential to understand different barriers, which are vital to identify attributes of safety incentive schemes. This will help to address the following:

- Setting clear goals;
- Understand effective safety incentives selection methods;
- Understanding performance measurement;
- Improvement management commitment to health and safety practices;
- Financial planning for safety incentive schemes;
- Stir workplace behavioural change towards safety practices;
- Develop effective safety incentives policy;
- Improved construction firm safety programme;
- Promote positive peer supervision and feedback;
- Adherence to safety guidelines and regulations;
- Reduced workers' compensation claims; and
- Encourage collaborative planning for safety incentive schemes.

## 4 Conclusion and Recommendation

The study reviewed the barriers to safety incentive scheme design and implementation in construction firms in developing countries. The literature review established that safety incentive scheme design and implementation barriers are linked to workers' factors, organisation or construction firms' factors, and prevailing subcontracting practices in the construction industry. The study adds to the existing knowledge of safety incentive scheme barriers to help understand and identify variables and performance indicators affecting safety incentive schemes in the construction industry. The study recommends that having consistent safety incentive schemes in the construction industry will increase health and safety practices, reduce incident rates and project delays and ensure that specific performance-related goals are met. It will also help to understand and improve the administrative processes of safety incentive design and implementation in the construction industry. Further research is suggested to survey the perception of stakeholders on the identified barriers to enrich further the knowledge of safety incentives about its application in the construction industry.

## 5 Ethics Statement

Not applicable.

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## References

1. Abas NH, Nurahim MH, Yasin N, Rahmat MH (2020) Safety incentive program for construction project: case studies of several construction projects in Klang Valley, Malaysia. Civ Eng Archit 8(3):359–365
2. Abdel-Hamid M, Mohamed Abdelhaleem H (2022) Impact of poor labour productivity on construction project cost. Int J Constr Manag 22(12):2356–2363. https://doi.org/10.1080/15623599.2020.1788757
3. Abukhashabah E, Summan A, Balkhyour M (2020) Occupational accidents and injuries in the construction industry in Jeddah city. Saudi J Biol Sci 27(8):1993–1998
4. Agwu MO, Olele HE (2014) Fatalities in the Nigerian construction industry: a case of poor safety culture. Br J Econ Manag Trade 4(3):431–452
5. Ahassan R (2001) Legacy of implementing industrial health and safety in developing countries. J Physiol Anthropol Appl Hum Sci 20(6):311–319
6. Ahiabor G (2013) The impact of incentives on the productivity of firms in Ghana: A case study of Ghana Airport Company Limited. Prob Manag 21st Century 8(1):6–15
7. Ahmed I, Faheem A (2020) How effectively do safety incentives work? A randomised experimental investigation. Saf Health Work 12(1):20–27
8. Aina OO, Akinyemi TA (2014) Analysis of factors influencing the selection of incentive schemes in selected construction firms in Lagos State, Nigeria. Civ Environ Res 6:1–11
9. Alfandi AM, Alkahsawneh MS (2014) The role of the incentives and reward system in enhancing employee's performance "A Case of Jordanian Travel and Tourism Institutions." Int J Acad Res Bus Soc Sci 4(4):326
10. Australian Constructors Association (ACA, 1999) Relationship contracting–Optimising project outcomes. North Sydney, Australia, NSW
11. Banjoko SA (2006) Managing corporate reward systems. Pumark Nigeria Limited, Lagos
12. Boadu EF, Wang CC, Sunindijo RY (2021) Challenges for occupational health and safety enforcement in the construction industry in Ghana. Constr Econ Build 21(1):1–21
13. Boadu EF, Wang CC, Sunindijo RY (2020) Characteristics of the construction industry in developing countries and its implication for health and safety; an exploratory study in Ghana. Int J Environ Res Public Health [e-journal] 17(11):4110. https://doi.org/10.3390/ijerph17114110
14. Brandhorst S, Kluge A (2021) When the tension is rising: a simulation-based study on the effects of safety incentive programs and behaviour-based safety management. Safety 7(1):9

15. Bruni L, Pelligra V, Reggiani T, Rizzolli M (2020) The pied piper: prizes, incentives, and motivation crowding in. J Bus Ethics 166:643–658
16. Choi TN, Chan DW, Chan AP (2012) Potential difficulties in applying the Pay for Safety Scheme (PFSS) in construction projects. Accid Anal Prev 48:145–155
17. Cox A, Brown D, Reilly P (2010) Reward strategy: Time for a more realistic reconceptualisation and reinterpretation? Thunderbird Int Bus Rev 52(3):249–260
18. Danish RQ, Usman A (2010) The impact of reward and recognition on job satisfaction and motivation: an empirical study from Pakistan. Int J Bus Manag 5(2):159–167
19. Eshun FKD (2011) Rewards as a motivation tool for employee performance. Master Dissertation submitted to Blekinge Institute of Technology, School of Management. Available online: https://www.diva-portal.org/smash/get/diva2:832968/FULLTEXT01.pdf
20. Eyiah AK, Kheni NA, Quartey PD (2019) An assessment of occupational health and safety regulations in Ghana: a study of the construction industry. J Build Constr Plann Res [e-journal] 7:11–31. https://doi.org/10.4236/jbcpr.2019.72002
21. Gerhart B (2017) Incentives and pay for performance in the workplace. In: Advances in motivation science, vol 4, pp 91–140. Elsevier
22. Goodrum PM, Gangwar M (2004) Safety incentives—a study of their effectiveness in construction. Prof Saf 24–34:2004
23. Guo BH, Yiu TW, González VA (2015) Identifying behaviour patterns of construction safety using system archetypes. Accid Anal Prev 80:125–141
24. Hasan A, Jha KN (2013) Safety incentive and penalty provisions in Indian construction projects and their impact on safety performance. Int J Inj Contr Saf Promot 20(1):3–12
25. Hinze J (2002) Safety incentives: do they reduce injuries? Pract Period Struct Des Constr 7(2):81–84
26. Hughes WP, Yohannes I, Hillig JB (2007) Incentives in construction contracts: should we pay for performance? pp 2272–2283
27. International Labour Organisation (ILO, 2015) Construction: a hazardous work Available online: https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_356576/lang--en/index.htm. Assessed 28 Nov 2022
28. Ji L, Liu W, Zhang Y (2021) Research on the tournament incentive mechanism of the safety behaviour for construction workers: considering multiple heterogeneities. Front Psychol 12:796295
29. Jiang W, Luo L, Wu Z, Fei J, Antwi-Afari MF, Yu T (2019) An investigation of the effectiveness of prefabrication incentive policies in China. Sustainability 11(19):5149
30. Kanchana S, Sivaprakash P, Joseph S (2015) Studies on labour safety in construction sites. Sci World J. https://doi.org/10.1155/2015/590810
31. Karakhan A, Gambatese J (2018) Hazards and risk in construction and the impact of incentives and rewards on safety outcomes. Pract Period Struct Des Constr 23(2):04018005
32. Kheni NA (2008) Impact of health and safety management on the safety performance of small and medium-sized construction businesses in Ghana. Doctoral dissertation, Loughborough University
33. Koehn E, Sheikh AA, Jayanti S (2000) Variation in construction productivity: developing countries. AACE International Transactions, I4A, 7
34. Kohn A (1995) Punished by reward: cited in Geller ES (1996). The truth about safety incentives. Prof saf 41(10):34
35. Krause TR, Hodson SJ (1998) A close look at safety incentives. Occupational Health Saf, 28–30
36. Masoetsa TG, Ogunbayo BF, Aigbavboa CO, Awuzie BO (2022) Assessing construction constraint factors on project performance in the construction industry. Buildings 12(8):1183
37. Mohammadfam I, Kamalinia M, Momeni M, Golmohammadi R, Hamidi Y, Soltanian A (2017) Evaluation of the quality of occupational health and safety management systems based on key performance indicators in certified organisations. Saf Health Work 8(2):156–161
38. Mohammed Hatem Z, Abdul Hamid AR, Kunle Elizah O, Zahid A et al (2021), Examing the practice of management aspects and maintenance implementations of welfare facilities in Iraq's construction industry. Malays J Civil Eng 33(2). https://doi.org/10.11113/mjce.v33.1640

39. Nordgren-Selar A (2022) Psychological perspectives on performance-based compensation: implications for work-related and health-related outcomes. Doctoral dissertation, Department of Psychology, Stockholm University
40. Nyoni T, Bonga WG (2016) An empirical investigation of factors affecting construction sector labour productivity in Zimbabwe. Int J Bus Manag Invention (IJBMI) 5(8):68–79
41. Ofori G (2000) Challenges of construction industries in developing countries: lessons from various countries. In: 2nd international conference on construction in developing countries: challenges facing the construction industry in developing countries, Gaborone, November 5 (24), pp 15–17
42. Ogunbayo BF, Ohis Aigbavboa C, Thwala WD, Akinradewo OI (2022) Assessing maintenance budget elements for building maintenance management in Nigerian built environment: a Delphi study. Built Environ Project Asset Manag 12(4):649–666
43. Ogunde AO, Dafe OE, Akinola GA, Ogundipe KE, Oloke OC, Ademola SA et al (2017) Factors militating against prompt delivery of construction projects in Lagos megacity, Nigeria: contractors' perspective. Mediterr J Soc Sci 8(3):233
44. Ogundipe KE, Ogunbayo BF, Olofinnade OM, Amusan LM, Aigbavboa CO (2021) Affordable housing issue: experimental investigation on properties of eco-friendly lightweight concrete produced from incorporating periwinkle and palm kernel shells. Results Eng 9:100193
45. Ogundipe KE, Ogunde A, Olaniran HF, Ajao AM, Ogunbayo BF, Ogundipe JA (2018) Missing gaps in safety education and practices: academic perspectives. Int J Civil Eng Technol (IJCIET) 9(1):273–289
46. Ogundipe KE, Olanirah FH, Ogundipe UL, Ajao AM, Ogunbayo BF (2018) Assessing the impact of quality supervision on construction operatives' service delivery. Int J Civil Eng Technol 9(9):426–439
47. Ogwueleka AC (2015) Evaluation of incentive mechanisms on performance-based contracting systems in South Africa and Nigeria. Doctoral dissertation, University of Pretoria
48. Olanipekun AO, Saka S (2019) Response of the Nigerian construction sector to economic shocks. Constr Econ Build 19(2):160–180
49. Oloke OC, Oni AS, Babalola D, Ojelabi RA (2017) Incentive package, employee's productivity and performance of real estate firms in Nigeria. Eur Sci J 13(11):246–260
50. Poon WF, Ma CH, Ho KL (2000) Statistical analysis on factors in reducing construction site accident frequency rate in Hong Kong. In: Proceedings of the 6th annual conference of the Australian and New Zealand association of occupational health and safety educators, Hong Kong, pp 341–355
51. Rao BP, Sreenivasan A, Babu PNV (2015) Labour productivity: analysis and ranking. Int Res J Eng Technol 2(3):2395–72
52. Rose T, Manley K (2011) Motivation toward financial incentive goals on construction projects. J Bus Res 64(7):765–773
53. Saracino A, Curcuruto M, Antonioni G, Mariani MG, Guglielmi D, Spadoni G (2015) Proactivity-and-consequence-based safety incentive (PCBSI) developed with a fuzzy approach to reduce occupational accidents. Saf Sci 79:175–183
54. Shui YB, Li Q, Li H (2014) The analysis of safety investment behaviour of the long-term incentive mechanism in the construction enterprise. In: Applied mechanics and materials, vol 580, pp 2735–2739. Trans Tech Publications Ltd.
55. Singh BN (2021) Theory A, Theory B and Theory C of managing people at work. Corp Gov Organ Beh Rev 5(1):69–75
56. Tang W, Qiang M, Duffield CF, Young DM, Lu Y (2008) Incentives in the Chinese construction industry. J Constr Eng Manag 134(7):457–467
57. Taylor FW (1911) Principles and methods of scientific management. J Accountancy, 12(3):3
58. Taylor FW (2003) Scientific management, vol 1. Routledge
59. Taylor FW (2003) Scientific management. London: Routledge
60. Tongo CI (2011) Incentive factors affecting the productivity of public servants in Ogun State: evidence from Ado-Ota local Government area. IFE PsychologIA Int J 19(2):1–27

61. Wong FKW, So LSL (2004) Chapter 10—multi-layers subcontracting practice in the Hong Kong construction industry. Construction Safety Management Systems. Spon Press, USA and Canada, pp 147–159
62. Yeow PH, Goomas DT (2014) Outcome-and-behaviour-based safety incentive program to reduce accidents: a case study of a fluid manufacturing plant. Saf Sci 70:429–437
63. Yik FWH, Lai JHK (2007) Multilayer subcontracting of specialist works in buildings in Hong Kong. Int J Project Manage 26(4):399–407
64. Zulkefli FA, Ulang NM, Baharum F (2014) Construction health and safety: effectiveness of safety incentive programme. In: SHS Web of conferences, vol 11, p 01012. EDP Sciences
65. Pianigiani O (1907) Vocabolario etimologico della lingua italiana di Ottorino Pianigiani (1). Società editrice Dante Alighieri di Albrighi, Segati

# Eliminating Building Quality Issues: A Theoretical Framework Using the Theory of Planned Behaviour

**Fei Ying, Grace Y. Wang, and Matthew Curtis**

## 1 Introduction

Quality issues are one of the primary causes of inferior performance in construction work, which cause project cost and schedule overruns, reduce labour productivity and the profitability of construction firms, and undermine clients' and stakeholders' satisfaction. It is estimated that the economic cost of quality defects in New Zealand's residential construction is $2.5 billion per year [6]. If the quality issues are eliminated, residential construction output could increase by $112 million annually. The productivity improvement could lead to a 1.3% wage increase throughout the economy [6]. Previous research observed common defects [38], identified the causes of quality defects [21], developed frameworks for correlated causes [25] and suggested the use of technology for classifying, auditing and inspecting the quality defects [39, 43]. However, despite these contributions, quality issues continue to be a widespread problem in the residential sector [13, 14], as evident in the quality surveys across various new building types [9, 10].

The key recommendations for raising the quality are education and training in the workforce, utilising technologies to contain and reduce errors and improving the construction process [16, 36, 41]. Recently, the focus of quality management has shifted from post-control to in-process control and pre-control. Factors such

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as workers' motivation, awareness, attitude, emotion, and ability are considered to determine their behaviour and affect the quality of the product [28]. If work quality meets standards or specifications in each process, there is a high probability that the final product will meet acceptable quality. However, it is found that the current measures, including regulations and technologies, have limited influence at the operational level. Furthermore, the emergence of Industry 5.0 leads to a shift from technology-driven progress to a thoroughly human-centric and society-centric approach [42]. This calls for an innovative idea to facilitate behavioural change in industry professionals towards eliminating quality issues.

While behaviour change is a complex process, many psychology theories try to explain why and how individuals or groups change their behaviour. Various factors, including personal and psychological (individual) characteristics and environmental, sociological, and cultural context, influence the propensity toward behavioural change. Sometimes, small changes could lead to long-term impacts. Multiple strategies derived from these psychology theories have shown their effectiveness in health prevention, such as substance use, gambling, and diet control [18].

In response, the present study proposes a new scheme to investigate the underlying issues in quality management and develop a systematic framework for forming desirable attitudes and behaviours. The framework is built on the theory of planned behaviour (TPB). In doing this, a literature review maps the causes of defects. The theory of planned behaviour is explained with examples in the context of quality management. A systematic framework for forming desirable attitudes and behaviours to eliminate quality issues proactively is then presented.

## 2 Quality Issues in the Construction Industry

In New Zealand, the government, industry-leading firms, and research develop measures to address building quality issues, including the regulatory environment, the workforce, materials, construction process and knowledge and information [11]. Legislation such as the Building Act 2004 consolidated and reformed the law relating to building for better regulation and control of buildings [30]. It also provides the incentives to deliver a building free from defects. The construction industry and government agencies developed a construction sector workforce plan after the 2011 Canterbury Earthquake to address the skills shortages in the construction workforce. The Building and Construction Industry Training Organisation (BCITO) was set up to develop and implement industry qualifications for the sector. However, the construction industry still needs more skilled people to respond to the industry's needs successfully [32]. Material testing conducted independently by the Building Research Association of New Zealand (BRANZ) provides the industry with confidence regarding material quality [7]. Promoting lean construction and prefabrication is implemented to address the quality issues in construction processes [8, 26, 40].

Nevertheless, most construction firms do business in a traditional format, which can be reflected in their logistics management performance [44]. Significant investment has been deposited to accelerate the use of technologies in the growing knowledge and information-rich construction industry. Digital technologies, such as BIM and simulation, are considered the powerhouse for improving quality in construction due to the potential to improve the construction process planning [1].

### *2.1 Causes of Quality Defects*

Researchers have categorised the causes of quality issues into single and interacting factors. Single factors are those direct causes of a defect, such as poor workmanship. Interacting factors focus on the conditions that allow a defect to occur, such as in the circumstance that the fundamental objective is timeliness over quality [17]. In New Zealand, the most common single causes are poor workmanship, build error (work in the wrong location), material faults and failures, poor coordination between trades, poor design (difficult to build or incomplete design), procedural errors (including construction methods and sequencing) [37]. Jingmond and Agren [21] classify the defect causes as either endogenous or exogenous. Endogenous factors are those ascribed to the organisational level (such as lack of holistic approach), while exogenous factors are primarily related to materials, technologies and markets (such as material behaviour).

Further studies explore alternative approaches to classify the causes. Considering that a root cause is the most fundamental reason for an undesirable condition or problem [12], studies fundamentally divide defect causes into the root and direct causes. Root causes are seen as pre-existing and dormant conditions inherited in defects, while direct causes are related to human actions that trigger these dormant conditions [22]. Through the lens of the Swiss Cheese model, Aljassmi et al. [4] further illustrate that defects originate from different levels of the organisation, namely organisational influence (OI), defective supervision (DS), and preconditions for defective acts (PDA). Here, PDA is the bottom layer of the root causes, including the conditions of the worker and environmental and personal factors. These factors are usually the most immediate cause of defective acts. DS denotes that supervisors can influence the worker's conditions. OI comprise decisions made by upper-level management that can directly affect supervisors' practices. Correlations and inter-causalities analysis indicate that defects' causes are at personal, operational and organisational levels [21, 25]. Defects are produced and handled in the social practices of construction projects [24]. Thus, it could be argued that root causes will be attended to only when studying defects in the social context. Proactively eliminating defects and quality issues are only possible if the beliefs and attitude of defective acts are addressed and positively influenced.

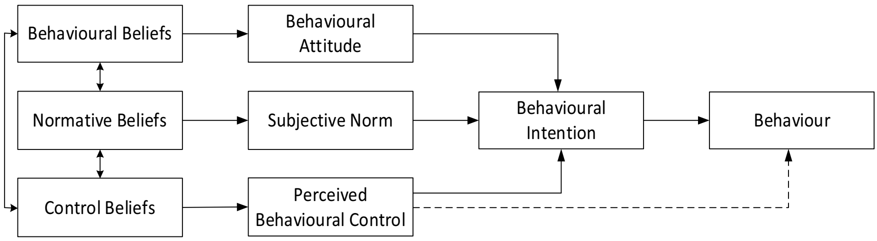


**Fig. 1** Structural diagram of the theory of planned behaviour [2]

## 3 The Theory of Planned Behaviour (TPB)

The TPB was developed by [2] as a general predictive model explaining behavioural intention across many contexts, from physical activity to drug use, from recycling to choice of travel model [3]. The TPB is also increasingly used as a framework for designing and evaluating the effects of behaviour change interventions [19].

As illustrated in Fig. 1, intentions are the most proximal determinant of behaviour, which are influenced by behavioural attitude, subjective norm, and perceived behavioural control, each with its own determinants [23]. In TPB, intentions are defined as the indication of an individual's willingness to perform a given behaviour [20]. Behavioural attitude refers to an individual's evaluation toward performing a specific behaviour, be it favourable or unfavourable [20]. This attitude is determined by a person's belief of whether this behaviour will lead to a particular outcome (their behavioural belief). Subjective norms refer to the general perception of the prevailing opinion held by society and significant others about them performing a behaviour. In the context of construction quality management, that is, a person's perception of whether those closest to them think they should or should not manage quality proactively. Subjective norms are a product of normative beliefs and the motivation to comply with a particular referent. Normative beliefs refer to the perception of an individual's thoughts towards performing a particular behaviour. The importance of this referent to the individual will determine the value given to this belief. The more pertinent the referent is, the more likely the behaviour will reflect what they believe the referent expects from them. Perceived behavioural control (PBC) refers to the perceived difficulty level in performing the target behaviour. PBC is the only determinant with the potential to influence behaviour both directly and indirectly via its influence on behavioural intentions, and directly.

## 4 Research Method

We used a theory-building research method to guide the development of the theoretic framework. While a theory is often described as a well-substantiated and scientifically tested explanation and representation of observed phenomena in the natural world

[15], theory building is the ongoing process that lead to production, confirmation and application of theory. It is considered that applied theory-building research is an important and useful method in developing and expanding our understanding of challenging phenomena and problems, as a theory becomes explicitly observable through the interactive processes of theory construction and empirical inquiry [29]. The inductive–deductive natural aspect of his theory-to-research strategy is well suited to the applied nature of the behavioural and human sciences.

Thus, five distinct phases are involved in the roadmap in theory-building research, namely development of the core concept and operational protocols, application of concept and methods, and testing for confirmation or disconfirmation, and refinement and development of the theory [29]. In the phase of conceptual development, initial ideas depict the up-to date and most informed understanding and explanation of the research problem which provides. The purpose a conceptual framework that addresses the focus of the theory. The operationalisation of a theory needs to be confirmed or tested in its real-world context. The confirmation or disconfirmation phase falls within the practice component of applied theory building, while the application phase enables further study, inquiry and understanding of the theory in action. The continuous refinement and development phase marks a further overlap between the practice and theorising components of the applied theory-building research [29].

This paper reports the findings of the conceptual development by providing the initial understanding and explanation of proactive quality management in the construction context.

## 5 Theory of Planned Behaviour and Proactive Quality Management

It has long been recognised that quality management is required by all actors in the construction process and by a change in attitudes and culture [27]. To be able to proactively manage quality, the behaviour to be promoted is “right-first-time” (RFT). Originating from the well-known quality management philosophy Total Quality Management, the right-first-time approach is believed to strive for zero defects [34].

Considering the advocation of addressing the root causes of quality defects in the social context [24], we suggest that TPB can be used to understand the workforce’s intentions to support right-first-time as the behaviour of interest. From a practical point of view, factors related to behaviour change including attitudes, perceived social norms, and self-efficacy are worth to investigate in construction quality management because they are all characteristics that can conceivably be changed or influenced. When these characteristics relevant to proactive quality management are clearly identified, efforts and resources would be better strategically allocated for intervention programs development.

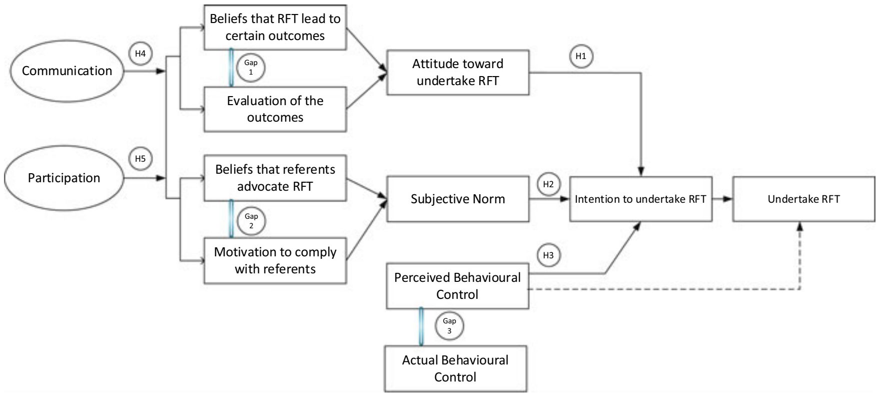


**Fig. 2** The framework of utilising TPB in quality management

Hence, we propose a framework of TPB and moderating variables as applied to a person's decision to support right-first-time, as shown in Fig. 2. The framework illustrates how the attitude toward RFT, normative support, and perceived behavioural control lead to the intention to accomplish RFT, which subsequently leads to behaviour change.

In the context of this research, an individual's attitude toward the behaviour of RFT is a function of their positive or negative evaluation of complying with RFT. Underlying these attitudes are the individual's beliefs about the outcome of complying with RFT. If they believe many positive outcomes are highly likely, they will have a positive attitude toward it. Thus, attitude toward RFT may be described as the extent to which the workers feel positively or negatively that doing things right the first time will lead to specific outcomes. Workers may believe that doing RFT will save their time and costs, improve the quality of work life, etc. These outcomes can relate to tangible things, such as financial profit and intangible ones, such as personal and company reputation. This would lead to a more favourable attitude toward RFT, despite the concerns about thin profit margin, low productivity, and the vast impact of mental health issues in the construction industry [5, 31, 35]. Hence, we hypothesise the following:

H1 Workers' positive perception of RFT (worker attitude) will be positively associated with their intention to comply with RFT.

The second determinant of behavioural intervention is subjective norm, which is a person's perception that most people who are important to them think they should or should not perform the behaviour in question. In the context of this research, the referents can be clients, co-workers, supervisors, competitors and suppliers. It is hence essential to appreciate these referents' perceptions of right-first-time whether product functionality, aesthetics, or information reliability. However, this perception may or may not reflect what the significant others actually think. Normative beliefs determine individuals' perception of norms and their motivation to follow with specific referents. Normative support influences the social aspects of decision-making that entails the workers' belief whether others in their support network want them to support or oppose the RFT initiation and whether motivation to comply is in line the wishes of those persons. TPB suggests that the perceived support of significant others will influence workers' decisions regarding RFT. The perspectives of peers are critical in shaping the views of workers due to the effects of the organisational culture of the quality control [21], the need for quality defective supervision [25] and the impact that peers have on the work environment where workers learn problem-solving for quality issues [24]. Together the focal person's work peers, clients and community expectations for quality build motivate workers to comply with RFT. Accordingly, the second hypothesis is as follows:

H2 Increases in work perception of normative support for RFT will lead to enhanced intention to comply with RFT.

Control beliefs are beliefs related to the key factors that facilitate or hinder the performance of a behaviour. Suppose workers believe that they have the required resources and opportunities that enable them, as well as the lack of obstacles that impede the implementation of doing things right the first time. In that case, they should have greater levels of perceived behaviour control. This control belief can be enhanced by their past experiences or by observation of others proactively managing the quality. This reflects the importance of company culture and the general attitude of the workforce. Perceived behavioural control refers to the workers' assumption of the barriers individuals are facing and their ability to overcome them. Previous literature found that the dominant cause of quality defects lies within organisational shortcomings [21]. Existing research probed in depth for the actual behavioural control, including the required opportunities and resources to manage quality, such as training, skills and technologies. Anecdotal evidence suggests that workers believe they have limited control of the construction process and the quality of others' work [33]. Hence, we expect the following:

H3 Workers' perceived behavioural control will be positively associated with their intention to support RFT.

Indeed, TPB typically focuses on attitude, subjective norm, and perceived behavioural control to target an individual's respective underlying beliefs. It also suggests that some of the most potent ways to change behaviours are through persuasive communications, information provision, newsletters, face-to-face meetings and discussions, and observational modelling. By providing information and participative opportunities for workers to develop beliefs about the likely consequences (attitude) of RFT, the normative expectations of others regarding support undertaking RFT (subjective norm) and potential facilitators and barriers to performance (perceived behaviour control), workers can foster readiness to support the RFT initiative. Thus, the following main and mediating relationships are proposed:

H4 Workers who report receiving accurate and purposeful communication about proactive quality management are likely to exhibit higher levels of intentions to engage in RFT, and this relationship will be mediated by attitude, subjective norm, and perceived behavioural control.

H5 Workers with better opportunities to participate in the RFT initiative will show greater levels of intentions to engage in RFT, and this will be mediated by attitude, subjective norm, and perceived behavioural control.

## 6 Conclusions and Further Research

Developing an effective intervention for preferred/targeted behaviour would require identifying all influencing factors and their associations as the first step. A summary of the working hypotheses is depicted in Fig. 2. First, it was hypothesised that attitude, subjective norm, and perceived behavioural control would be positively associated with intentions to engage in RFT (Hypotheses 1 to 3, respectively). Also, communication and involvement of the knowledge, impact and process of proactive quality management are hypothesised to be positively related to intentions (Hypotheses 4 and 5). Drawing from literature findings, this paper demonstrated the potential of applying the TPB in the context of quality control and proposed hypotheses for future research. Answering these hypotheses would solidify the design and evaluation of the interventional programme.

Three research gaps were identified while developing the TPB framework for proactive quality management. The first research gap is quality management's social and environmental outcomes and its impact on individual workers or construction firms. While the economic outcomes of quality management have been widely discussed, limited research dwells on this, which is critical to identify and shape the beliefs of individual and social norms.

The second research gap concerns referents and their thoughts about proactive quality management. To address this gap, further research will determine the referent groups that have valuable social impacts on construction workers in quality issues and referents' expectations of RFT. Considering the fragment of the construction industry, it is crucial to depict each trader's perception of what is right the first time. For example, for plumbers, right the first time is about more than just getting their work done without defects. It also includes leaving workable space for downstream traders if space is constrained. Further, research can start with the trades having the most recurrent defects to understand the expectations in various scenarios.

The third research gap exists the link between actual and perceived behavioural control. In situations where one's perceived behavioural control is inaccurate in predicting actual behaviour control, then perceived behavioural control would be unlikely to predict actual behaviour directly. Worse, perceived behavioural control becomes an erroneous prediction of actual behavioural control when the individual has little information about the behaviour, when requirements or available resources have changed, or when new and unfamiliar elements have entered the situation. Therefore, aligning perceived and actual behavioural control is essential to support behaviour change. Further research is to establish the perceived behaviour control according to different trades and stakeholders, to provide actual behavioural control matching the perceived behaviour control.

In sum, human behaviour is complex and influenced by multiple interrelated variables. Some variables are related to individual characteristics, while others are associated with a wide range of social and environmental factors. The TPB offers a holistic approach to understanding the mechanisms underlying human behaviours. This framework itself does not appear simple but provides a clear structure for an improved understanding of human behaviours and intervention design for behavioural change.

## 7 Ethics Statement

Not applicable.

**Author Contributions** Fei Ying contributes to conceptualization, investigation, draft preparation, and manuscript editing. Grace Wang contributes to conceptualization, framework development, and draft preparation. Matthew contributes to conceptualization and manuscript editing. All authors have read and agreed with the manuscript before its submission and publication.

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## References

1. Abdelmegid MA, González VA, O'Sullivan M, Walker CG, Poshdar M, Ying F (2020) The roles of conceptual modelling in improving construction simulation studies: a comprehensive review. Adv Eng Inf 46(October). https://doi.org/10.1016/j.aei.2020.101175
2. Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50(2):179–211
3. Ajzen I, Schmidt P (2020) Changing behavior using the theory of planned behavior. In: Hagger MS, Cameron L, Hamilton K, Hankonen N, Lintunen T (eds) The handbook of behavior change (Cambridge Handbooks in Psychology). Cambridge University Press
4. Aljassmi H, Perera J, Han S (2013) Identifying and analyzing the correlations and inter-causalities of the root causes of construction defects. Int J Eng Technol 5(4):469–472
5. BDO New Zealand (2017) The construction survey report. B. N. Zealand
6. Bealing M, Morel LL (2020) The economic cost of quality defects
7. BRANZ (2016) Appraisals https://www.branz.co.nz/appraisals/process/
8. Burgess JC, Buckeet NR, Page I (2013) Prefabrication impacts in the New Zealand construction industry (SR 279, Issue
9. Clarke C, Lockyer O (2022) New house owners' satisfaction survey 2021 (Study report SR471, Issue)
10. Curtis M, Brunsdon N (2018) Medium-density housing construction quality survey
11. Curtis M, Gordon G (2018a) Prioritising quality
12. Dew JR (1991) In search of the root cause. Qual Prog 24(3):97–102
13. Forcada N, Macarulla M, Gangolells M, Casals M (2014) Assessment of construction defects in residential buildings in Spain. Build Res Inf 42(5):629–640. https://doi.org/10.1080/09613218.2014.922266
14. Forcada N, Macarulla M, Peter EDL (2013) Assessment of residential defects at post-handover. J Constr Eng Manag 139(4):372–378

15. Gioia DA, Pitre E (1990) Multiparadigm perspective on theory building. Acad Manag Rev 15(4):584–602
16. Gordon G, Curtis M (2018a) Building-quality issues: a literature review (SR375, Issue)
17. Gordon G, Curtis M (2018b) Building-quality issues: a literature review
18. Hagger MS, Cameron LD, Hamilton K, Hankonen N, Lintunen T (2020) Changing behavior: a theory and evidence-based approach. In: Hagger MS, Cameron L, Hamilton K, Hankonen N, Lintunen T (eds) The handbook of behavior change (Cambridge Handbooks in Psychology). Cambridge University Press. https://doi.org/10.1017/9781108677318
19. Hagger MS, Cheugn MW, Ajzen I, Hamilton K (2022) Perceived behavioral control moderating effects in the theory of planned behavior: a meta-analysis. Health Psychol 41(2):155–167
20. Jimmieson NL, Peach M, White KM (2008) Utilizing the theory of planned behavior to inform change management. J Appl Behav Sci 44(2):157–286
21. Jingmond M, Ågren R (2015) Unravelling causes of defects in construction. Constr Innov 15(2):198–218
22. Josephson PE, Hammarlund Y (1999) The causes and costs of defects in construction. A study of seven building projects. Autom Constr 8(6):681–687
23. Kan MPH, Fabrigar LR (2017) Theory of planned behavior. In: Zeigler-Hill V, Shackeford TK (eds) Encyclopedia of personality and individual differences. https://doi.org/10.1007/978-3-319-28099-8_1191-1
24. Koch C, Schultz CS (2019) The production of defects in construction—an agency dissonance. Constr Manag Econ 37(9):499–512
25. Lambers R, Lamari F, Skitmore M, Rajendra D (2023) Key residential construction defects: a framework for their identification and correlated causes. Constr Innov Ahead-of-Print. https://doi.org/10.1108/CI-05-2022-0103
26. Likita AJ, Jelodar MB, Vishnupriya V, Rotimi JOB (2023) Lean and BIM integration benefits construction management practices in New Zealand. Constr Innov. https://doi.org/10.1108/CI-06-2022-0136
27. Love P, Smith J (2018) Unpacking the ambiguity of rework in construction: making sense of the lilterature. Civ Eng Environ Syst 35(1–4):180–203
28. Luo H, Lin L, Chen K, Antwi-Afari MF, Chen L (2022) Digital technology for quality management in construction: a review and future research directions. Dev Built Environ 12. https://doi.org/10.1016/j.dibe.2022.100087
29. Lynham SA (2002) The general method of theory-building research in applied disciplines. Adv Dev Hum Resour 4(3):221–241
30. MBIE (2017) How the building code works. https://www.building.govt.nz/building-code-compliance/how-the-building-code-works/
31. MBIE (2022) Building and construction sector trends annual report 2022
32. Ministry of Business, I. a. E. (2019) Construction skills and training
33. Mostofi F, Tokdemir OB, Togan V (2023) Comprehensive root analysis of construction defects using semisupervised graph representation learning. J Constr Eng Manag 149(9)
34. Pheng LS, Teo JA (2004) Implementing total quality management in construction firms. J Manag Eng 20(1):1–31
35. Plessis D, Simpson A (2021) The mental health and wellbeing of small and medium-sized construction firms in New Zealand (Study Report, Issue)
36. Riaz H, Khan KIA, Ullah F, Tahir MB, Alqurashi M, Alsulami BT (2023) Key factors for implementation of total quality management in construction sector: a system dynamics approach. Ain Shams Eng J 14. https://doi.org/10.1016/j.asej.2022.101903
37. Rotimi F (2013) An evaluative framework for defects in new residential buildings: The New Zealand case Auckland University of Technology. Auckland
38. Rotimi FE, Tookey J, Rotimi JO (2015) Evaluating defect reporting in new residential buildings in New Zealand. Buildings 5:39–55. https://doi.org/10.3390/buildings5010039
39. Sandanayake M, Yang W, Chhibba N, Vrcelj Z (2022) Residential building defects investigation and mitigation—a comparative review in Victoria, Australia, for understanding the way forward. Eng Constr Archit Manag 29(9):3689–3771. https://doi.org/10.1108/ECAM-03-2021-0232

40. Sarhan S, Pretlove S (2021) Lean and sustainable construction: state of the art and future directions. Constr Econ Build 21(3):1–10
41. Wang D, Ren B, Cui B, Wang J, Wang X, Guan T (2021) Real-time monitoring for vibration quality of fresh concrete using convolutional neural networks and IoT technology. Autom Constr 123. https://doi.org/10.1016/j.autcon.2020.103510
42. Xu X, Lu Y, Vogel-Heuser B, Want L (2021) Industry 4.0 and industry 5.0—Inception, conception and perception. J Manuf Syst 61:530–535
43. Yang D, Kim B, Kim H (2021) Automated defect classification in the maintenance phase using a channel attention-based convolutional neural network model of natural language processing. Int J Sustain Build Technol Urban Develop 12(2):96–109. https://doi.org/10.22712/susb.20210009
44. Ying F, Tookey J, Seadon J (2018) Measuring the invisible: a key performance indicator for managing construction logistics performance. Benchmarking: An Int J 25(6):1921–1934. https://doi.org/10.1108/BIJ-11-2016-0176

# Organisational Leadership as a Driver for the Delivery of Sustainable Construction in South Africa

**Matthew Ikuabe, Clinton Aigbavboa, Samuel Adekunle, Murendeni Liphadzi, and Peter Adekunle**

## 1 Introduction

Sustainability has been a topic of germane concern for various individuals of different countries, of varying professions and diverse disciplines. The United Nations (UN) has set goals and objectives towards the attainment of sustainability in terms of the social, economic and environmental concepts [4, 13]. In construction, there have been challenges in the design of buildings resulting from a variety of impacts to the environment such as the utilisation of energy and water, the loss of biodiversity from raw material extraction, deforestation for new infrastructure and waste resulting from construction processes and facilities usage [14]. Sustainability in the construction industry accounts for economic, social and environmental factors to effectively reduce the construction industry's impact on the environment. This includes the use of sustainable policies and practices when dealing with the design, material and methods of construction projects. The entire construction industry is regarded as a vital sector for achieving sustainable development in society, but the change towards adopting the process of sustainable practice has been termed to have a "lazy view" [1]. Furthermore, it has been seen to be inhibited by leadership challenges, as Opoku and Ahmed [15] noted that the much-desired change needed in the construction industry is demanded from its leaders.

Construction has been characterised to be largely a key contributor to the cause of environmental problems which spans from a high volume of consumption of resources across the globe both in terms of construction projects and operations

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of buildings to the polluting of the environment [14]. The construction industry in South Africa is one of the largest employers who make provision for infrastructure and support for local economic activities; it, therefore, plays a vital role in the social, economic and environmental development of the nation. Due to South Africa's past, the construction industry faces a number of developmental and transformational challenges such as the inability to access opportunity, finance and training with regards to leadership [11]. The construction industry in South Africa focuses more on the management aspect of construction rather than in the leadership towards sustainability. This orientation by the construction industry results from a short supply of skilful project leaders. There is a lack of output with regards to research on leadership in the South African construction industry due to the inadequate knowledge with regards to social engineering within the industry. However, there has been an increase in the consciousness among construction industry stakeholders for the need to reposition leadership so as to enhance project delivery and performance. The need for leadership and its development is extremely important in South Africa [11]. Also, Velsor [21] highlighted the significance of instituting the relationship between sustainability and leadership.

Sustainable construction is important in the sense that it is a holistic process which aims at the maintenance and re-establishment of the harmonious relationship between nature and the built environment, by creating spaces which encourages economic quality and upholds human dignity. Therefore, the delivery of sustainable construction projects through organisations should be supported by the commitment and inspiration of leadership, which has a clear understanding of the sustainability challenge [16]. Leadership and sustainability have been studied separately over the years in the context of the built environment but have yet to be further explored together. The construction industry needs intra-organisational leadership which is poised for a sustainable outcome, and which provides "the collective vision, strategy and direction towards a sustainable future", as Songer et al. [19] indicates that the industry is plagued by numerous problems, and one of it is leadership. Sustainable construction project delivery demands the active support of leadership that is committed, willed and inspired with a clear understanding of sustainability and its implementation [16]. Based on the aforementioned, this study seeks to evaluate the roles of organisational leadership in the delivery of sustainable construction. The study gives professionals and construction industry stakeholders the knowledge on the roles of organisational leadership in delivering sustainable construction and the various sustainable practices that can be adopted and the benefits of delivering sustainable construction.

# 2 Literature Review

## *2.1 Contextualising Sustainable Development in South Africa*

The aim of sustainable development is to enhance the social and economic conditions whilst minimising and preventing the negative environmental impacts. However, the attainment of sustainable development comes with a lot of challenges. It needs a comprehensive and integrated approach, whereas the construction industry predominantly functions in a disjointed system. Sustainable development application in the industry has faced challenges to be understood and which has not been sufficiently interpreted into practical implementation [7]. The construction and built environment contribute tremendously towards global warming, and it has a vital role to play in the world's economies. The impacts of the concepts of sustainability on the built environment on an aggregate scale are energy use (40%), freshwater use (17%), wood harvest (25%), material use (40%), world workforce (10%) and erection of buildings on productive land [7].

In the environmental perspective, scenario modelling and legislation indicates the importance of the built environment to encourage the adoption of sustainable development. For the adoption of sustainable development, its measures and applications need to be easily understood. Objectives can be set for achieving sustainable development in the built environment. These objectives should ensure the adherence of the built environment in the drive for sustainable development within the tenets of its framework. Department of Environment Affairs [3] proposed sustainable development objectives for the built environment, which includes the integrated land use and development with prevailing and future planned infrastructure, for the certainty of a well-encompassing deployment of land use and efficient systems. The development of water, sewage and storm water runoff should minimise the use of municipal water which is potable as well as minimise the disposal of sewage into municipal systems. Materials used in construction developments should aim to curtail the negative impacts of construction projects on the environment and further bring about a reduction of resources consumption. Construction project's economic and social impacts ought to bring about maximised positivity. Local economies which create work and sustainable enterprises in diverse production lines should be supported by development. Transport development must aim to reduce the use of cars in order to ensure energy efficiency; transportation which is environmentally friendly should be encouraged. Housing developments should support the inclusion of people to reduce travelling times and distances as well as affordable housing. Developments should also support social cohesion and inclusion. Targets which resonances the context of South Africa ought to be established for developments and the correct administration and monitoring of developments should be carried out to ensure success [7].

### 2.2 Organisational Leadership and Sustainable Construction

An organisation's pursuit of its strategic direction, desired outcomes, sustainable success and survival is essentially hinged on its organisational leadership [18]. It is a vital component in the construction industry and a key factor in the direction towards a sustainable built environment. Reference [2, 20] outlined the importance of leadership in the provision of a supportive working environment for stakeholders. Leadership is needed to provide a united vision, common goal and strategy in an effort to creating a sustainable future for the construction industry and society. This is pertinent to the construction industry considering its large and complex nature coupled with its involvement in the fusion of specialised and multidisciplinary skills [12]. The sustainable approach taken by leadership should be embedded in the organisation's activities and sustainable development as well as be a part of the business strategy [16]. Leadership entails the mindset, knowledge, talents, skills and abilities to lead people and organisations coupled with the ability to positively bring change towards a sustainable future through the perspectives and reflections of reality. Leadership is about creating success for other people and ensuring that they have the means and mechanisms for achieving success. Good leaders have a solid core of precepts and beliefs that gives direction in their leadership; these are essential elements [18].

According to Opoku et al. [16], the role of organisational leadership is diverse and includes giving direction while outlining the vision and driving the organisation towards sustainability. Strategic procedures for the adoption and implementation of sustainable practices can put the organisation on the path of sustainable development. These include driving forward the sustainability agenda within the organisation by providing guidance notes, training and awareness courses for staff. Furthermore, top management cadre engages in cascading managerial decisions down as a result of the impacts of sustainability are often localised [5]. Also, Paraschiy et al. [17] portrayed the significance of visionary management in the projection of sustainability among responding organisations. Others are marketing and promoting the benefits of sustainability to potential clients and other project-related stakeholders and lobbying government for legislation to promote sustainable change, also, by acting as sustainability integrator across all sections and departments of the organisation as well as developing, utilising and maintaining an environmental management system across the organisation. Equally, by promoting a culture of compliance with statutory and related legislation, setting and monitoring sustainability targets, and performance. Project players have particular roles to play in the course of project execution, and the guarantee of a successful project depends on the work diligence of the project players [9, 10].

# 3 Methodology

The study focussed on assessing the roles of organisational leadership in the delivery of sustainable construction in South Africa. A questionnaire survey was adopted for the study with Gauteng Province, South Africa, as the study area. Construction professionals, namely architects, quantity surveyors, engineers, construction managers and project managers, made up the population of the study. The questionnaire was made up of two divisions, the first elicited the demographic information of the respondents while the other entailed respondents being asked to rank the roles of organisational leadership in the delivery of sustainable construction; also they were asked to rank the internal and external factors affecting organisational leadership on the delivery of sustainable construction based on the level of their agreement. A total of eighty-six questionnaires were distributed to the respondents, while fifty-five were retrieved for analysis. The methods of data analysis deployed are percentages, mean item score, standard deviation, and Kruskal–Wallis *h*-test. The Mean item score was used in ranking the identified roles of organisational leadership in the delivery of sustainable construction, and also the internal and external factors affecting organisational leadership in sustainable construction delivery. Also, Kruskal–Wallis *h*-test was deployed in ascertaining if there is a difference in opinions of the sampled professionals with respect to the roles of organisational leadership in the delivery of sustainable construction. On this basis, any variable with p-value greater than 0.05 implies that there is no significant difference in the responses provided by the professionals, while a variable having a *p*-value less than 0.05 implies that there is a significant difference in the responses provided by the professionals. Furthermore, Cronbach's Alpha test was conducted to determine the reliability of the questionnaire. Alpha value of 0.911, 0.926 and 0.899 were derived thus indicating a high reliability of the research instrument.

# 4 Results

## *4.1 Demographic Information of Respondents*

The result of the background information of the respondents shows that 36% of the respondents are architects, 28% construction managers, 20% quantity surveyors, 12% engineers and 4% project managers. Also, 79% of the respondents work in private organisations while 21% work in public organisations. Respondents' information on the highest educational qualification indicates that 44% of the respondents have a bachelor's degree, 36% have a diploma, 16% have master's degree and 4% have Doctoral degree. Based on years of working experience, respondents with 4–6 years was the highest with 48%, 1–3 years with 20%, 7–10 years with 12% and 11 years and above 20%.

### 4.2 Roles of Organisational Leadership in the Delivery of Sustainable Construction

Table 1 reveals the respondents ranking of the roles of organisational leadership in the delivery of sustainable construction in the South African construction industry. According to the respondents, the top roles are act as sustainability integrators, and providing direction and setting vision which is ranked first with a mean item score (MIS) of 4.00, respectively; closely followed and ranked third is leading, encouraging and supporting employees and departments on sustainability rank with MIS of 3.96. Fourthly ranked is creating awareness on sustainability with MIS of 3.80. The least ranked among the roles in developing sustainability strategies having MIS of 3.52. Results from the Kruskal–Wallis H-test conducted shows that all the identified roles all have a *p*-values greater than 0.05, thus indicating that there is no significant difference in the responses provided by the respondents with respect to professional affiliation.

**Table 1** Roles of organisational leadership in sustainable construction delivery

| Roles | MIS | R | K-W | |
|---|---|---|---|---|
| | | | $X^2$ | Sig |
| Act as sustainability integrators | 4 | 1 | 5.298 | 0.339 |
| Providing direction and setting vision | 4 | 1 | 3.882 | 0.521 |
| Leading, encouraging and supporting employees and departments on sustainability | 3.96 | 3 | 11.391 | 0.072 |
| Monitoring sustainability targets and performance | 3.84 | 4 | 3.092 | 0.936 |
| Creating awareness on sustainability | 3.8 | 5 | 4.228 | 0.452 |
| Driving the sustainability agenda | 3.76 | 6 | 9.925 | 0.444 |
| Formulating policies and influencing implementation | 3.76 | 6 | 1.207 | 0.395 |
| Providing and leading training on sustainability | 3.72 | 8 | 6.839 | 0.649 |
| Lobbying government for sustainable change | 3.56 | 9 | 5.915 | 0.487 |
| Developing sustainable guidance notes and policies | 3.52 | 10 | 10.229 | 0.329 |
| Developing sustainability strategies | 3.52 | 10 | 9.321 | 0.551 |

N.B: *MIS* Mean Item Score, *R* Rank, *K-W* Kruskal–Wallis H-test

**Table 2** Internal factors affecting organisational leadership in the delivery of sustainable construction

| Internal factors | MIS | SD | Rank |
|---|---|---|---|
| Organisational policy | 4.20 | 0.866 | 1 |
| Opportunities for learning | 4.16 | 0.688 | 2 |
| Organisational mission | 4.16 | 0.800 | 2 |
| Organisational culture | 4.08 | 0.997 | 4 |
| Organisational goals | 4.04 | 1.060 | 5 |
| Fostering of innovation | 4.00 | 1.041 | 6 |
| Communication methods | 4.00 | 1.080 | 6 |
| Team interactions | 3.96 | 1.098 | 8 |
| Organisational Structure | 3.88 | 0.927 | 9 |
| Leadership | 3.88 | 1.092 | 9 |
| Hierarchical systems | 3.76 | 0.926 | 11 |

N.B: *MIS* mean item score, *SD* standard deviation

### *4.3 Internal Factors Affecting Organisational Leadership in the Delivery of Sustainable Construction*

Table 2 shows the respondents ranking of the internal factors affecting organisational leadership in the delivery of sustainable construction in the South African construction industry. Accordingly, the topmost ranked factors are organisational policy ranked first with MIS of 4.20 and SD of 0.866; two factors are ranked second which are opportunities for learning and organisational mission with MIS of 4.16 and SD of 0.688 and 0.800, respectively. The least ranked factor is hierarchical systems having MIS of 3.76 and SD of 0.926.

### *4.4 External Factors Affecting Organisational Leadership in the Delivery of Sustainable Construction*

Table 3 reveals the respondents ranking of the external factors affecting organisational leadership in the delivery of sustainable construction in the South African construction industry. Based on the response gotten, the top factors were technology ranked first with MIS of 4.16 and SD of 0.943, client ranked second with MIS of 4.12 and SD of 0.971, industry demands and economy both ranked third having MIS of 4.08 and having SD of 0.812 and 0.909 respectively. The least ranked factor is suppliers having MIS of 3.72 and SD of 1.021.

**Table 3** External factors affecting organisational leadership in the delivery of sustainable construction

| External factors | MIS | SD | Rank |
|---|---|---|---|
| Technology | 4.16 | 0.943 | 1 |
| Clients | 4.12 | 0.971 | 2 |
| Industry demands | 4.08 | 0.812 | 3 |
| Economy | 4.08 | 0.909 | 3 |
| Availability of manpower | 4.00 | 0.913 | 5 |
| Physical resources | 4.00 | 1.041 | 5 |
| Society | 4.00 | 0.866 | 5 |
| Communal values | 3.96 | 0.889 | 8 |
| Competitors | 3.88 | 1.013 | 9 |
| Politics | 3.88 | 0.971 | 9 |
| Legislation | 3.88 | 1.013 | 9 |
| Investors | 3.80 | 1.323 | 12 |
| Suppliers | 3.72 | 1.021 | 13 |

N.B: *MIS* mean item score, *SD* standard deviation

## 5 Discussion

The roles of organisational leadership in delivering sustainable construction in the South African construction industry were analysed in the study. Based on the findings, prominent among the roles are acting as sustainability integrators and providing direction and setting vision. This is in consonance with the study of Opoku et al. [16] which stated that the leadership of organisations should serve as drivers of sustainability by steering the organisation towards attaining modern ideas that meet up with keeping up with sustainability concepts. Also, Rainey [18] and Ofori and Toor [12] noted that strategic direction is a paramount value of leadership. Hence, in actualising the dream of attaining sustainable construction, the leadership of organisations ought to have a clear strategy devoid of impairments which yield the desired outcome. Thus, for the South African construction industry to attain the lofty heights of sustainable development, it is imperative that the leadership of construction organisations inculcate the tenets of sustainability its core vision and policy statements.

As indicated in the study, a variety of factors affect organisational leadership in the delivery of sustainable construction. Top among the internal and external factors are organisational policy and technology, respectively. This is corroborated by Gleeson [8] stating that an organisation is clearly influenced by its adopted aim and purpose which influences decisions taken by the top hierarchy of the organisation. This reinforces the notion that the policies enacted by the top management of organisations gives a direction as to the chances and possibilities of delivering construction projects within the ambits of sustainable construction. Also, Finch [6] stated that technological innovations at the disposal of top management of organisations affect decision making. Hence, the drive towards sustainable construction by organisational leadership is highly influenced by the availability and technicalities behind the use of technology in achieving such a purpose. Technological innovations would go a long way in aiding sustainable construction, hence, when readily available, project delivery using sustainable construction would be highly encouraged by top management.

## 6 Conclusion

A scrutiny of the roles of organisational leadership towards delivering sustainable construction was carried out by the study. Revealed from the study are the most important roles for organisational leadership in attaining the pursuit of sustainable construction, and these include acting as sustainability integrators and providing direction and setting a vision. The top management of organisations has prominent roles to play in delivering the much-desired goal of sustainable construction; hence they act as key players by providing the necessary direction and formulating policies that adequately inculcates the tenets of sustainability. The major factors that affect organisational leadership in delivering sustainable construction are organisational policy and technology. On this premise, the study recommends that leaders in organisations and policy formulators should be acquainted with the demands driving sustainability in construction processes. Hence, in steering the organisation towards attaining its core mandates, sustainability principles should be incorporated to allow for the coherent pursuit of achieving organisational goals in line with sustainable construction.

## References

1. Aigbavboa C, Ohiomah I, Zwane T (2017) Sustainable construction practices: "a lazy view" of construction professionals in the South African construction industry. In: The 8th international conference on applied energy, energy procedia, vol 105, pp 3003–3010
2. Bryman A (2004) Qualitative research on leadership: a critical but appreciative review. Leadersh Q 15(6):729–769
3. Department of Environment Affairs (2011) National strategy for sustainable development and action plan 2011–2014, South Africa
4. Ekins P (2010) Eco-innovation for environmental sustainability: concepts, progress and polices. Int Econ Policy 7:267–290
5. Epstein M, Buhovac A, Yuthas K (2010) Implementing sustainability: the role of leadership and organisational culture. Strateg Finance 41–47
6. Finch C (2019) External factors affecting leadership. Available at: https://bizfluent.com/info-8583473-external-factors-affecting-leadership.html
7. Gibberd J (2010) Sustainable development criteria for built environment projects in South Africa. Human Settl Rev 1(1):34–58
8. Gleeson P (2017) Internal and external factors that affect an organization. Available at: https://smallbusiness.chron.com/internal-external-factors-affect-organization-16641.html

9. Irving J, Longbotham G (2007) Team effectiveness and six essential servant leadership themes: a regression model based on items in the organisational leadership assessment. Int J Leadersh Stud 2(2):98–113
10. Lester A (2017) Project management, planning and control. In: 7th Edn, Elsevier Butterwort Heinemann
11. Liphadzi M, Aigbavboa C, Thwala W (2018) Leadership development in the South African construction industry. In: Skibniewsky M, Hajdu M (eds) Proceedings at the creative construction conference 30th June–3rd July, Ljubljana, Slovenia
12. Ofori G, Toor S (2012) Leadership and construction industry development in developing countries. J Constr Dev Countries 1:1–21
13. Oke A, Aigbavboa C (2018) Sustainable value management for construction projects. Springer International Publishing
14. Opoku A (2018) Biodiversity and the built environment: implications for sustainable development goals (SDGs). Resour Conserv Recycl 141:1–7
15. Opoku A, Ahmed V (2015) Leadership and sustainability in the built environment. Routledge Taylor and Francis, 1st Edn
16. Opoku A, Cruickshank H, Ahmed V (2015) Organisational leadership role in the delivery of sustainable construction projects in UK. Built Environ Project and Asset Manag 5(2):154–169
17. Paraschiy D, Nemoianu E, Langa C, Szabo T (2012) Eco-innovation, responsible leadership and organisational change for corporate sustainability. Amfiteatru Econ J 14(32):404–419
18. Rainey D (2013) The pursuit of sustainable leadership. Information Age Publications, Charlotte, NC
19. Songer A, Chinowsky P, Butler C (2006) Emotional intelligence and leadership behavior in construction executives. In: Proceedings: 2nd specialty conference on leadership and management in construction. Grand Bahama Island, Bahamas, 4–6 May. PM Publishing, Louisville, Colorado, pp 248–258
20. Thamhain J (2003) Team leadership effectiveness in technology-based project environments. Proj Manag J 35(4):35–46
21. Velsor E (2019) Leadership and corporate social responsibility. Corp Gov 9(1):3–6

# Post-disaster Recovery: A Critical Assessment of Housing Reconstruction Types and Features in Fiji

**Mohamed Elkharboutly and Suzanne Wilkinson**

## 1 Introduction

Fiji, situated in the Pacific Ocean, is a collection of 322 islands covering an expansive area of 1.3 million square kilometres. Out of these islands, only 110 are presently inhabited. The overall land area of Fiji is 18,274 square kilometres. Notably, and as shown in Fig. 1, more than 85% of this land area is concentrated in the two largest islands, Viti Levu and Vanua Levu, constituting 87% of Fiji's total land area [38]

The capital of Fiji is Suva, located on the southeast coast of Viti Levu, the most developed and densely populated island. Additionally, three out of the five main cities are situated in Viti Levu: Lautoka, known for its significance in the sugarcane industry; Nadi, housing the primary international airport; and Ba, recognised as a prominent cultural centre in the country [25].

Fiji's total population stands at 884,887, with nearly 44% residing in rural communities. The distribution of the population among the Fijian Islands is depicted through divisions [18].

Fiji is administratively divided into Northern, Central, Eastern, and Western divisions, further subdivided into provinces, totalling 15 provinces, including Rotuma Island. Each province is composed of multiple villages, amounting to a total of 1193 villages, according to the Fiji Islands Bureau of Statistics [17]

The country is frequently affected by cyclones and flooding, resulting in loss of lives, homelessness, and the destruction of homes and livelihoods. These recurrent events impose a significant social and financial burden on the government, as reported by the Office for the Coordination of Humanitarian Affairs [31]. Between 1972 and

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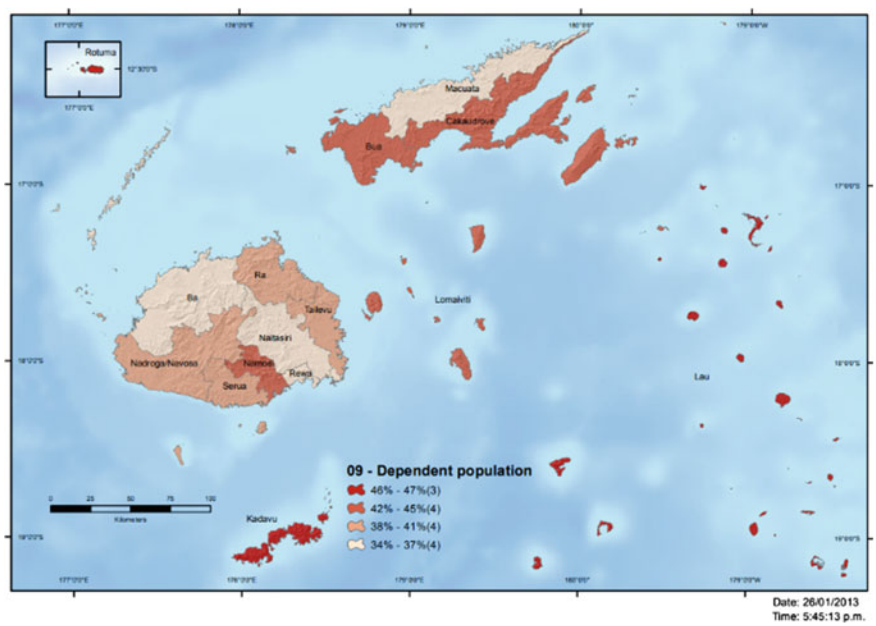


**Fig. 1** Map showing the population distribution in Fiji. *Source* Elkharboutly [13]

1982, cyclones led to the destruction of over 17,000 homes and 700 schools [9]. The United Nations situation reports on Fiji revealed that from 1993 to 2012, the country incurred nearly 1 billion Fijian dollars in damages due to tropical cyclones. The tropical cyclone season spans from early November to late April, as outlined by the Fiji Meteorological Service [40].

In February 2016, Fiji experienced the impact of tropical cyclone (TC) Winston, with the Western Region and Koro Islands identified as the areas most severely affected, as reported by the United Nations Office for the Coordination of Humanitarian Affairs in Fiji OCHA [31]. The devastation caused by the cyclone had repercussions for 540,000 individuals, equivalent to 67% of the nation's total population, as noted by Esler in 2016. The Fijian Ministry of Economy estimated the recovery costs from TC Winston's aftermath to be 1.69 billion Fijian dollars, according to Cirikiyasawa [11].

In the aftermath of the cyclone, the Fijian government introduced the Help for Homes scheme (HFH), characterised as an owner-driven, government-assisted initiative, as outlined by the Government of Fiji in 2016. This study centres on the primary natural hazards in Fiji, specifically cyclones and their impact on housing, considering it the most vulnerable sector in the country due to tropical cyclones. The recurrence of cyclones necessitates the construction of houses with specific features to effectively withstand cyclone damage. The paper undertakes an analysis of the prevalent construction types in Fiji and evaluates their features in comparison to internationally recognised standards for cyclone-resistant housing.

## 2 Literature Review

### *2.1 Tropical Cyclones in Fiji*

Tropical cyclones represent a common threat to communities in the South Pacific, bringing about significant challenges. The formidable winds accompanying these cyclones, coupled with heavy rainfall, high tides, and flash floods, result in the loss of lives and widespread property destruction [10]. The impact of tropical cyclones on Fijian communities has been profound, marked by centuries of recurring devastation. These recurrent destructive events not only cause considerable social distress but also impose a substantial financial burden on the government [31].

Historical records reveal the severity of the impact, with statistics indicating that between 1972 and 1982, over 17,000 homes and 700 schools succumbed to destruction caused by cyclones [9]. Additionally, as outlined in Table 1, the period from 1993 to 2012 witnessed frequent cyclones resulting in a staggering loss of nearly 1 billion Fijian dollars in damages due to tropical cyclone events. In Fiji, the tropical cyclone season spans from early November to late April, as outlined by the Fiji Meteorological Service [40].

Moreover, tropical cyclones are deemed multifaceted hazards, giving rise to various detrimental effects such as flash floods, landslides, coastal erosion, strong winds, airborne debris, and salinization [35].

As indicated in Table 1, the repetitive occurrence of tropical cyclones has inflicted substantial damage on Fiji's housing inventory, in addition to causing harm to infrastructure, agriculture, and livelihoods. The primary factor contributing to the destruction and impairment of houses is the development of strong wind gusts during tropical cyclones.

### *2.2 Post-disaster Housing in Fiji*

For generations, native Fijians adhered to the traditional practice of self-recovery following each natural disaster, encompassing activities like food redistribution, house reconstruction, and even the relocation of entire villages [36]. The government's involvement in house rebuilding activities only commenced in late March 1910, prompted by a severe cyclone that damaged all houses on Bau Island. This led to a government initiative to construct 80 homes in the affected region, providing assistance in the form of traditional building materials and grants for the victims. The traditional bure, a prominent housing type, played a crucial role in Fiji's self-recovery until the 1940s [4, 6].

In 1960, the Emergency Services Committee (EMSEC) was established as an ad-hoc national committee under the Ministry of Finance, primarily tasked with issuing warnings and providing short-term relief and rehabilitation during disasters [7]. However, limited budget allocations hindered the development of the intended

**Table 1** Fiji's major cyclones over 23 years

| Date | Natural hazard | Cyclone category | Houses destroyed | Houses damaged | Amount of loss, in millions (FJD) | References |
|---|---|---|---|---|---|---|
| 02/01/1993 | Tropical cyclone Kina | 4 | Value (110 FJD) | | 110 | UN-DHA situation report [32] |
| 1998 | Tropical cyclone Gavin | 4 | Value (18.3 FJD) | | 18.3 | UN-DHA situation report no. 4 [30] |
| 14/01/2003 | Tropical cyclone Ami | 3 | 2662 | 5890 | 3.0 | UN-DHA report no. 5 [1] |
| 04/04/2007 | Tropical cyclone Cliff | 1 | 18 | 92 | 6.25 | NDMO Report on TC Cliff [27] |
| 28/01/2008 | Tropical cyclone Gene | 3 | Value (5.187 FJD) | | 5.19 | APCEDI Report [2] |
| 16/12/2009 | Tropical cyclone Mick | 2 | Value (7.04 million FJD) | Value (12.85 million FJD) | 19.9 | NDMO Report on TC Mick, National disaster Management Office [28] |
| 11/03/2010 | Tropical cyclone Tomas | 4 | 649 | 1387 | 10.2 | NDMO report on TC Tomas [29] |
| 17/12/2012 | Tropical cyclone Evan | 4 | 2094 | 6403 | 27.83 | PDNA [16] |
| 20/02/2016 | Tropical cyclone Winston | 5 | Over 30,000 | | 751 | PDNA (2016) |

*Source* Elkharboutly [13]

services and efforts to provide housing capable of withstanding natural hazards were redirected towards offering temporary shelters and tents for affected communities [7].

The Prime Minister's Hurricane Relief Committee (PMHRC) was established after Cyclone Bebe in 1972, responding to the crisis that left 60,000 people without shelter [24]. Despite facing challenges, such as purchasing and distributing over 5000 tents, the committee initiated a housing program after Cyclones Bebe, Lottie, and Val. Due to insufficient funds, the PMHRC shifted its focus to rebuilding schools, offering soft loans for house reconstruction to individuals providing securities against the loans. In 1974, with foreign financial aid, a housing program commenced, adopting different models like the Woodtex house in Kadavu island and the Union Marketing model in the outer islands [9].

Tropical cyclone Bebe in 1972, considered one of Fiji's most devastating cyclones [42]. The damages prompted the PMHRC to introduce various housing models between 1972 and 1982 under the Hurricane Relief Homes program. These included concrete block walls with corrugated iron roofing in Rotuma and parts of the Yasawa group, traditional bure houses with concrete foundations in Lau Island, timber-framed houses in Lau, Yasawa, and Kadavu Islands, and the Woodtex house model originating from a New Zealand government donation. However, the Woodtex house had limitations, such as plywood's vulnerability to water, necessitating additional layers of mortar. Moreover, its construction required substantial water, impacting its feasibility in remote villages, and a shortage of skilled labour affected the houses' cyclone resistance [9, 37].

### *2.3 Damages to Housing Resulting from TC Winston*

In February 2016, tropical cyclone Winston struck the Fiji Islands, with its impact notably felt in the Western Region and the Koro Islands, as reported by the United Nations Office for the Coordination of Humanitarian Affairs in Fiji. TC Winston's effects reached 540,000 people, equivalent to 67% of the country's entire population, according to Esler [15]

The devastation caused by tropical cyclone Winston was extensive, leaving residents in the impacted areas as shown in the path of the cyclone Fig. 2, without essential necessities such as food and shelter. The affected communities faced disruptions in their livelihoods due to crop loss, damage to homes, public services, and infrastructure, including roads, affecting transportation to and from villages [21].

Following tropical cyclone Winston, the Fijian government conducted an assessment to gauge the extent of regional damage. This evaluation aimed to appropriately allocate assistance to the affected communities based on their specific needs [15]. According to the Post-Disaster Needs Assessment (PDNA), 57% of Fiji's housing stock was reasonably well-constructed, comprising timber-framed houses with corrugated iron or timber cladding, while 40% consisted of concrete or masonry structures. Despite this, the estimated value of damage to the housing sector exceeded 750 million Fijian dollars [11]. The Fijian government reported that the anticipated costs for recovery and reconstruction after TC Winston in 2016 surpassed 0.9 billion USD, representing over 20% of the country's GDP in 2016 [22].

The havoc caused by tropical cyclone Winston was massive, leaving inhabitants in the affected areas without food or shelter. The livelihood of the affected communities was disturbed due to the loss of crops and damage to homes and public services, in addition to destroyed roads and infrastructure, which affected commuting to and from the villages.

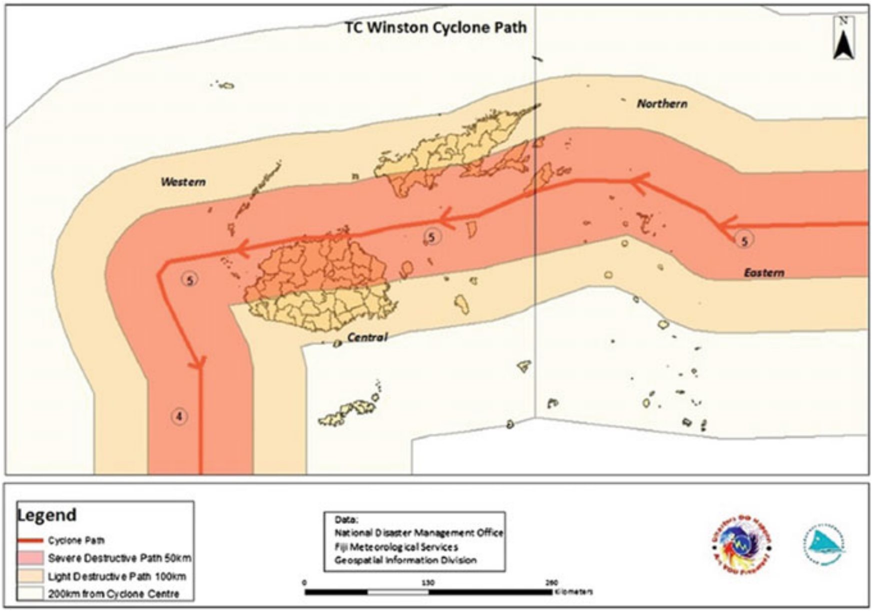


**Fig. 2** Tropical cyclone Winston 2016's path. *Source* Elkharboutly [13]

## 2.4 Village Damage After Tropical Cyclone Winston

Tropical cyclone Winston struck the village during the night and owing to its geographical position and the confluence of high tide and heavy rainfall, the entire village was inundated. Combined with the intense winds, this made it one of the most severely affected areas in Fiji. The village faced extensive flooding, and out of its 98 houses, 54 suffered irreparable damage, while 33 sustained partial damage. Seeking refuge, the village community sought shelter in two concrete houses and the village church. The extent of damage to housing, stored food, and crops cultivated in the village is depicted in Fig. 3.

## 2.5 The HFH Scheme in Post-TC Winston

In the post-Tropical cyclone Winston reconstruction efforts, the Fijian government implemented the Help for Homes scheme (HFH) as a government-assisted, owner-driven initiative [19]. Under this scheme, homeowners were eligible to receive hardware assistance valued up to 7000 Fijian dollars for the reconstruction or repair of their damaged homes. To determine eligibility and the allocated amount, the government established specific criteria for homeowners to meet.


**Fig. 3** Damage to Namuaimada village after Cyclone Winston. *Source* Elkharboutly [13]

The implementation of HFH occurred in three phases, targeting 12 districts significantly impacted by TC Winston, and the final phase concluded on July 24, 2017 [33]. The project followed an electronic-voucher-based system, where vouchers could only be redeemed for the purchase of house-building materials from designated hardware stores, as outlined in the flowchart of activities presented in Fig. 4 [19, 39].

To participate in the program, beneficiaries underwent an application process and were assessed by a representative from the Ministry of Women, Children, and Poverty Alleviation (MWCPA) to determine their eligibility and the approved financial assistance amount. Beneficiaries received 1500 Fijian dollars for minor damage, 3000 Fijian dollars for significant damage, or 7000 Fijian dollars for a complete house rebuild. Eligible beneficiaries were issued a voucher card loaded with the approved cash amount.

The program encountered challenges related to material availability, often necessitating imports. Another issue involved the logistical difficulty of delivering materials to individuals, particularly in maritime and rural communities. Additionally, a lack of construction expertise within the communities had a detrimental impact on the quality of houses, consequently heightening the vulnerability of these communities.

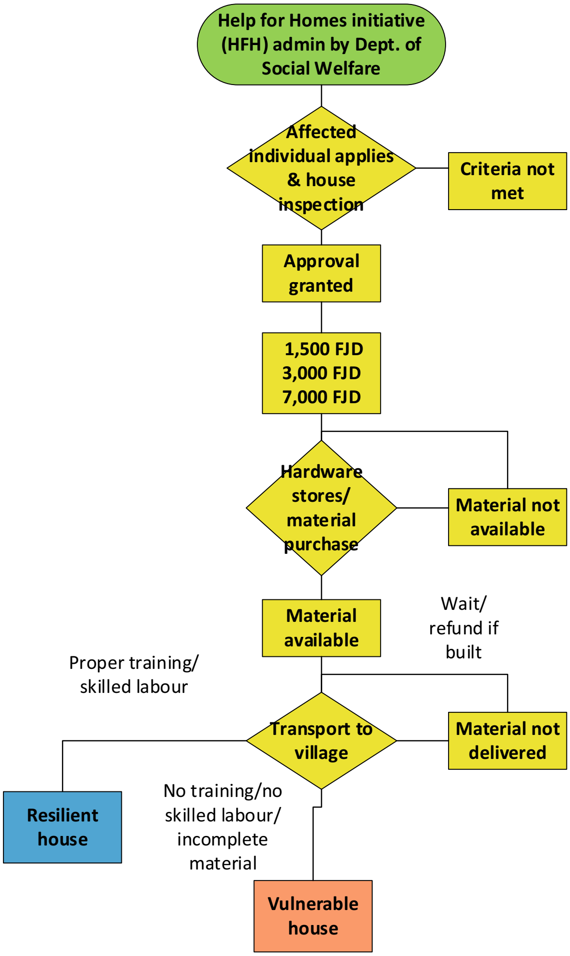


**Fig. 4** Flowchart of HFH process. *Source* Elkharboutly [13]

# 3 Research Method

## *3.1 Overview*

This research examined the homes constructed through the Fijian government's HFH scheme, focussing on Namuaimada village, which was devastated by TC Winston. The housing reconstruction in this village served as a case study for the investigation. The qualitative research approach involved analysing documentation, conducting semi structured interviews with various stakeholders. The study also included field observations in the village to gather housing related comprehensive data. The interviews and field observations were conducted between August 2017 and July 2018.

The chosen methods align with recommended practices for qualitative research as outlined by Becker et al. [5], Creswell and Poth [12].

## 3.2 Data Collection Process

The study commenced with establishing the objectives for assessing post-disaster housing construction in Fiji after TC Winston. Desktop analysis of various documents was undertaken to assess the situation related to post-disaster housing in Fiji and the best practices for cyclone-resistant homes. Based on the literature review findings and the study objectives, interview questions were developed for each group of respondents. For government officials, the questions centred around legislative issues, codes, logistics, and process timelines. For not-for-profit organisations, the questions were developed to capture their overall role in the reconstruction process. For the community, the questions were formulated to uncover their experience from the day the disaster struck to the accomplishment of village reconstruction. All questions were open-ended to capture the respondents' thoughts surrounding the reconstruction process.

### 3.2.1 Interviews with Various Stakeholders

The chief of Namuaimada village was interviewed by the researcher, providing a comprehensive account of the village's condition before, during, and after TC Winston. Additionally, government officials from the Rural Housing Unit (RHU) at the National Disaster Management Office (NDMO) were interviewed. Furthermore, discussions were held with shelter specialists from both Habitat for Humanity Fiji (HFHF) and Fiji Red Cross Society (FRCS) to elucidate the roles played by governmental and non-governmental organisations in the implementation of the HFH scheme.

### 3.2.2 Site Observations

In this research, alongside semi-structured interviews, site observations were carried out to gather information regarding the reconstructed houses in the investigated case. Transect walks were conducted throughout the village, involving visual inspections and measurements of each house. Data were documented through note-taking and digital photography. The descriptive notes and digital images were subsequently organised based on identified features aimed at enhancing the cyclone resistance of houses. A summary of categorised findings was then compared to conclusions drawn from the reviewed literature to evaluate the resilience of the reconstructed houses in the village under study.

### 3.3 *Study Area and Demographics*

Namuaimada is a sizable village situated along the northern coast of Viti Levu, one of Fiji's primary islands. It is part of the Rakiraki district in the Ra province, consisting of five villages. Geographically, Namuaimada is positioned on a level plain nestled between the coastline and the elevated hills of Rakiraki. The village is home to a population of 447 individuals residing in 98 houses. Location as shown in Fig. 5.

## 4 Study Findings

In this section, study findings are analysed and categorised. The first subsection discusses how the houses were reconstructed in Namuaimada village post-TC Winston. In the second, the types of houses and their physical features are discussed. In the third, the results relating to the house features are categorised under roofs, structural connections, roof extensions, walls, and foundations and discussed.

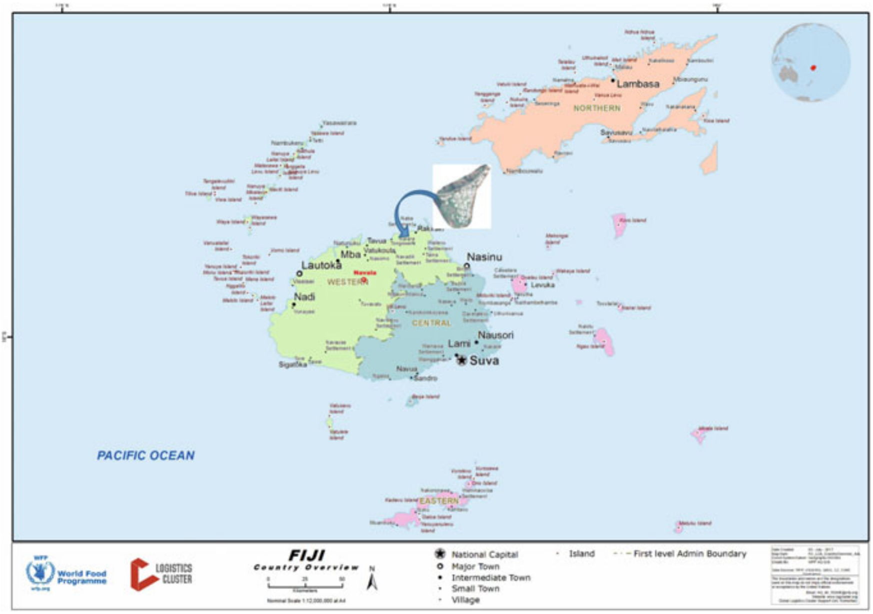


**Fig. 5** Map of Fiji showing the location of Namuaimada. *Source* Logistics Capacity Assessment home page, https://dlca.logcluster.org). *Source* Elkharboutly [13]

### 4.1 Village Damage After Tropical Cyclone Winston

During the night, tropical cyclone Winston struck the village, causing extensive damage. The village's geographical location, coupled with a combination of high tide and heavy rainfall, led to severe flooding. Alongside the intense winds, Koko experienced one of the most severe impacts in Fiji. The entire village suffered significant destruction, with 54 out of its 98 houses rendered irreparable and 33 partially damaged. To seek refuge, the village community sought shelter in two concrete houses and the village church.

### 4.2 The HFH Scheme and Technical Support

Carpentry training is an important aspect of ensuring the adequacy of the reconstruction of houses. Participants N1&N2 mentioned that they provided house-building training for the affected communities using the build back safer guidelines. N1 mentioned that they constructed more than 115 transitional houses and used the construction of those houses as practical carpentry training on house building. The training included about 1400 trainees from 261 rural communities. Participant N4 mentioned that 35 model houses were constructed and were voluntarily meant to complement the HFH scheme by providing a model for what can be included in a house worth 7000 FJD and using the house construction for training the communities. According to participant N4, the house materials cost escalation affected the house's estimated cost. The cost of the house constructed reached 30,000 FJD. Participants N1, N2, N3, and N4 indicated that the training was not coordinated with the HFH scheme as some villages were trained while they did not have the required house-building material.

In contrast, other villages had the training after completing the village reconstruction. Participant G1 identified that the NDMO's role in the HFH was confined to providing help to other government organisations in the villages' damage assessments, but the NDMO was never consulted on the HFH scheme. Training rural communities is one of the main activities G2 & G3 participants mentioned they performed regularly after TC Winston. They provided Four regional carpentry training covering the four Fijian main regions with an allocated budget of 231,000 FJD. The training was also based on the Build Back Safer techniques. The program managed to train 150 rural carpenters and provided the trainees with a complete toolbox and a certificate. As G2 and G3 participants stated, it was meant to raise the local capacity; nevertheless, it was not coordinated with the HFH scheme.

## 4.3 Houses in Namuaimada After Tropical Cyclone Winston

Following the disaster, the village chief convened the villagers to construct temporary shelters using materials salvaged from the damaged houses. Within two weeks post-disaster, the community managed to build 16 such shelters, providing some immediate relief. However, recognising the necessity for permanent housing to restore normalcy, the villagers embarked on a six-month recovery journey.

During this period, the village chief led the reconstruction efforts, leveraging the government's HFH scheme, which aimed to assist in rebuilding damaged houses. The scheme provided a credit of up to 7000 FJD for housing materials. The village chief was a former employee of a prominent local hardware store, took charge of collecting HFH voucher cards from the village community. Skilfully, he procured the required building materials—including timber pine poles, corrugated iron sheets, cement, and concrete blocks—promptly bringing them into the village.

To expedite the reconstruction process, the village chief organised the adults into six groups, each supervised by one of the village's four carpenters, who lacked formal qualifications in carpentry. In just six months, the concerted effort of these groups resulted in the complete rebuilding of the village. Remarkably, they even constructed 10 new houses for individuals in the village who had never owned a house before. The village chief noted that the role of NGOs in the village was limited to providing technical advice, with an international construction firm donating two houses and a missionary group building one. The village houses exhibited diverse designs, as some residents purchased designs from the Rural Housing Unit, while others opted to create their own. The housing typology in the village, based on field observations, will be further explored in the next subsection.

## 4.4 Types of the Reconstructed Houses

Various types of houses were observed in the reconstructed village. The houses in general were timber framed houses and concrete block houses. All the roofs where constructed out of corrugated iron sheets and where either flat roofs or gabled roofs.

### 4.4.1 Timber Frame Houses with Raised Concrete Floor

Prior to the cyclone, a prevalent architectural element in houses was the elevated timber platform supported by short stilts. Originally, this platform served as the foundation, with the house structure subsequently erected on it. However, this design proved ineffective during the cyclone, leading to the complete destruction of the house structure and partial damage to the timber platform, as shown in Fig. 6 (left). In the aftermath of the cyclone, a significant shift occurred in the reconstruction of houses, with the majority adopting a raised concrete foundation. The house perimeter was

**Fig. 6** Concrete foundation with timber corner post embedded into the foundation (left); damaged raised timber platform (right). *Source* Elkharboutly [13]

defined by concrete blocks, positioned approximately three blocks above ground level, with two blocks embedded, and the space between filled with earth. The top of the foundation featured a 5 cm concrete screed. In the case of new timber-framed houses, corner posts were embedded in the house backfill using poured concrete. The elevated concrete floor with corner post embedment is depicted in Fig. 6 (right).

### 4.4.2 Timber-Framed Houses

The predominant architectural model adopted for new constructions in the village was the timber frame. These houses exhibited variations in size and the materials utilised for wall claddings. Some featured timber weatherboard, while others utilised corrugated iron sheets for wall cladding. The construction styles also differed, with certain houses built on a raised concrete floor (Fig. 7, right), while others were elevated on stilts (Fig. 7, left). Regardless of the construction method, all timber-framed houses shared a common design with corrugated iron roofing material placed on a gabled timber roof structure.

**Fig. 7** Timber-framed houses on stilts (left) and a concrete foundation (right). *Source* Elkharboutly [13]

**Fig. 8** Concrete-block house with reinforced columns (left); a concrete-block house without steel reinforcement (right). *Source* Elkharboutly [13]

#### 4.4.3 Concrete-Block Houses

In the midst of tropical cyclone Winston, villagers sought shelter in two concrete houses and the church, emphasising their trust in the resilience of concrete structures against powerful winds and flooding. Notably, certain concrete-block houses in the village featured reinforced concrete columns, while others lacked steel reinforcements. Figure 8 illustrates both variations, with corrugated iron roofing sheets adorning either a gabled or nearly flat timber-framed roof structure.

However, uniformity in the construction of concrete houses throughout the village was notably absent. While some structures showcased high-quality professional construction, others were of inferior quality. This discrepancy is clearly illustrated in Fig. 8 (left), where a red arrow draws attention to deterioration in the reinforced concrete structure.

### *4.5 Physical Features of the Houses*

(1) **Roof Pitch, Eaves, and Overhangs**

It was found that most of the roofs had zero pitch meaning completely flat (Fig. 9, top left) or gabled with pitch varies between 5 and 15° (Fig. 9, top right). The majority of village houses featured eaves extending up to 800 mm in width, as depicted in Fig. 9 (bottom right). Additionally, certain houses boasted a substantial, wide, exposed overhang utilised as either a veranda or patio, as illustrated in Fig. 9 (bottom left).

(2) **Structural Connections**

In the village, the houses inspected showed a lack of use of metal straps, as in Fig. 10 (right). The house floor is seen as connected to the stilts with no straps.


**Fig. 9** Flat roof (top left); gabled roof with exposed eaves (top right); large roof overhang (bottom left); flat roof with wide eaves (bottom right). *Source* Elkharboutly [13]

The photo in Fig. 10, (left) shows a house owner attempting to strengthen the roof structure by strapping it to the sides of the house. In the case of one stilt-supported house, the floor beams were affixed to the side of the stilts without any indication of metal strapping to secure the floor structure to the stilts, as depicted in Fig. 10 (right). It was also observed that most of the iron roofing was connected to the purlins using nails, and there was no sign of using screws to hold down the roof material.

(3) **House foundation**

In Namuaimada, the rebuilt houses featured various foundation types. Following tropical cyclone Winston, the village community firmly embraced the belief that a

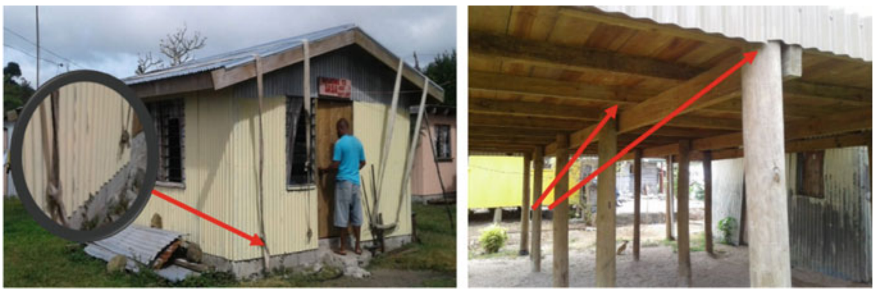

**Fig. 10** Locals attempting to strengthen the roof structure (left); a house's structural connection with no metal straps (right). *Source* Elkharboutly [13]

**Fig. 11** A house on raised timber platform (left); a house on an elevated platform (right). *Source* Elkharboutly [13]

sturdy foundation was integral to constructing a resilient house. Without the presence of building codes, it was noted that there were two primary categories of house foundations in the village: timber and concrete.

i. **Timber Foundation**

Certain houses, particularly those situated along the shoreline, were constructed on timber pine posts, resembling stilts, as illustrated in Fig. 10 (right). This innovative approach by homeowners aimed to mitigate the risk of flooding during extremely high tides, a concern heightened by the village's experience during tropical cyclone Winston. The raised timber foundation was specifically observed in only two houses near the shoreline.

Conversely, timber platform house foundations, exemplified by the one depicted in Fig. 11 (right), were still in use, despite being one of the features susceptible to damage during the cyclone, as previously shown in Fig. 11 (left).

ii. **Concrete Foundation**

The predominant foundation type in Namuaimada is the concrete block foundation, as illustrated in Fig. 12. This foundation design incorporates concrete blocks along the house perimeter, complemented by an earth backfill and a 50 mm concrete screed atop the backfill. Notably, the use of a concrete foundation was widespread for both concrete-block houses and timber-framed houses. The exact number of courses embedded below ground level was not explicitly determined. Nevertheless, observations revealed a consistent pattern, indicating that all village houses with a concrete foundation had a uniform configuration of only two courses above ground level.

(4) **House Walls**

As depicted in Fig. 13, the village residences generally follow a rectangular layout. The houses exhibit varying lengths, ranging from 7200 mm to 9000 mm, and widths spanning from 4000 mm to 5600 mm. A characteristic feature of these houses is their

**Fig. 12** Concrete houses on a concrete foundation, with two courses above the ground being common practice. *Source* Elkharboutly [13]

elevated walls, with heights ranging from 2400 mm on the eave sides to 3400 mm on the ridge sides.

The majority of houses in the villages featured wide louvred glass windows and sizable doors, a characteristic observed in both timber-framed and concrete houses. Residents explained that adequate ventilation was essential to regulate indoor air temperature, especially considering the heat generated by the iron roofing. Some houses incorporated protective measures for windows, including wooden storm shutters, while others utilised steel mesh installed outside the window openings. Figure 14 depicts the three distinct types of windows found in the village.

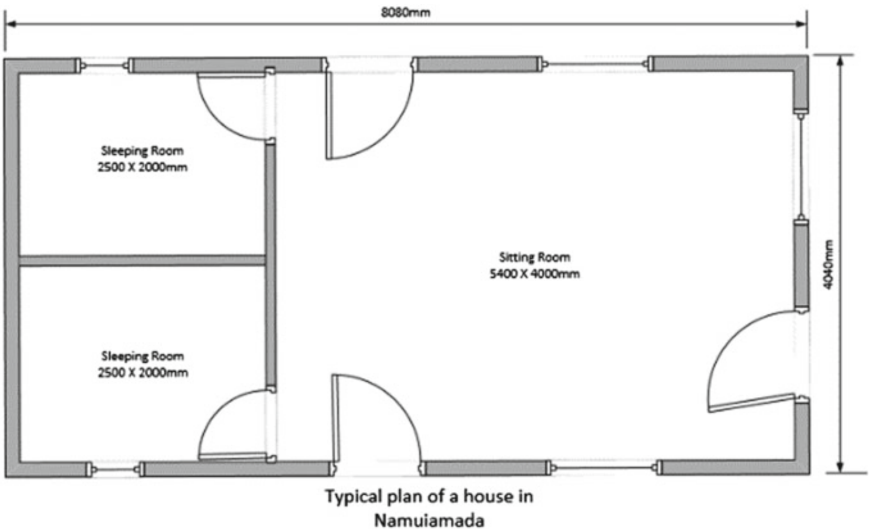


**Fig. 13** Plan for a typical house in Namuaimada. *Source* Elkharboutly [13]

**Fig. 14** Windows protected with timber shutters (left); unprotected louvred glass windows (middle); steel-mesh-protected glass windows (right). *Source* Elkharboutly [13]

## 5 Discussion

The Help for Homes (HFH) scheme provided affected individuals with credit for materials to repair or reconstruct their damaged houses. The scheme lacked the provision of technical support, and it was found that in Namuaimada, the houses constructed under the HFH scheme lacked the basic internationally accepted cyclone-resistant house features. Post Topical cyclones Winston, the villages damage questions the resilience of the constructed houses in the Fijian villages, which mostly featured timber frames and corrugated iron roofing. This study focussed on gathering information related to housing reconstruction schemes and methods following TC Winston.

Namuaimada, situated as one of the coastal villages, endured substantial devastation from tropical cyclone Winston in 2016. Post-cyclone, a staggering 80% of the houses were damaged, significantly impacting the lives of all 447 village residents. Undeterred, the villagers undertook the reconstruction of 64 new houses and the repair of 33 more through the HFH scheme. Spearheading the recovery efforts, the village chief assumed the responsibility of procuring building materials from the hardware store and orchestrated the entire village reconstruction. Remarkably, this initiative occurred without any external technical support or training in resilient house-building techniques.

There was no evidence that the village community was trained on carpentry or housing construction best practices. The trainings provided by the various NGOs and the RHU were all based on the best practices summarised in the Build Back Safer (BBS) handbook published by the shelter cluster. What was included in the BBS will not be discussed in this study. However, it became clear from the findings that all training efforts undertaken by the NGOs and the RHU were not coordinated with the HFH scheme.

As asserted by the village chief, the houses reconstructed after the cyclone are considered to be stronger than those in place before the cyclone. The study findings, however, identified the vulnerability of the reconstructed houses under the HFH scheme in Namuaimada regarding cyclone resistance. This was clearly observed in the houses' details, especially the full-size windows that was observed in most of the constructed houses. The wide windows deemed necessary due to the use of corrugated iron sheets for roofing and some houses with Iron sheet wall cladding. The Iron sheeting raises the house's internal temperature, rendering it necessary to have wide windows for ventilation. However, comparing the timber frame houses to traditional Fijian houses, the thatching roof material in the traditional houses provided good heat insulation, and the breathable walls from bamboo reeds or mats allowed for house ventilation without the need for wide windows [8]. In addition, very few window protection like timber shutters were found. As highlighted by Elkharboutly [13], Arya and Agarwal [3] and Minor [26], during heavy wind, wide glass windows with no protection can easily break and damage the building envelope in due to pressure build-up inside the house. Another finding was the average wall height of the houses in Namuaimada is close to 3 m. This wall height is not recommended in cyclone-prone areas, as the wall elevations must be kept low [14, 41]

Contrary to the recommended foundations for cyclone-resistant houses, research emphasises the necessity of secure anchorage of the building to the ground for enhanced cyclone resistance [14, 20, 23]. Additionally, studies advise against the construction of houses on stilts in cyclone prone areas (Taher 2007). In Namuaimada, it was observed that certain houses were erected on raised platforms or stilts, deviating from the suggested guidelines for cyclone-resistant housing. However, a more effective approach was evident in some timber-framed houses in the village, where direct posts with secured anchorage to the foundations were utilised.

In Namuaimada, most reconstructed houses differ from the recommended cyclone-resistant design, featuring flat or slightly sloped roofs and gabled roofs with pitches below 30°. Contrary to international guidelines, these houses also commonly incorporate wide roof overhangs. This deviates from the recommended practices to prevent roof failure under heavy wind conditions as highlighted by Elkharboutly and Wilkinson [14]. This proves the vulnerability of houses constructed post-TC Winston 2016 in Namuaimada, particularly in terms of their gabled or flat roofs, despite the overall strength of the concrete-block house structures.

Finally, the structural connections of the houses also did not produce the desired strength for a cyclone-resistant structure. For concrete houses, the connection between the wall and the roof beams could be considered the weakest connection in the structure. It was also observed that there was a lack of use of hurricane straps in the connections of the timber frame houses where hurricane straps were proven, in experiments by Riley and Sadek [34], to be efficient in preventing the failure of the connections under heavy wind conditions.

The study recommends that future housing schemes, especially those restricted to providing cash or material credits, be complemented with a technical support aspect that is well coordinated with the construction activities.

The study also recommends the implementation of some technical features to increase the resilience of the constructed homes, including metal strapping in the structural joint connection and screws for the attachment of roof sheets.

Given Fiji's climate, it is advisable to incorporate roof insulation with iron roofing. This approach helps to regulate the indoor climate without relying on full windows, a practice discouraged in cyclone-prone areas. Also, the recommended roof configuration is a hipped design with an incline from all four sides, featuring a steep pitch of approximately 30°. Opting for a roof structure with trestles is preferred over a simpler design with beams and purlins. Beyond roof material, shape, and structure, it is recommended to eliminate overhangs and keep eaves to a minimum, not exceeding 30 cm, with the roof edge attached to a perimeter beam.

For the house foundation, the study recommends an elevated foundation to protect the houses from flood threats. Adding to this, the structural columns carrying the house roof should be “direct posts”, which was noticed in some of the houses and it is recommended to be a standard practice. It is not recommended for houses to be constructed on a timber platform foundation, as from observation, it failed as a result of the cyclone.

The study analysed the houses in Namuaimada village constructed after TC Winston under the HFH scheme. Further study can take place to assess houses in other villages, especially those reconstructed by the NGO or the RHU.

## 6 Conclusion

The study has analysed the houses constructed in Namuaimada village under the HFH scheme. The studied case provided a comprehensive picture of post disaster self-recovery supported by the government. The constructed houses were mainly concrete block and timber frame houses with corrugated iron roofing and unprotected wide glass windows.

Cyclones are the most prevalent natural hazard in Fiji, and the research showed that the paucity of cyclone-resistant house features in the reconstructed houses seems to point to a short-term solution being provided for an ongoing problem, ultimately negatively affecting the community and increasing its vulnerability for being damaged due to heavy winds.

This paper demonstrated the importance of providing coordinated technical support with the post-disaster housing schemes that provide house-building materials. Almost all the houses studied in Namuaimada were not constructed to a sufficient level that protects houses during cyclones. The houses’ features did not comply with the internationally accepted cyclone-resistant features. It is recommended that technical support should be provided at the core of owner-built housing schemes. The constructed houses, however, should include cyclone-resistant features to assist resilience building in the affected communities.

## 7 Ethics Statement

The authors confirm that all research involving human participants in this study was conducted in accordance with relevant ethical standards and regulations. Ethical approval for this study was obtained from the University of Auckland ethics Committee.

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## References

1. Affairs U. o. f. t. c. a. H. (2003) Fiji-cyclone ami OCHA situation report no. 5
2. APCEDI (2008) Asia Pacific center for emergency and development information, Alert SP/FJ 15P Gene#7-2008. Available: https://reliefweb.int/report/fiji/apcedi-alert-spfj-15p-gene-7-2008-cyclone-gene-pounds-southern-vanuatu-and-causes
3. Arya A, Agarwal A (2007) Cyclone resistant building architecture
4. Bayliss-Smith T, Brookfield M, Bedford R, Brookfield H, Latham M (1988) Islands, islanders and the world: the colonial and post-colonial experience of eastern Fiji. Cambridge University Press
5. Becker H, Berger P, Luckmann T, Burawoy M, Gans H, Gerson K, Gerson K, Gerson K, Glaser B, Strauss A (2002) Observation and interviewing: options and choices in qualitative research. Qual Res Action 6:200–224
6. Bedford RD (1988) Population movement in post-colonial Fiji: review and speculation. GeoJournal 16**:**179–192. https://doi.org/10.1007/bf02433013
7. Benson C (1997) The economic impact of natural disasters in Fiji. Overseas Development Institute, London
8. Campbell J (2009) Islandness: vulnerability and resilience in Oceania
9. Campbell JR (1984) Dealing with disaster hurricane response in Fiji. Govt. of Fiji
10. Chand SS, Dowdy A, Bell S, Tory K (2020) A review of South Pacific tropical cyclones: impacts of natural climate variability and climate change. In: Climate change and impacts in the pacific. Springer
11. Cirikiyasawa P (2016) Disaster recovery framework: tropical cyclone Winston 20th February 2016. Suva, Fiji
12. Creswell JW, Poth CN (2016) Qualitative inquiry and research design: Choosing among five approaches. SAGE Publications
13. Elkharboutly M (2020) Post-disaster response and recovery in Fiji: a qualitative analysis of response and reconstruction post-tropical cyclone Winston 2016. ResearchSpace@ Auckland
14. Elkharboutly M, Wilkinson S (2022) Cyclone resistant housing in Fiji: the forgotten features of traditional housing. Int J Dis Risk Reduction 82:103301
15. Esler S (2016) Post disaster needs assessment: tropical cyclone Winston, 20 Feb 2016
16. Fiji GO (2013) Post-disaster needs assessment: tropical cyclone Evan, 17th Dec 2012
17. Fiji Islands Bureau of Statistics (2007) 2007 Fiji census of population and housing
18. Fiji Islands Bureau of Statistics (2017) 2017 Population and housing census
19. Government of Fiji (2016) Hon PM Bainimarama speech at launch of Help for homes initiative and launch of adopt a school website. News and Press Release, Government of Fiji
20. INTERTECT (1982) Improvement of low-cost housing in Fiji to withstand hurricanes and earthquakes. Dallas
21. Magee AD, Verdon-Kidd DC, Kiem AS, Royle SA (2016) Tropical cyclone perceptions, impacts and adaptation in the Southwest Pacific: an urban perspective from Fiji, Vanuatu and Tonga. Nat Haz Earth Syst Sci 16:1091–1105. https://doi.org/10.5194/nhess-16-1091-2016
22. Mansur A, Doyle J, Ivaschenko O (2017) Social protection and humanitarian assistance nexus for disaster response: lessons learnt from Fiji's Tropical Cyclone Winston, World Bank
23. Mayo A (1988) Cyclone-resistant houses for developing countries. Building Research Establishment, Overseas Division
24. McLean RF (1977) The hurricane hazard: natural disaster and small populations. Australian National University for UNESCO, Development Studies Centre
25. Ministry of National Planning F (2010) Millennium development goals: 2nd report, 1990–2009 Report for the Fiji Islands

26. Minor JE (2005) Lessons learned from failures of the building envelope in windstorms. J Archit Eng 11:10–13
27. National disaster Management Office, N., 2007 (2007) February/March/April 2007 flood and tropical cyclone cliff, Northern, eastern and Western Division
28. National disaster Management Office, N., 2010 (2010) Tropical cyclone MICK report: 13th–16th Dec 2009, damages assesments, response and relief actions and rehabilitation and reconstruction recommendations. National disaster Management Office, NDMO
29. (NDMO) N. d. M. O. (2010) Tropical cyclone Tomas Report: 12th–16th March 2010 damages assessments, response & relief actions and rehabilitaion & reconstruction recommendations
30. OCHA (1997) Fiji-cyclone Gavin DHA situation report no. 4. The Republic of Fiji, United Nations department of Humanitarian Affairs
31. OCHA (2016) Fiji: severe tropical cyclone winston, situation report no. 20 (as of 31 March 2016). The Republic of Fiji (OCHA)
32. OCHA (1993) Fiji-cyclone Kina Jan 1993 UN DHA situation report 1–6. The Republic of Fiji
33. Ravulo A (2018) Over $100million used for help for homes
34. Riley MA, Sadek F (2003) Experimental testing of roof to wall connections in wood frame houses. US Department of Commerce, Technology Administration, National Institute of Standards and Technology, Maryland
35. Terry JP (2007) Tropical cyclones, climatology and impacts in the south Pacific. Springer
36. Thompson L, Bronislaw M (1940) Fijian Frontier. American Council, Institute of Pacific Relations
37. Tighe M (1980) The cyclone christened Meli. Fiji. Ministry of Information Suva, Fiji, Suva
38. UNFCCC (2013) Republic of Fiji, Second National Communication to the united nations framework convention on climate change. Republic of Fiji. Available: http://unfccc.int/resource/docs/natc/fjinc2.pdf
39. Vacala K (2016) Criteria for home rebuild assistance. Fijian Broadcasting Corporation, 29/04
40. Fiji Meteorological Service (2018) Fiji climate outlook. Nadi, fiji. Available: www.met.gov.fj.
41. Yazdani N, Townsend T, Kilcollins D (2006) Construction aspects of in-home hurricane wind shelter rooms. J Coastal Res, pp 862–871
42. Yeo SW, Blong RJ (2010) Fiji's worst natural disaster: the 1931 hurricane and flood. Disasters 34:657–683

# Theme: Innovation

# A New Approach Toward Hazard Mitigation by Designing Moveable Architectural Space

**Seyedehfatemeh Kamali and Han-Hsiang Wang**

## 1 Introduction

Due to global warming, scarce resources, and environmental degradation natural disasters have been occurring with increasing frequency and effects in recent decades around the world [9]. Particularly in underdeveloped nations, they have taken a disproportionately severe toll in terms of human losses and physical damages [9]. It is undeniable that construction is an essential part of human beings' lives, and the impact of the modern construction industry on the Earth's ecosystem and humans' quality of life cannot be ignored [12]. Clearly, as the population grows and rural–urban immigration rates rise up since urban development cannot cope with the demands, a salient portion of each community has to live in sub-urban hazard-prone areas [2, 12].

Nowadays, more than one billion people reside in marginal and informal settlements, many of whom have lack access to basic services, usually dwelling in high-risk areas and this number will continue increasing [2]. Accordingly, it is of great significance for human societies to seek building environmental resiliency in order to equip people for disaster management, particularly in developing countries that are less able to deal with natural disasters' causes and impacts [9, 12].

As most countries have widespread and increasing concerns about the growing population, sustainable development of society, land shortage crisis, and inevitable natural disasters the requirement for making more lands habitable in order to respond to the demands has been continuously posing challenges for the architecture, engineering, and construction (AEC) industry, as did the need to take an action for effective disaster management in many countries at the international level [8].

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However, since structures are mostly static and non-adjustable to either climate changes or inhabitants' requirements, the construction industry has fallen far behind to achieve the goal through traditional immoveable architectural styles [5]. Although we live in a dynamic universe filled with movement, the design approach that has been given to architecture is obviously static since buildings are still and their configuration doesn't change either [4]. Struggling to find constructional substitutions over the years, many approaches and methods have been developed, from which kinetic architecture satisfies the scientists' and engineers' expectations as a modern innovation [1]. In the world of growing and changing demands on buildings, moveable elements help to increase the responsibility for inhabitants' needs and requirements [11]. The idea of portable architecture that can react effectively to environmental demands or reply to specific user requests, is the one that grabs the imagination of both designers and users simultaneously [10]. The utilization of kinetics started from moveable building components emersions such as sun shades, windows, stages, and turntables, then continued to buildings that revolve as a whole [6]. Moveable systems vary in their complexity assessed by the level of applying embedded controlling systems, advanced materials, and high technologies [6]. Movability actually used to be added as a feature through mechanical means; however, nowadays, it can be the construction nature using artificial intelligence (AI), and computation in construction [6]. Creating moveable buildings can serve different purposes including responsibility for users' needs, space efficiency, adaptation, and interaction with climate changes as well as hazard mitigation in danger-prone environments [5] that is the focus of this study.

## 2 Proposed Methods and Current Findings

In order to better meet current and future needs, this study is focused on how buildings or their components must integrate with their surroundings. In order for this to happen, the idea of mobility is employed as a design strategy to develop efficient novel building forms that are flexible, displaceable, and adaptable to a variety of purposes [7]. To put it another way, this research considers movability as a technical design framework and approaches hazard mitigation as a design challenge. The kinetic function of a structure in the context of architecture depends on included mechanical elements that are capable of motion. As a result, a whole new design methodology is required evidently, in which the architectural form may be innately adjustable, deformable, expandable, or in some other manner able to move [7].

The research methodology begins with a thorough literature review including case studies, during which the facing problems while building the simulated models are discussed, and the solutions with the help of kinematic methods are offered. The reason for preferring this method is to prove the applicability of kinetics in the architecture field toward natural hazard mitigation. The key elements of kinetic design and its actual components are determined after the detailed literature review is done.

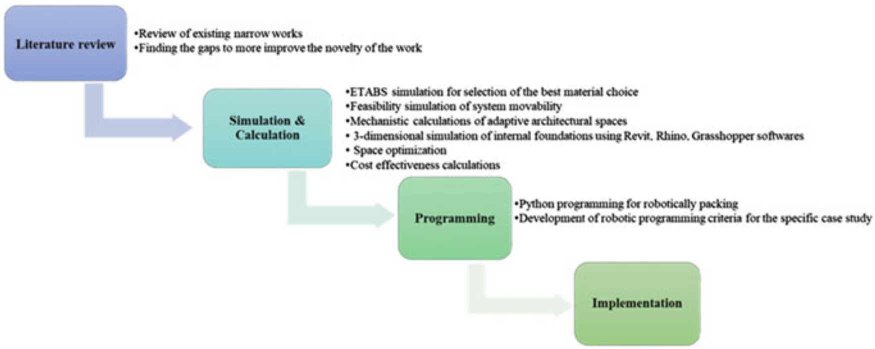


**Fig. 1** Proposed research methodology (Author)

Within the scope of this research, the main questions requiring the realization of kinetic architecture include what they are, what they can do for us, and how we can go about designing them. Figure 1 demonstrates the proposed research methodology.

The measurements of existing kinetic structures have been used throughout this study to demonstrate the feasibility of kinematic methods in the design process of interacting space organizations, and the following results are found to be significant:

## 2.1 *The Flexibility of Space is Facilitated by the Ability of Kinetic Structures to Move*

Contemporary structures are expected to be adaptable and responsive. Currently, a variety of structures are developed to allow further application of flexibility concepts, but none of them are capable of meeting all demand. The flexibility of space is enhanced by the kinetic structures' moving capacity. An architectural space would be more adaptable with a convertible structure that can respond to hazard mitigation requirements by using a different design technique, like motion [7].

## 2.2 *The Architects' Perspective of a Valuable Construction Has to Modify*

A kinetic designer must make significant adjustments to their design process, hence the transformation must begin from the designer's mind. In contrast to what is now the case and instead of aiming to build a monument for decades, an architect's ultimate purpose should be to develop a responsive structure encountering our dynamic universe. This will have a substantial impact on all aspects of project construction, including the project site analysis stage. Traditional methods of conducting analysis are not time-oriented and do not account for potential changes over time, but they are now taking on new significance and meanings, necessitating the use of new techniques and methods since it is essential to foresee changes of a building that is to have kinetic characteristics. As a result, the architectural form can be constructed to accommodate the abovementioned range of change, once the scope of these possibilities has been established. The design process thus begins with an estimation of changes through time. In other terms, the architect would design a variety of forms instead of simply one. To assess if the design can adapt to a certain range of changes, simulation methodologies will need to be developed [7].

### *2.3 For a Single Volume, Kinetic Structures Are More Appropriate*

The kinetic structure's ability to move will place some limitations on the architectural space. To put it in another way, the easiest space to design is a singular unit that may interact independently in response to its uncertain surroundings. Otherwise, a building will be a complicated kinetic mechanism with its kinetic structure, envelope, and inner partitions [7].

### *2.4 There is a Need to Investigate Materials Specifications to Identify the Most Compatible Ones to the Characteristics of the Kinematic Structures*

Utilizing specific lightweight materials is essential for the effective creation of many kinetic structures. A mobile structure can benefit economically by having a high strength-to-weight ratio and high stiffness, in line with a general rule of construction. Future research could be directed to accelerating the development of new materials specifically created to satisfy the demands of moveable structures. Certain materials including composites, metal complexes, textiles, and polymers can now be incorporated into intelligently responding kinetic systems. Solutions in the area of kinetic architecture are made easier by the extensive usage of such materials [7].

### *2.5 New Construction Strategies and Mechanical Equipment Are Required to Be Devised*

Approaching buildings from a different point of view such as motion, provides an opportunity for new ways of construction to better serve the purpose. As kinetic architecture gains popularity among designers, new construction techniques should emerge, placing a greater emphasis on joints, connections, and motion controllers [7].

### 2.6 Modern Technology Makes Intelligent Kinetic Structures Almost Feasible Today

The architecture being described here is not static, as it has been through time, but rather is capable of interacting with its constantly changing environment by varied geometry or movement through artificial intelligence (AI). Future studies shall center on intelligent kinetic structures containing an embedded computer system acting like an artificial brain that will enable them to transform on their own [7].

## 3 Expected Results

The course of this study, as a part of an ongoing research, provides the ability to apply kinematic methods to architectural structures for creating totally functional buildings and serves many purposes, bringing tremendous advantages to traditional construction systems. The following list is of the most significant ones, resulting in the generation of super-smart architectural spaces:

1. Evaluating the Feasibility of System Movability in Urgent Circumstances such as Earthquakes, Flooding, etc.
2. Determining the Most Efficient, Feasible, and Cost-Effective AI in Different Hazard-Prone Zones with Distinct Climates
3. Investigating a Variety of Methods in order for Mechanistic Selection of the Most Efficient One to Generate Adaptive Architectural Spaces
4. Determination of the Best Programming Method for AI Based on the Acquired Programming Results
5. Ascertaining the Overlaps of the Robotic Programming Criteria and the Required AI for the Project in order to Motivate the System toward Robotic Packing
6. Simulation and Determination of the Best Material Choice for the Components to be Light Enough as a Moveable Property Using ETABS Software and the Like
7. Designing the Internal Foundation of the System Employing 3D Max, Revit, Rhino, and Grasshopper Software at which No Utilization of Fixed Structural, Mechanical, or Electrical Installation is Assured
8. Conducting the Numerical Calculation in order to Find the Most Effective Design for Incorporation of Smaller Components by Which All is Narrowed in One Single Space

9. Implementation of Simulated Results and Calculations in a Real Hazard-Prone Site in Taiwan
10. Evaluation of the Most Desired Hardware of Choice on the Basis of the Cost-Effectiveness.

## 4 Discussion

The application of kinetics began with the emergence of moveable architectural elements, such as sun shades, windows, stages, and turntables, and progressed to the creation of buildings that revolve as a whole [6]. According to the degree of application of embedded controlling systems, advanced materials, and high technologies, moveable systems differ in their complexity [6]. Movability was once a property that could be provided through mechanical means, but in modern construction, it can be achieved using computation and artificial intelligence (AI) [6]. Developing mobile buildings can be done for a variety of reasons such as meeting user demands, space optimization, adapting to climate change by interacting with it, and risk reduction in hazardous conditions [5].

The first official definition of the moveable structure was announced in 1974 followed by this quotation: “A kinetic environment without the computation is like a body without a brain—incapable of moving”, Guy Nordenson mentioned [6]. Kinetic structures can be used in designing mobile transformable shelters/units ranging from the entire buildings to the small single-person enclosures that are able to be easily constructed, deconstructed, reassembled, stored, and moved from one place to another [6]. In order to design kinetic buildings, structures may include or consist of folding, sliding, expanding, and transforming parts [5]. Users and inhabitants of architectural space can have environments that change and adapt in accordance with the information gathered by means of computation and sensing technologies [6]. Such buildings can modify their behavior depending on the changing variables that may range from wind loads, precipitations, seismic conditions, temperature, and light [5]. Also, certain embedded technologies enable buildings to learn and discover their best choice of performance. Other systems help users to control and change settings with respect to their needs such as acoustics, lighting, climate, and security. The ability of being remotely controlled through communication means such as the short message service (SMS), mail, and internet are of embedded computation merits for kinetic systems [6]. Some existing kinetic systems within a larger architectural whole in a fixed location allow it to respond to changing conditions. Other standing kinetic structures in temporary locations allow buildings to be easily transported. There exist some kinetic structures within a larger whole while acting independently with respect to the larger context [6].

The technological achievements in different divisions of engineering such as structural, mechanical, and materials engineering as well as information and communication technologies have enormous effects on kinetic design from structural innovation and materials advancement to embedded computation and adaptive architecture creation [6]. The widespread adoption of technology in architecture is causing immense modifications in architecture design methodology [7]. Today, even creating almost smart creatures is feasible for construction engineers by harnessing robotic knowledge. The respective buildings with embedded intelligent machines into their design will be able to sense changes around them/receive users' orders through different sensors, collect the data as input, process it for making suitable decisions, and eventually respond to the changes/orders based on their perceptions [6], therefore, architecture stands at the edge of a new era.

Existing buildings fall far behind of complying with the expectations of today's modern society by failing to take advantage of new prospects provided by technological advancements. The majority of people currently reside in dwellings that are barely able to meet their needs. In the realm of architecture, where objects are typically static, kinetic structures are exceptional, their applications are often solitary, and responsive spatial adaptation is mostly neglected. Our perception of a valuable structure considers it stationary. Seemingly, in the static perfection of modernist architecture, the structure has shown no response but to stand still [7].

According to Charles Darwin, an object's capacity for environmental adaptation always has determined the possibility of its survival, and the architecture is not as an exception, therefore, an increasing interest in kinetic design implementation has been observed in recent years. The application of architectural solutions in responsive kinetic designs stems from concerns with spatial efficiency and adaptability. An adjustable space reconfigures easily to fit different human requirements, and it may vary from multifunctional interior rearrangement to an entire structure transformability [7]. From a resistant's perspective, the presence of kineticism in a structure means that the objects in a built environment are physically available only when necessary, otherwise, they are either vanished or modified. The aforementioned objects can be as small as a tiny component of the structure, such as a simple sun shield, or as great as an the entire building. This is to imply that responsive architecture comes with a new perception of aesthetics, a new concept of form, and new technology inherently [7].

Kinetic architecture can be defined as an architecture produced by movement, and the actual moveable architecture consists of a number of interrelated elements and dynamic transition structures consisting of structure, connections, actuators, materials, and control systems (Fig. 2). However, for a structure to be considered moveable, it is not required that all the aforementioned items are capable of movement [5].

Also, the foundation of kinetic design is based upon three main components briefly listed below in Table 1 along with their respective important aspects [6].

It is worth mentioning that hinges, independent components, or bearings are needed to enable moveable connections between two load-bearing elements and

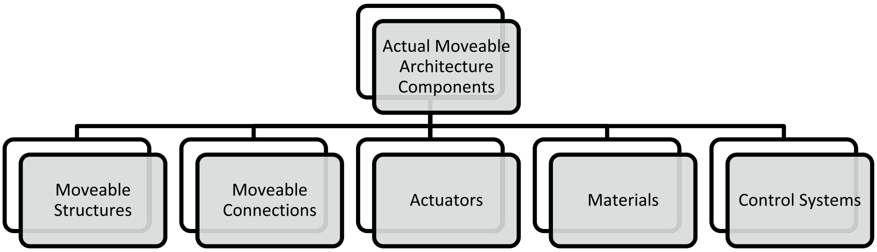


**Fig. 2** Actual moveable architecture components [5]

**Table 1** Kinetic design key elements [6]

| Innovation in structure and materials | | Incorporated computation | | Adjustable architecture | |
|---|---|---|---|---|---|
| Methods and means of structural solutions | Methods: folding, sliding, expanding, or transforming | Trends in embedded computation | Active control research | Adaptive architecture environments | Living environments |
| | Means: pneumatic, chemical, magnetic, natural or mechanical | | Adaptive control | | |
| Kinetic structures typologies | Embedded | | Home automation | | |
| | Deployable | | External communication | | |
| | Dynamic | Levels of control mechanisms | Single variable-man control | | Working environments |
| | | | Multivariable-man control | | |
| | | | Multivariable automatic control | | |
| | | | Multivariable heuristic control | | |
| | | Typology of controlling systems | Direct control | | Entertainment environments |
| | | | In-direct control | | |
| | | | Responsive in-direct control | | |
| | | | Ubiquitous responsive in-direct control | | Public environments |
| | | | Heuristic responsive in-direct control | | |

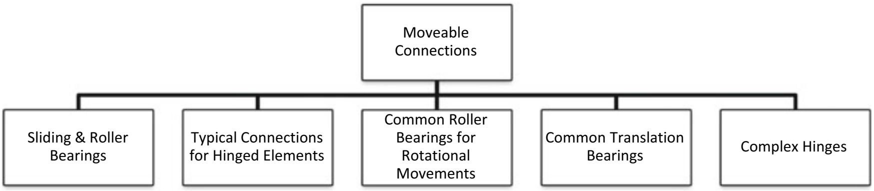


**Fig. 3** Moveable connection types [5]

among these three, a feature that distinguishes hinges from others is it allows rotation, translation, or a combination of the two movement kinds, which can provide up to five degrees of freedom. Depending on the hinge's design, limitations can be used to artificially limit the amount of movement that can be made [5]. Different useful types of connections for developing moveable structures are being demonstrated in the illustration below (Fig. 3).

As it was briefly mentioned earlier, the purpose of kinetic application in architecture and construction is to reduce the damage we're causing to the ecosystem as a single species in the whole life cycle, to accommodate the growing population and their different activities, plus enhancing their quality of lives. In this respect, a moveable structure can be utilized to better response to an occupant's demands for life quality improvement, such as a simple interior reorganization for controlling light, air, acoustics, etc., or might be optimal land usage to magnify the available space by the same land extent under construction. Moreover, kinetics provide structures with the ability to adjust, adapt, and interact with their environment, so the outcome would be flexible toward ever-changing climatic and seismic conditions. In case of natural disaster, that is quite prevalent nowadays, due to the global warming phenomenon, a dynamic structure is capable of survival by the aid of moveability and its artificial brain. There might be other functional or aesthetical purposes that utilization of kinetics might fulfill them, as it is quite promising.

## 5 Conclusion

Given the severity of global climate change leads to more natural disasters and population growth dilemmas as well as the anticipated potentials of kinetics in addressing them, the aim of this research is to investigate moveable architecture capabilities in natural disaster hazard mitigation through creating adaptive spaces that will accordingly be able to move, interact, and adjust themselves to the particular surrounding environment changes or users' needs with the aid of the AI, acting as the brain of the architectural spaces making them possible to sense, process, make decisions, and even be taught [6]. As mentioned, the present research is a part of an ongoing study that discusses the possibility of defining a new way to overcome natural disasters by use of computation in construction to create the capability of environmental interaction, reconfiguration, adaptation, and determination of the potential of kinetic architecture in hazard mitigations. As a result, super-smart architectural spaces are anticipated to be designed which could be easily packed and moved to other places in urgent circumstances such as earthquakes, floods, etc. Within the limits of this study, the behavior of kinetic structures and the possibilities to develop kinetic architecture are discussed. It is concluded that there is a new vocabulary to be formulated, a new type of construction method to be developed, and a new aesthetic to be expressed. The moveable architecture is expected to have many hidden and discovered potentials for hazard mitigation considerations. The carried out research so far in the application of kinetics into architecture is very promising, and has resulted in the discovery of a number of novel spatial organizations.

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## References

1. Asefi M (2012) Transformation and movement in architecture: the marriage among art, engineering and technology. Proced Soc Behav Sci 51:1005–1010
2. Collado JRN, Wang H-H (2020) Slum upgrading and climate change adaptation and mitigation: Lessons from Latin America. Cities 104:102791
3. Cudzik J, Radziszewski K (2018) Artificial intelligence aided architectural design
4. de Antonio Crespo A (2007) Conceptual design of a building with movable parts. Massachusetts Institute of Technology
5. Elkhayat YO (2014) Interactive movement in kinetic architecture. JES J Eng Sci 42(3):816–845
6. Fouad S (2012) Design methodology: kinetic architecture. Architectural Engineering, Alexandria University
7. Korkmaz K (2004) An analytical study of the design potentials in kinetic architecture
8. Li S, Liu L, Peng C (2020) A review of performance-oriented architectural design and optimization in the context of sustainability: dividends and challenges. Sustainability 12(4):1427
9. Ofori G (2002) Construction industry development for disaster prevention and response. In: Proceedings of i-Rec conference on improving post-disaster reconstruction in developing countries, Citeseer
10. Youssef MM (2017) Kinetic behavior, the dynamic potential through architecture and design. Int J Comput Methods Exp Measur 5(4):607–618

11. Zanelli A, Monticelli C, Mollaert M, Stimpfle B (2019) Moveable membranes-smart solutions in the field of architecture
12. Zou Y, Zhan Q, Xiang K (2021) A comprehensive method for optimizing the design of a regular architectural space to improve building performance. Energy Rep 7:981–996

# Introducing an Integrated Agent-Based and Reinforcement Learning Model of Contracting and Subcontracting in Construction Sector

**Jaleh Sadeghi, Mostafa Babaeian Jelodar, Teo Susnjak, Monty Sutrisna, and Suzanne Wilkinson**

## 1 Introduction

New Zealand's construction industry faces ongoing challenges regarding skill and labour shortages, price increases, supply chain disruptions, credit limitations, delays and overdue tasks, cyclical boom-bust, sub-sector fragmentation and, on the other hand, growing demand for construction projects. Yet, the capacity to deliver the growing pipeline of construction projects and the capability to resource various project types are to be investigated [2, 22, 48]. Indeed, a thorough evaluation of future projects against the available resources has not been conducted in the New Zealand construction industry, and the Construction Sector Transformation Plan and CanConstructNZ programme are introduced to bridge this gap [3, 27, 42].

Management of various construction projects with time conflicts and constraint resources is a complex procedure [5] that fits a nondeterministic problem-solving approach [14, 17, 34, 37, 44]. Also, multi-project management is hinted at in portfolio modelling literature, e.g. [7, 34]. Model is "*a simplified or idealised description or conception of a particular system, situation, or process for theoretical or empirical understanding, or for calculations, predictions,* etc." [31]. Modelling is important to explore and explain the dynamics of a target system and the mechanics of the components' relationships [13]. The complex system embedded in the construction sector is also a fitting subject for modelling as it includes various stakeholders required to

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manage conflicting construction projects. Different approaches to construction portfolio modelling are so far taken, like fuzzy expert system for risk management [6], network mapping for project selection [8], Tabu search algorithm for scheduling [1], ant colony optimisation for prioritisation [23], and agent-based modelling for under-constraints resource allocation [11, 36]. However, no national-scale multi-project portfolio model has been developed, and a comprehensive model considering the resource allocation stages (i.e. the relationships among diverse-scaled construction contractors) and interrelated risks are overlooked. This study addresses this gap and aims to develop a novel model for improving resource allocation in the New Zealand construction industry, thereby mitigating the risk of project delays and cost overruns [32].

Considering the New Zealand construction sector as a portfolio of projects, the aim is to understand the resource allocation practices in within the sector. This research asks, "How does the resources' over-estimation impact a construction project?" It also collects data on sector status quo and its historical performance, including construction contractors' data, on one side and the national construction pipeline of work (including type, location, value, and lifecycle of the projects) on the other.

## 2 Literature Review

### *2.1 Construction Projects Contracting*

Each construction project is to be undertaken by one or more contractors, and the client is to evaluate the contractors' qualifications. The contractor selection by each organisation includes a process called prequalification. i.e. "*contractors being assessed over a range of quality criteria and then being registered for specific types and sizes of work*" [9]. For instance, New Zealand Transport Agency (NZTA) developed its own prequalification system for each work type: (1) routine and minor works, (2) surfacing, (3) bridge construction, and (4) construction. Each category's contractors have four possible quality levels: A, B, C, and C [29]. Table 1 is the summary of the performance criteria for each level.

Each contractor has its own criteria influencing subcontractors selection, and they evaluate lower-level contractors' undertaken projects' cost, time, quality, and risk, as well as their experience and reputation [26]. Although one of the risks associated with the delivery of the construction project is subcontracting failure [15, 21], subcontracting is inevitable due to future benefits. Benefits associated with subcontracting include but are not limited to work specialisation, which can lead to improved quality [26] and risk reduction for the main contractor, the subcontractor is to bear the risk of cost overruns, delays, and low quality [21, 33]. Table 2 indicates the summary of crucial differences between contractor and subcontractor.

Accordingly, a subcontractor undertakes a portion of all construction works or a "work package", i.e. a part of the project that needs resources different from others

**Table 1** Summary of NZTA prequalified contractor levels [29]

| | Level A | Level B | Level C | Level D |
|---|---|---|---|---|
| Capability, resources, and experience status | Projects estimated above 20$ million | Projects estimated between 5$ and 20$ million | Projects estimated between 0.5$ and 5$ million | Projects estimated to be < 0.5 million |
| Risk | High | Medium to high | Low to medium | Low |
| Prequalification status | Class of high-value capital works contracts | Class of medium to high-value capital works contracts | Class of low to medium-value capital works contracts | Class of low-cost, low-risk, and minor works |

**Table 2** Contractors versus subcontractors

| | Contractor | Subcontractor |
|---|---|---|
| Role | Overall project manager | Specialist |
| Responsibility | Management, planning, scheduling, budgeting, permits, approvals, coordination | Execution of specific task or scope of work |
| | Ultimately responsible for the quality of the finished product | Responsible for quality of work, but the contractor may retain some responsibility |

[12]. Therefore Vsubcontractor is less than Vcontractor, where Vsubcontractor is the value of the "work package" undertaken by the subcontractor (also equals the value of special resources), and Vcontractor is the value of the construction work undertaken by the main contractor (also equals the value of all resources).

## 2.2 *Construction Resource Allocation Models*

The problem of sharing the constraint resources among the projects is addressed in the previous research on portfolio management [38]. Enterprises need to understand available resources and projected demands, i.e. portfolio conditions [7, 19]. In other words, construction portfolio conditions are indicated by resource constraints and project requirements [34, 35]. The dynamic nature of the portfolio conditions makes it a befitting approach for dynamic decision-making [38] and complex system computational modelling [14], which has been a topic for field research.

For instance, Farshchian et al. [11] and Farshchian and Heravi [10] employed agent-based modelling and considered the projects as the system components within a resource-limited environment to simulate resource allocation in a construction multi-project portfolio. In this model, each project is treated as an individual with particular attributes like milestone dates and values. Individual- or agent-based modelling is a bottom-up approach for modelling, simulating, and predicting multi-agent systems (MASs) [16, 41]. ABM helps understand the collective behaviour of a set of attributed individuals (agents) acting in their environment. It can explain how individuals' changes affect emerging outputs [24, 47]. In other words, AB models include two essential components: agents and environment. It helps understand the collective behaviour of multitudes (agents) in a context (environment and applied rules for interactions) [25, 45, 47].

Farshchian et al. [11] and Farshchian and Heravi [10] inputted project attributes like physical planes, cost flow, and relative outcome to each agent project class after completion. Dealing with the critical issue of budget limitation and its consequences, i.e. elimination or postponement of projects, the model facilitates the financial management of several ongoing construction projects in a portfolio to lower project costs and delays. The objective of this research was simulation and prediction of construction projects' progress and revealing the efficient constraint budget allocation scenarios from the owner's perspective.

On the other hand, although portfolio management requires different strategies than single project management [34, 44], some advanced solutions developed for construction tasks and resource conflict reduction in a particular construction project could be inspiring for multi-project management. For instance, resourcing projects is a familiar research topic on machine learning (ML) applications in construction. K-means clustering and artificial neural networks (RNN) are employed to enhance data-driven solutions for forecasting labour utilisation, i.e. the hours spent per task, in particular construction projects [12]. The recent research clarifies that labour utilisation estimation is accessible at each work package. The study collects and processes the time series data from 250 construction projects, and the applied ML technique is highly performed in such a rich-data environment. Another example is Arabiat et al. [4], where the dataset from completed projects, including their as-planned and actual data on cost and duration, is used to predict the cost and time overruns, utilising K nearest neighbour and ANN techniques.

The pre-mentioned ML examples are unsuitable for poor-data environments and uncertain knowledge scopes, like high-level construction management [46]. An ML technique to approach such an environment where no explicit training data is available is reinforcement learning (RL) [18, 20, 43]. RL follows a similar agent-environment relationship to ABM, while, in RL, an agent is an intelligent decision-maker entity which interacts with its environment and receives feedback (rewards) according to its actions (Reinforcement learning [39]). Indeed, the agent experiences the updated environment state after each action and is featured with learnability while no training dataset is available. So far, in low-level construction management, RL solutions have been developed for resource-constraint project scheduling problems. Focusing on automation of the look-ahead scheduling (LAS: next 6/8 weeks of construction work planning), Soman and Molina-Solana [39] introduced an RL model, which speeds up the process of conflict-free LAS. This model includes a decision-maker agent as a project manager. Also, focusing on the problem of critical construction activity sequencing, Kedir et al. [18] developed a hybrid ABM-RL where the "activity agent" aims to reach the completion status by experiencing an activity on node network.

The previous research on ABM application in multi-project portfolio simulates the portfolio dynamics where all the projects start simultaneously; also, they overlook the portfolio management from the contractors' perspective. On the other hand, due to RL compatibility with data scarcity, high-level multi-project construction management is also approachable via this technique. However, no RL model has yet been developed for improving multi-project resourcing on a national construction scale. Due to their compatibility, this research explores both ABM and RL techniques and their potential integration to enhance insights into multi-project resourcing scheduling with the construction sector.

## 3 Research Methodology

In this section, the structure of the New Zealand construction sector is virtualised through a hybrid modelling methodology. First, a New Zealand organisation is chosen as a case study to initiate the model and assess its feasibility. Accordingly, a thorough search of available organisational data is conducted. Results show that the New Zealand Transport Agency (NZTA) is among the few organisations in the country that publishes data on construction works and their prequalified contractors. Indeed, the NZTA dataset was chosen due to its comprehensive nature, encapsulating diverse project types and contractor categories, which enables realistic modelling of the New Zealand construction industry. NZTA data is first evaluated regarding features and quality, then cleaned and fed to the model development process.

### *3.1 Data Evaluation*

The obtained data on the pipeline of NZTA's construction works include the construction projects with start and end dates from 2009 to 2031. In total, 801 projects located in New Zealand's central region (including Gisborne, Hawkes Bay, Manawatu–Whanganui, and Taranaki in New Zealand's North Island) and their total cost and work type are mentioned in the dataset (Table 3). The annual expenditure for the projects is not mentioned; therefore, it could be assumed that the total cost of the project is distributed through its life cycle and is identical for all the life years.

April 2023's update on prequalified contractors [30] indicates that 140 contractors are prequalified to undertake the NZTA works at diverse levels (Table 1 and various work type categories (see Appendix; Table 5). The data include the serving regions by each contractor (based on major New Zealand region categories, i.e. North Island, South Island), their work-type specialities, and their corresponding levels, e.g. the company ID 3 serves the North Island and contributes to the category 1 and 4 of works, while it can undertake projects that match the level B contractors' criteria in both work types (Table 4).

**Table 3** Sample of NZTA pipeline of work

| Activity ID | Work type | Start year | End year | Local government region | Duration (years) |
|---|---|---|---|---|---|
| 1 | Road construction | 2017 | 2021 | Taranaki | 5 |
| 2 | Bridge construction | 2013 | 2021 | Hawkes Bay | 9 |
| 3 | Pavement maintenance | 2013 | 2021 | Taranaki | 9 |
| 4 | Road maintenance | 2020 | 2023 | Manawatu/ Whanganui | 4 |

**Table 4** Sample data from NZTA prequalified contractors

| Registered company ID | Geographic location served | Routine and minor works (1) | Surfacing (2) | Bridge construction (3) | Construction (4) |
|---|---|---|---|---|---|
| 1 | North Island, South Island | 1A | 2C | 3A | 4A |
| 2 | North Island, South Island | 1C | | 3C | 4C |
| 3 | North Island | 1B | | | 4B |
| 4 | North Island | | | 3C | |

## 3.2 Model Development

ABM has been used to simulate portfolio dynamics in previous research, but these models have assumed that all projects start at the same time and have not considered the contractors' perspective. On the other hand, reinforcement learning (RL) has shown promise in managing high-level multi-project construction, especially in situations with limited data. However, no RL model has been developed yet for optimising multi-project resourcing on a national construction scale. As the two methods are also incorporative, this study examines the use of ABM integrated with RL to illustrate the mechanics and dynamics of New Zealand's national construction sector. Based on the knowledge obtained from the available construction sector data, this section introduces an agent-based (AB) model of the construction sector. It presents a modular and individual-based structure of the construction works and contractors' dyads. As the AB model integrates with the RL technique to enhance individuals' decision-making abilities, the research method includes two critical steps: (1) defining the initiator AB model and (2) facilitating the agents with learnabilities.

Each AB model includes two main entities: agents and the environment. The agents have goals to reach while exploring the environment and following the circumscribing rules [24, 25, 45, 47]. In this research, the AB structure of the construction sector is defined as follows:

- Agent: A block of a particular project's value (known as a portion of work) which belongs to a particular work package. Multiple agents from a single project represent a particular project family of agents and have a specific start date.
- Agent starting time: When the agent presents in the environment for the first time, identical to the corresponding block of work commencement.
- The environment module, also known as the cell, is a block of work value from the contractor. Each cell has the same value as the project agent. A cell can be featured as "in-house" to be accomplished by the main contractor or "out-sourced" to be allocated to a prospective subcontractor. Each cell is part of a particular contractor family and belongs to its specific level (A, B, C, and D) and work-type category (1, 2, 3, and 4).
- Level of the module (cell level): Identical to the pre-mentioned levels of contractors (A, B, C, and D), considering A–D as high-level to low-level contractors. These levels are renamed to the IDs 0, 1, 2, and 3 for coding and implementation purposes.
- Agent objective: To visit an in-house cell.
- Environment rules: Each agent can occupy only one cell, and no cell includes more than one agent (i.e. each portion of work can only be undertaken and resourced by a specific contractor while a module of the contractor can only resource one agent and once). Therefore, the visited cell by an agent is "unavailable" for other agents to visit.

### 3.2.1 Integrated AB-RL

In the next step, the RL integrates with the AB model and facilitates the agents with learning abilities. As indicated in Fig. 1, RL includes agents, environment, state, actions, and rewards. The agents and environment are introduced earlier, and the action and rewards are defined as follows:

- Action: An action executable by an agent as a particular decision on selecting a specific cell of a contractor to visit. The cell state (in-house, out-sourced, un-sourced) is unrevealed until the cell is selected. If no cell is available to visit in the current time-interval, the agent should visit a virtual cell as un-sourced. Agents can take multiple actions and experience multiple states in a time-interval.

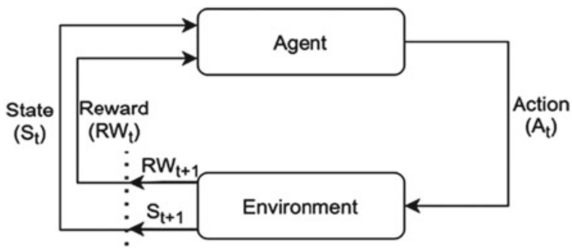


**Fig. 1** Reinforcement learning [39]

- Time-interval: A calendar year (according to data granularity in Table 3). The current time-interval for each agent cannot be lower than the agent's starting time.
- Reward: Also, "$r$" is given to the agent for each executed action and corresponds to the reached state, where:

$$r_{\text{un - sourced}} < r_{\text{out - sourced}} < r_{\text{in - house}}.$$

- Agent objective: Reach an in-house state with a higher accumulative reward.
- Agent terminal state: The first in-housing state visited by the agent.

In RL, each state is a Markvoe state [43]. Markvoe's decision process includes a set of possible actions and succeeding states [18]. Although there is no generalisation regarding the various levels of relationships and subcontracting rules, two possible relationship graphs are presented in Fig. 2. Graph "a" addresses the relationships between various contractors with only one constraint, i.e. the upper level cannot subcontract the lower levels, and graph "b" illustrates a simpler graph in which each lower level can only be subcontracted by a one-level-up contractor; for example, a relationship between levels A and C is possible only if level B mediates.

RL presents a unique machine learning approach where agents actively learn through trial and error in dynamic environments without relying on predefined labelled data. The agent starts from the Aalpha state in the default time-interval and chooses a possible path until it reaches a green—also known as terminal state. Notably, in a learning process, the agent accomplishes multiple episodes until found the best way to reach their terminal state. Indeed, each episode starts from the agent's starting time and ends in a terminal state [43], while the accumulative rewards for each episode vary (Fig. 3). The detailed reward data is collected in the agent's memory. The rewards corresponding to each possible action in the given states are addressed in Fig. 3 as the labels on the links. The reward for green, red, and second-time visited Alpha states are, respectively, 1000, −100, and −1000.

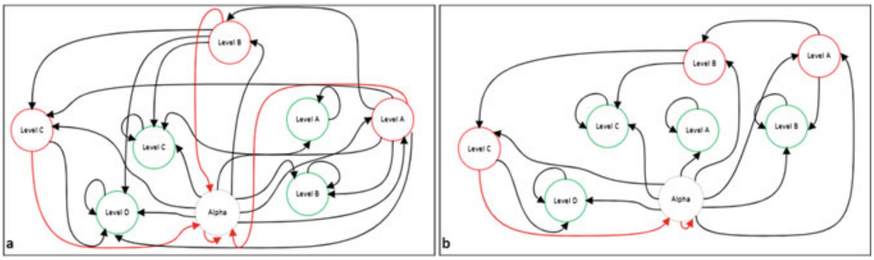


**Fig. 2** Markov graph of subcontracting mechanism in a particular time-interval; **a** higher level cannot be subcontracted to the lower levels; **b** each lower level can only be subcontracted by a one-level-up contractor; Green node: in-house state, Red node: out-sourced state, Grey node (Alpha): un-sourced state, Red links: links to the grey node in the next time-interval

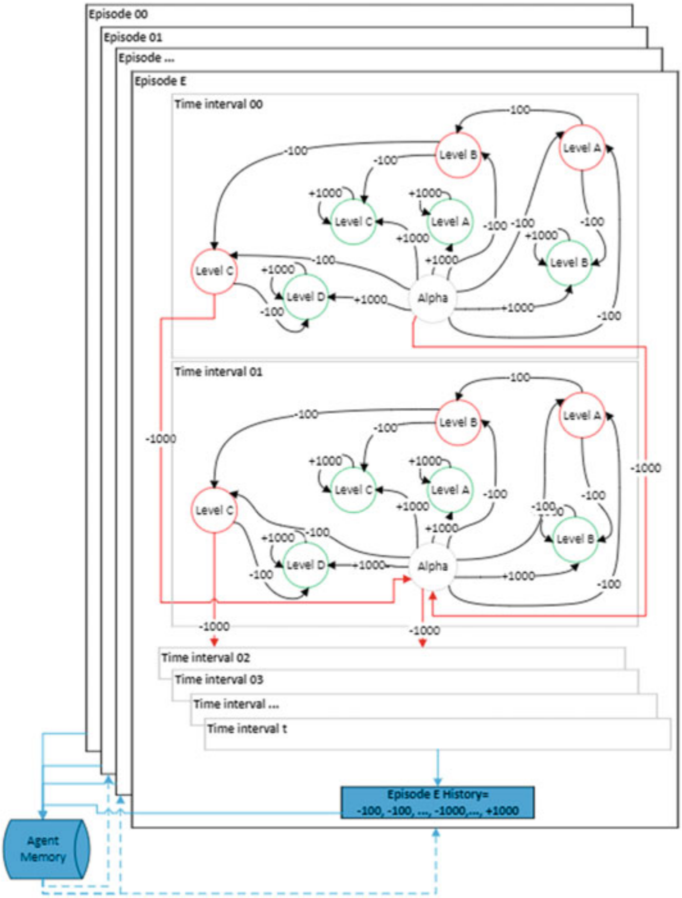


**Fig. 3** Learning process for an agent in conceptual RL process

The process of action selection (deciding to visit a particular contractor cell) is affected by the external forces of each contractor. Each cell imposes forces on the agent decision-making process according to its attributes to attract the agents and win the tendering for a particular project; the higher the velocity of the cell's force, the higher the chance of attracting the agent. It is assumed that, in each time-interval, the force's velocity from each cell to each agent is proportional to the cell family's type, level, hunger, reputation, and location, defined as follows:

- Type: The work type that the contractor is qualified for should match the agent's work package type.
- Level: The level at which the contractor is recognised and should fit the project scale.
- Hunger: Number of available cells in the contractor family (green and red cells).

- Reputation: A score given by the construction community to each contractor; the score varies in each time-interval and clings to the contractor's historical performance.
- Location: Contractor serving geographical location or contractor's base location distance to the project location.

## 4 Results: Model Feasibility Check

The proposed model is implemented by Python in Grasshopper visual coding canvas (Rhino3D, Version 7 SR26 [28]. The model feasibility is assessed using the NZTA pipeline of construction work and its list of prequalified contractors. To simplify this stage, the early implemented model is fed by one category of project types, i.e. category 4 (see Appendix, Table 5). The contractors and projects that relate to this category are chosen; 87 contractors serve New Zealand's central region, and 499 projects belong to the fourth category. Notably, since investigating the contractors' Reputations and Hunger index is a long-term process and beyond the scope of this paper, these indexes are considered random variables affecting the cells' forces in each action selection process. Furthermore, each contractor's modules are divided randomly into three types: in-house, out-sourced, and unavailable. The agent will then be attracted by a winner cell which could be in-house or out-sourced.

Moreover, the projects are categorised by their scales, where the level 0–3 in project categorisation match the levels 0–3 (A–D) of contractors, and it is assumed that each project can only be tendered by the same-level contractor in the first-time contracting. Accordingly, the results of four different agents' simulation from four different project levels are presented in the following sections. The simulation results for one time-interval are presented, through which each agent experiences five different episodes in their first year of existence. The agent chooses various contractors and receives different rewards.

### *4.1 Level 0 Project Sample*

Figure 4 is the result of the five episodes that experienced the agent 106 from project ID 640's eighth scheduled year—corresponding to the calendar year 2023. The agent details also clarify that project ID 640 is identical to project ID 2 in its relative level (level 0). This sample agent belongs to a project family from the 0th level, which the same-level contractor should undertake for the first-time contracting in the year 2022. Therefore, the cell representative of the level 0 contractors should force this agent.

In the first episode (episode{0}), the agent visits the cell representative of contractor ID 111, a 0-level contractor. The visits cell presents an in-house state,

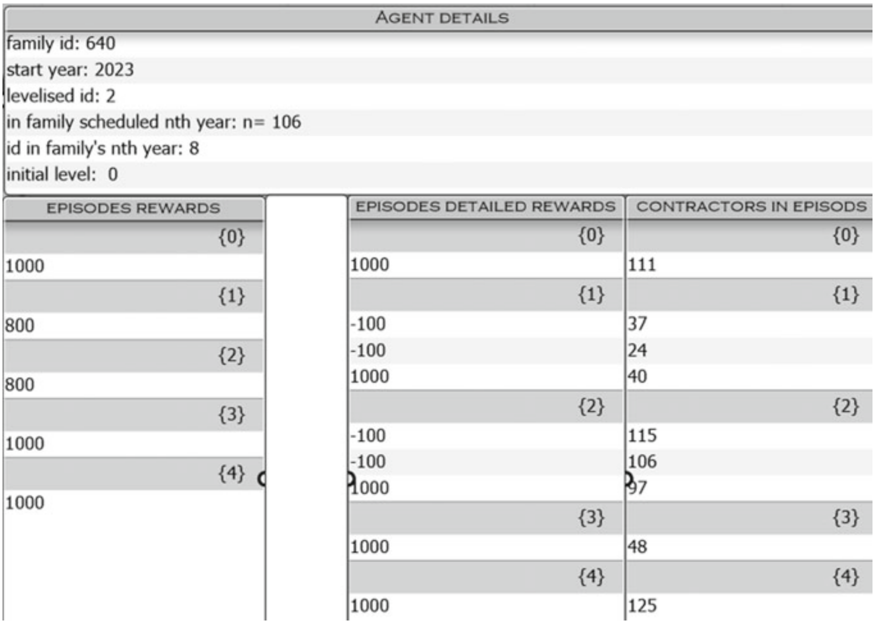


**Fig. 4** Sample of level 0 agent: episodes and rewards

and the agent accumulates the reward of "+1000" for its first action. Episodes {3} and {4} also successfully terminated visiting green cells of level 0 contractors 48 and 125.

In episode {1}, the agent then is attracted by the cell representative of contractor 37—a level 0 contractor—and visits a red (out-sourced) state. Therefore, the objective is not obtained, and the reward of "−100" is received. This episode continues with visiting the red cell from contractor 24 and then terminates in the next step as the agent reaches the terminal and visits the green cell by contractor 40. The accumulative reward for this episode would be 800. Episode {2} also ends up with an 800 reward after experiencing the red cells from contractors 115 and 106 and terminating visiting the green cell of contractor 97.

### 4.2 Level 1 Project Sample

Figure 5 shows the results of five episodes experienced by an agent from project family 714. This project is originally from the level 1 category and will be contracted by the same-level contractors while its first-time presence in the environment is in the year 2023.

The episodes {0}, {1}, {2}, and {3} end in a terminal state for the agent with accumulative rewards of 900, 900, and 900 and 800. The result of episode {3}

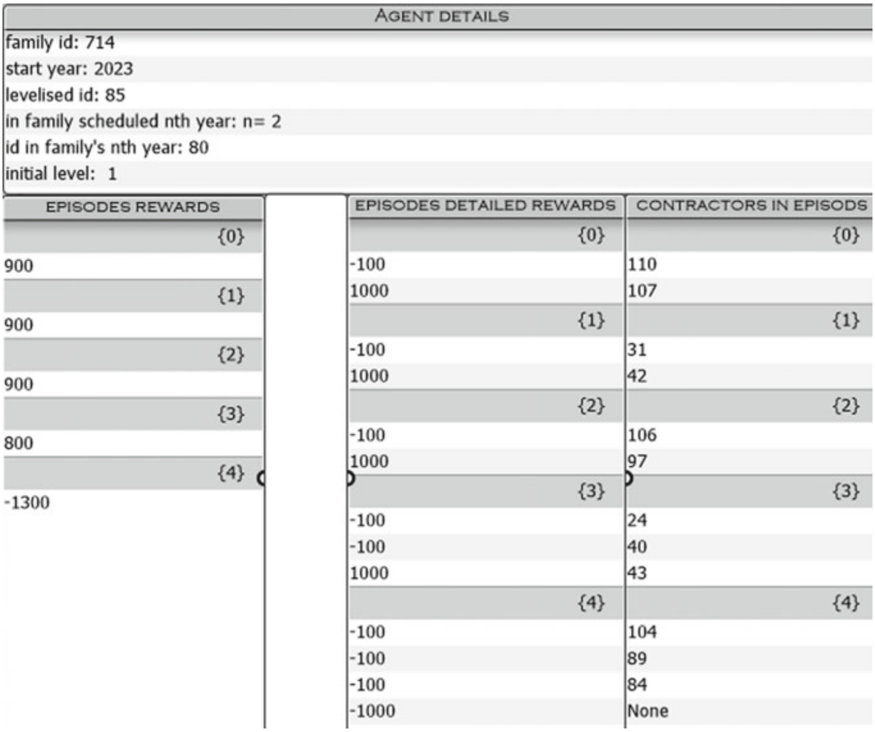


**Fig. 5** Sample of level 1 agent: episodes and rewards

indicates two times out-sourcing and one time in-housing by the contractors, as, in this episode, the agent visited the representative cells of contractors 24, 40, and 43 from levels 1, 2, and 3.

On the other hand, the agent failed to visit a terminal in episode {4}. In this episode, contractors 104, 89, and 84 represent out-sourced cells to the agent, and it concludes the episode in the "None" contractor cell. The "None" contractor means that the agent takes the last action to reach a new Alpha state and place in the next year's pool of agents; the corresponding "−1000" is then received.

## *4.3 Level 2 Project Sample*

Figure 6 includes the episodes and rewards accomplished by a 2020 scheduled agent. This agent is from project family 747, a second-level project. All the episode ends up in a terminal. In episodes {0}, {1}, {3}, and {4}, the agent visits the green cells of contractors 89, 40, 42, and 107. In episode {2}, however, contractor 97 out-source the agent to visit the cell from contractor 84; thus, a "−100" reward is achieved.

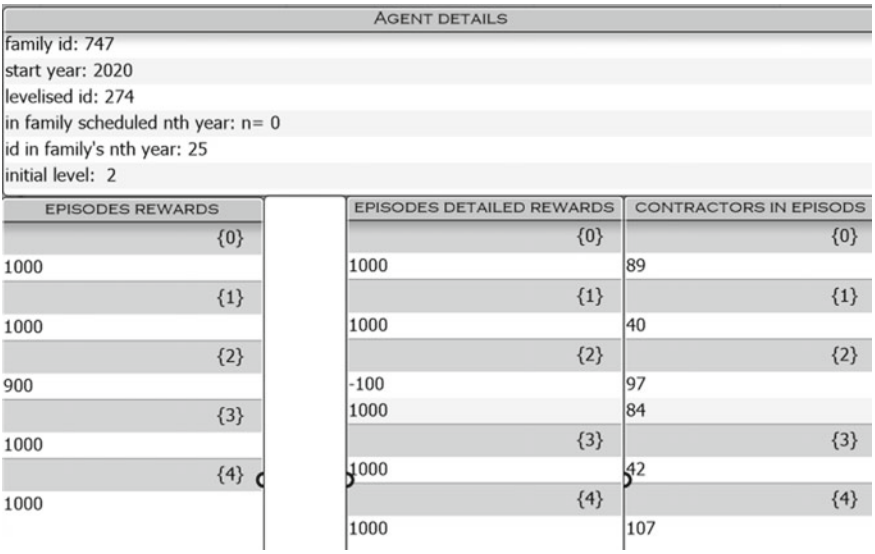


**Fig. 6** Sample of level 2 agent: episodes and rewards

### *4.4 Level 3 Project Sample*

Figure 7 shows an agent representative of the project family 711. This agent belongs to level 3 and is to be undertaken by a small-scale contractor. The result reveals that the agent reaches a terminal state in all episodes as it visits the cells from contractors 84, 43, and 126.

## 5 Discussion and Future Developments

The result of agents' experiences in various episodes could be interpreted from an agent—or project—perspective. For instance, a representative of a level 0 project experiences green state by contractor 111 in episode {0}. This informs the project's stakeholders that contractor 111 has sufficient in-house resources to deliver the work without delay and risk of subcontracting. On the other side, the agent representative of the level 1 project experienced consecutive subcontracting after its first-time contracting by contractor 104. This project's stakeholders surmise from episode {4}'s result that the risk of getting subcontracted and delayed is high. On the other hand, experiencing the multitudes of episodes, an agent can learn about each contractor's performance. Indeed, after each episode, the agent can make informed decisions about choosing the best cell to visit in the following episode. Notably, the agent can also explore new actions rather than sticking to exploiting one guaranteed solution. For instance, the level 3 agent experienced a successful visit to contractor 84's cell;

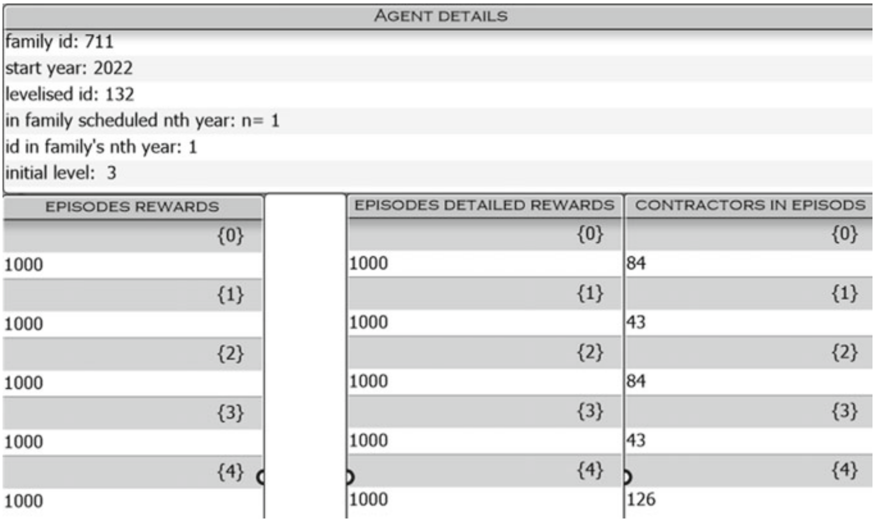


**Fig. 7** Sample of level 3 agent: episodes and rewards

however, it also explored visiting other cells of contractors 43 and 126 to enhance its memory and evaluate different contractors.

The model feasibility check results prove that the early-stage concept of AB-RL integration is compatible and aligned with the research aim. It brought more insight into the resource allocation process for construction projects and the roots of the corresponding risk of being overdue and delayed. The overestimated resource by the contractor is represented via out-sourced cells. Visiting the red cells, the projects are more exposed to the risk of schedule extension. This interpretation is an alternative answer to the primary research question; for instance, the early planning lay on an overestimation that could adversely impact a construction project's progress.

In the studies conducted by Farshchian et al. [11] and Farshchian and Heravi [10], portfolio management is approached from the project owner's perspective. The main objective is to simulate the progress of projects to facilitate the allocation of budgets. Although this owner-oriented approach to portfolio management impacts the early scheduling of projects, it is worth noting that construction projects' initial schedule and cost estimates often undergo significant changes until their completion, as highlighted by Son and Rojas [40]. Therefore, assessing the project's resource allocation from the contractor's perspective is important, as this provides deeper insights into potential challenges and risks associated with resource conflicts and shortages. This study strongly addresses this concern where the AB-RL model is feasible to reveal the adverse effects of resource misevaluation on the progress of the projects.

On the other hand, compared with Soman and Molina-Solana [39] and Kedir et al. [18], the study at hand clings to a wider perspective on resource scheduling. They focus on automating the LAS process and optimising the single projects activity

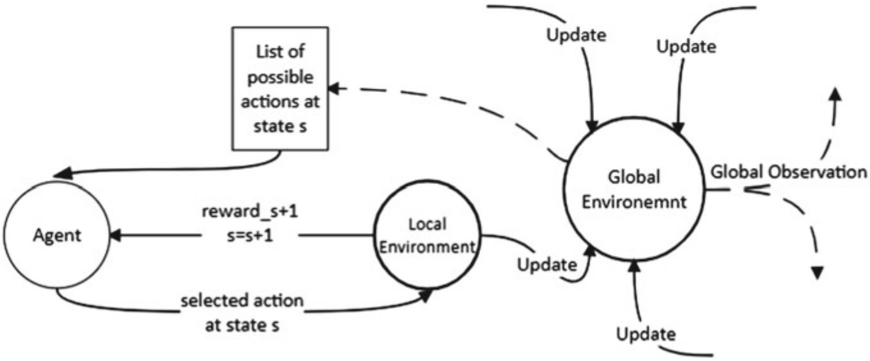


**Fig. 8** Modified reinforcement learning in a multi-agent model in a time-interval

network, which involves short-term planning of the construction works to ensure conflict-free scheduling and resourcing. On the other hand, this research deals with an extendible time frame, i.e. the whole project life cycle, while considering it as an actant in a multi-project environment. The decision-maker at a high level is not a project manager but a collective of project stakeholders. This complexity is also addressed in AB-RL proposed in this study (Fig. 8).

The proposed AB-RL is yet to be developed in future research and could include the following potential steps for precise construction sector structure explanation:

- Hybridisation with critical path method: Postponing the agent to the next year has consequences. Work schedules follow the critical path in construction schedules, i.e. the sequence of accomplishing the work packages is essential. Therefore, no two agents in a particular project from original different years can exist simultaneously in one time-interval simulation.
- Modules specialisation: Breaking the projects and contractors into their representative modules could be featured by different work types. For instance, the agent representing the construction foundation work in the "bridge construction" category could be attracted by its counterpart cell from a relative contractor resource.
- Cell forces manipulation: As in the real world, the contractors can choose specific lower-hand subcontractors, facilitating the model with probabilistic calculations would better relate its results with reality.
- Multi-agent RL development: Since the contractors' portfolios often include several projects, the agents from different projects simultaneously affect the cells representative of the contractors. As the RL process for multi-agent systems is different, the principal components of RL are modified and proposed in.
- Local environment is a "cell" with a particular "state" to be visited by the agent, while the "Global environment" is a directory of all the states considered the point of contact between all the agents.

## 6 Conclusion

This research focuses on the challenges faced by New Zealand's construction industry to growing construction demands and resource limitations. The research aims to understand resource allocation practices in the sector by treating the New Zealand construction sector as a portfolio of projects. It investigates the impact of overestimating resources in pipeline development and tendering process. An integrated agent-based modelling and reinforcement learning (AB-RL) technique is conceptualised and implemented. This study is original in introducing a novel method to explain the construction sector mechanics and dynamics in the scope of construction work contracting practices.

The model feasibility is checked and proved using NZTA data of the projected pipeline of construction works and associated prequalified contractors. As representatives of the projects, the agents experience various episodes of getting contracted by different contractors. The results then inform stakeholders about specific contractors' capabilities and risks. By analysing multiple episodes, agents can learn about contractor performance and make informed decisions about future tendering events. Integrating agent-based modelling and reinforcement learning proves compatibility with the aim of the study. It is concluded that it provides valuable insights into construction resource allocation and the risk of delays and overruns. The model also highlights the impact of overestimating resources (represented by outsourced contractor cells), which could adversely affect the extension of the project's lifecycles.

The model developed in this study is contributed to the national-scaled construction management and is feasible in finding the practicality of the earlier construction project plans by evaluating the schedules against the available resources. However, due to a lack of data on contractors' resources, the implementation process poses challenges. The contractors' resources are randomly divided into in-house and outsource, while real-world resource assessment is necessary to relate the model to reality and validate the results. Indeed, the AB-RL model developed in this study effectively approaches the complex contractors' relationship and construction sector data unavailability; however, some assumptions still need to be validated against real-world information. Therefore, the model is expected to enable the revisiting of the national construction sector through further development and validations. This validation process will involve comparing the model's predictions with actual project outcomes and evaluating its ability to deliver precise insights into resource allocation and project risk assessment.

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**Table 5** Work category description by NZTA

| References | Work category |
|---|---|
| 1 | Routine and minor works |
| | Pavement maintenance<br>Traffic services<br>Carriageway lighting<br>Vegetation control<br>Amenity/safety maintenance<br>Traffic management<br>Minor safety |
| 2 | Surfacing |
| | Reseals/seal extension |
| 3 | Bridge construction |
| | Bridge maintenance/repairs bridge construction |
| 4 | Construction |
| | Rehabilitation/pavement treatment drainage improvements road construction |

## Appendix

See Table 5.

## References


1. Abdzadeh B, Noori S, Ghannadpour SF (2022) Simultaneous scheduling of multiple construction projects considering supplier selection and material transportation routing. Autom Constr 140:104336. https://doi.org/10.1016/j.autcon.2022.104336
2. Accord (2020) Construction sector transformation plan 2022–2025. https://www.constructionaccord.nz/assets/Construction-Accord/files/construction-sector-transformation-plan-2022-2025.pdf
3. Accord (2021) Construction sector accord progress report. https://www.constructionaccord.nz/progress/2021-construction-sector-accord-progress-report/
4. Arabiat A, Al-Bdour H, Bisharah M (2023) Predicting the construction projects time and cost overruns using K-nearest neighbor and artificial neural network: a case study from Jordan. Asian J Civil Eng. https://doi.org/10.1007/s42107-023-00649-7
5. Amirtash P, Parchami Jalal M, Jelodar MB (2021) Integration of project management services for international engineering, procurement and construction projects. Built Environ Project Asset Manag 11(2):330–349. https://doi.org/10.1108/BEPAM-06-2020-0106
6. Banihashemi SA, Khalilzadeh M (2022) A novel fuzzy expert system for project portfolio risk management: case study of a construction company. Jordan J Civil Eng 16:436–456
7. Bathallath S, Smedberg A, Kjellin H (2022) Managing project interdependencies in IT/IS project portfolios: a review of managerial issues. Int J Inform Syst Project Manag 4:104
8. Delouyi FL, Ghodsypour SH, Ashrafi M (2021) Dynamic portfolio selection in gas transmission projects considering sustainable strategic alignment and project interdependencies through value analysis. Sustainability 13:5584–5584. https://doi.org/10.3390/su13105584
9. Douglas-Jones Z (2012) Prequalification for construction category contracts. Auckland Transport (AT)

10. Farshchian MM, Heravi G (2018) Probabilistic assessment of cost, time, and revenue in a portfolio of projects using stochastic agent-based simulation. J Constr Eng Manag 144:1476. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001476
11. Farshchian MM, Heravi G, Abourizk S (2017) Optimising the owner's scenarios for budget allocation in a portfolio of projects using agent-based simulation. J Constr Eng Manag 143:1315. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001315
12. Golabchi H, Hammad A (2023) Estimating labor resource requirements in construction projects using machine learning. Constr Innov
13. Graebner C (2018) How to relate models to reality? An epistemological framework for the validation and verification of computational models. J Artif Soc Soc Simul 21:8
14. Hans EW, Herroelen W, Leus R, Wullink G (2007) A hierarchical approach to multi-project planning under uncertainty. Omega 35:563–577. https://doi.org/10.1016/j.omega.2005.10.004
15. Hinze J, Tracey A (1994) The contractor-subcontractor relationship: the subcontractor's view. J Constr Eng Manag 120:274–287. https://doi.org/10.1061/(ASCE)0733-9364(1994)120:2(274)
16. Jennings NR, Sycara K, Wooldridge M (1998) A roadmap of agent research and development. Autonom Agents Multi-agent Syst 1:7–38. https://doi.org/10.1023/A:1010090405266
17. Kao H-P, Wang B, Dong J, Ku K-C (2006) An event-driven approach with makespan/cost tradeoff analysis for project portfolio scheduling. Comput Ind 57:379–397. https://doi.org/10.1016/j.compind.2005.11.004
18. Kedir NS, Somi S, Fayek AR, Nguyen PHD (2022) Hybridisation of reinforcement learning and agent-based modeling to optimise construction planning and scheduling. Autom Constr 142:104498. https://doi.org/10.1016/j.autcon.2022.104498
19. Khalifa Mohammed A-S, Shaligram P, Galal MA (2020) Perspectives on the capabilities for the selection of strategic projects. Sustainability 12:8191. https://doi.org/10.3390/su12198191
20. Kurinov I, Orzechowski G, Hämäläinen P, Mikkola A (2020) Automated excavator based on reinforcement learning and multibody system dynamics. IEEE Access 8:213998–214006. https://doi.org/10.1109/ACCESS.2020.3040246
21. Law TH, Lew Y-L, Salihudin H, Muniandy R (2012) Review of subcontracting practice in construction industry. IACSIT Int J Eng Technol 4:442–445. https://doi.org/10.7763/IJET.2012.V4.406
22. Le ATH, Domingo N, Sutrisna M (2022) Construction industry classification systems: defining the construction sector in New Zealand. In: IOP conference series: earth and environmental science. IOP Publishing, p 042011
23. Lee HY (2011) An integrated model for planning development projects using ACO and construction simulation. Civil Eng Environ Syst 28:285–300. https://doi.org/10.1080/10286608.2011.604415
24. Lukszo Z, Nikolic I, Dam KHV (2013) Agent-based modelling of socio-technical systems. Springer, New York
25. Macal CM, North MJ (2008) Agent-based modeling and simulation: ABMS examples. In: Proceedings of the 2008 winter simulation conference, 2008. IEEE, pp 101–112
26. Marzouk MM, El Kherbawy AA, Khalifa M (2013) Factors influencing sub-contractors selection in construction projects. HBRC J 9:150–158. https://doi.org/10.1016/j.hbrcj.2013.05.001
27. MBIE (2020) Reforming the building regulatory system and building and construction sector. MBIE, Wellington. https://www.mbie.govt.nz/building-and-energy/building/reforming-the-building-regulatory-system-and-building-and-construction-sector/. Accessed 20 Jan 2023
28. McNeel (2023) Rhino3d. 7.28 ed.: Robert McNeel & Associates
29. NZTA (2021) Prequalification for physical works. New Zealand Transport Agency (NZTA), Wellington. https://www.nzta.govt.nz/resources/prequalification-information-pack/
30. NZTA (2023) NZTA prequalified contractors. Waka Kotahi NZ Transport Agency
31. OED (2023) Model, n. and adj. Oxford University Press, Oxford
32. Radman K, Babaeian Jelodar M, Ghazizadeh E, Wilkinson S (2021) Causes of delay in smart and complex construction projects. J Legal Affairs Dispute Resolut Eng Constr 13(4):05021006

33. Ramani B, Pitroda DJ (2018) A critical literature review on selection of subcontractors as the quality improvement tool in housing construction. J Struct Eng Appl Anal 1:26–33
34. Ravanshadnia M, Rajaie H, Abbasian HR (2010) Hybrid fuzzy MADM project-selection model for diversified construction companies. Can J Civil Eng 37:1082–1093. https://doi.org/10.1139/L10-048
35. Russell AD, Chiu C-Y, Korde T (2009) Visual representation of construction management data. Autom Constr 18:1045–1062. https://doi.org/10.1016/j.autcon.2009.05.006
36. Sadeghi J, Jelodar M, Wilkinson S, Sutrisna M (2023) The 39th annual conference of association of researchers in construction management (ARCOM). Leeds
37. Sadeghi J, Jelodar MB, Sutrisna M (2022) Construction industry capacity and capability evaluation; application of modelling techniques for resource allocation in multi-project portfolios. In: The 45th Australasian universities building education association conference. Sydney
38. Saiz M, Lostumbo MA, Juan AA, Lopez-Lopez D (2022) A clustering-based review on project portfolio optimisation methods. Int Trans Oper Res 29:172–199. https://doi.org/10.1111/itor.12933
39. Soman RK, Molina-Solana M (2022) Automating look-ahead schedule generation for construction using linked-data based constraint checking and reinforcement learning. Autom Constr 134:4069. https://doi.org/10.1016/j.autcon.2021.104069
40. Son J, Rojas EM (2011) Evolution of collaboration in temporary project teams: an agent-based modeling and simulation approach. J Constr Eng Manag 137:619–628. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000331
41. Stieler D, Schwinn T, Leder S, Maierhofer M, Kannenberg F, Menges A (2022) Agent-based modeling and simulation in architecture. Autom Constr 141:104426. https://doi.org/10.1016/j.autcon.2022.104426
42. Sutrisna M, Wilkinson S, Cameron R (2020) Solving capacity and capability problems. BRANZ. https://www.buildmagazine.org.nz/index.php/articles/show/solving-capacity-and-capability-problems. Accessed 09 Feb 2023
43. Sutton RS, Barto AG (2018) Reinforcement learning: an introduction, 2nd edn. MIT Press, Cambridge
44. Vacík E, Špaček M, Fotr J, Kracík L (2018) Project portfolio optimisation as a part of strategy implementation process in small and medium-sized enterprises: a methodology of the selection of projects with the aim to balance strategy, risk and performance. E&M Ekonomie a Manag 21:107–123
45. Van Dam KH, Nikolic I, Lukszo Z (2012) Agent-based modelling of socio-technical systems. Springer
46. Wu L, Ji W, Feng B, Hermann U, AbouRizk S (2021) Intelligent data-driven approach for enhancing preliminary resource planning in industrial construction. Autom Constr 130:3846. https://doi.org/10.1016/j.autcon.2021.103846
47. Younes A, Marzouk M (2018) Tower cranes layout planning using agent-based simulation considering activity conflicts. Autom Constr 93:348–360. https://doi.org/10.1016/j.autcon.2018.05.030
48. Zavvari A, Sutrisna M, Jelodar M (2022) Evaluating capacity and capability of the construction sector: the application of big data tools. In: Proceedings of the 7th New Zealand built environment research symposium (NZBERS)

# Systematic Review of the Adoption Level of Building Information Modelling in Construction Small and Medium-Sized Enterprises in Nigeria

**Olusayo A. Bamgbose, Babatunde F. Ogunbayo, and Clinton O. Aigbavboa**

## 1 Introduction

The advent of building information modelling (BIM) is transforming the construction industry from a regular two-dimensional drawing to a robust information model [18]. According to Azhar [8], applying BIM in construction projects improves collaboration among project stakeholders, leading to improved return on investment, cost reduction, time and resource management. Also, the relevance of BIM in various construction operations facilitates BIM acceptability in the construction industry [19]. According to Chong et al. [11], new BIM tools are needed to achieve sustainability. BIM is also helpful in refurbishment and demolition. Leveraging BIM holds significant importance in the quality monitoring and evaluation of construction projects, spanning from the initial design phase to the ongoing management of the facility [28]. However, many construction players are yet to understand the procedure for implementing BIM because there is no standard for its implementation [44]. Though BIM awareness is rapidly increasing, its poor understanding often poses a problem for implementation. Also, many construction professionals do not know BIM, especially small and medium-sized enterprises (SMEs) [13]. There is a digital divide or BIM gap between the firms that can invest in hardware and software and those that cannot. However, Singh and Holmstrom [38] opined that the need for BIM adoption could also be partly explained by Maslow's hierarchy of needs, such that an organisation's interest in BIM adoption is required to match new performance targets. However, the burning strategy mandates BIM usage for public and government projects to integrate public infrastructure design, construction, and operation [12].

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## 2 Research Methodology

The study systematically reviewed existing literature using a systematic research method. It is a structured approach to carrying out research that follows a set of protocols, which involves a clear and concise plan configured to ascertain that BIM adoption level in construction SMEs is conducted in a rigorous and detailed manner [33]. This study mainly relied on peer-reviewed secondary data on BIM adoption from online databases such as Google Scholar, ResearchGate, Science Direct, etc.). Relevant kinds of literature were explored with keywords such as BIM, BIM adoption in developing countries, level of BIM adoption in developing countries, BIM adoption in construction SMEs, and construction SMEs in developing countries. Thirty-five (35) related articles are found on BIM in the construction industry with global consideration, while the other nine (9) general papers are on construction SMEs. The extracted articles were used comprehensively to discuss the level and importance of BIM adoption in construction SMEs in Nigeria.

## 3 Building Information Modelling

Building information modelling (BIM) represents both a process and a technological shift from a traditional single sequential approach to contemporary multiple parallel forms of data integration [22]. According to Aranda-Mena et al. [7], BIM is an uncertain term that means different things to different professionals in the construction industry. BIM is known as a software application to some professionals, while some see it as a means to design and document building information and as well interpreted as a new approach to practice and projecting the profession through implementation of new policies, contracts, and collaboration among professionals. BIM can create and manage project information, resulting in a building information model output. Also, it involves a digital description and representation of all aspects of the project in view (Hall 2018). Building information modelling (BIM) is becoming relevant in various construction operations via its general acceptability by different construction professionals, especially in developed countries like the United Kingdom (UK) [19]. According to Bui et al. [10], BIM is a driving force for innovation and productivity in the construction industry. It is embedded with the potential to support sustainable construction practices that can facilitate the eradication of poverty in developing countries as outlined in the United Nations Millennium Goals (MDGs). Although BIM is gaining progressive momentum in developed nations, its implementation in developing countries is limited [10]. BIM has evolved as a notable tool in the construction industry, gaining recognition as a vital aspect of Industry 4.0. Nonetheless, its understanding and implementation pose significant challenges [14].

## 4 Construction Small and Medium-Sized Enterprises in Developing Countries

Construction small and medium enterprises (SMEs) took the more significant part of construction industries both in developed and developing countries; thus, construction SMEs make significant contributions to employment generation, economic growth, prosperity, and the diffusion of innovation, among other factors [16]. Developed nations like the United Kingdom have extensively employed BIM for the execution of public infrastructure projects, highlighting the advantages of implementing BIM in construction endeavours [1]. According to Ametepey et al. [41], SMEs play a crucial role in fostering economic growth and generating employment opportunities in developing nations. The construction industry's performance relies heavily on the operational capabilities of construction SMEs [24]. According to Ametepey et al. [5], SMEs significantly dominate the construction industry in most developing economies. In addition, SMEs comprise many businesses globally, including the construction industry, and thus play a vital role in job creation, poverty alleviation, and driving global economic development [43]. Ahiawodzi and Adade [3] also opined that construction SMEs play a vital role in driving economic development on a global scale. SMEs are the foundation of developed economies, research, and development, including employment and poverty reduction efforts [3]. Furthermore, facilitating the adaption of construction SMEs in an open environment and improving their engagement in digital transformation is crucial for stimulating economic growth towards achieving a more inclusive form of globalisation [29].

## 5 Adoption of Building Information Modelling in Developing Countries

Building information modelling has evolved as a ground-breaking innovation that revolutionises the management of the entire building lifecycle. It encompasses various stages of construction, from the design phase to monitoring and controlling the actual construction processes [39]. As an innovative approach, BIM showcases its practicality across multiple stages, encompassing project conceptualisation, design, construction, and ongoing building utilisation [42]. Integrating BIM into construction procedures can optimise the preparation of maintenance budgets, ultimately resulting in more efficient maintenance practices within the construction industry [27]. During the operational phase of a building, BIM data finds utility in aiding facility management activities like maintenance scheduling, asset monitoring, and energy performance assessment [27]. According to Hamma-Adama et al. [20], the construction industry has experienced a remarkable advancement with the introduction of BIM, which brought about transformative changes over time. The leading country in BIM adoption is the United States, while developed countries are also extensively embracing its implementation, especially in public projects.

However, developing countries such as Nigeria are lagging in the uptake of BIM due to challenges such as poor awareness and research on BIM implementation in various construction projects [30].

In addition, the construction industry in developing countries predominantly represents nascent industries regarding BIM adoption and implementation. Challenges such as government support hinder the adoption of BIM in developing countries, contrasting the situation in some developed countries where such backing is evident [36]. According to Saka et al. [34], the construction industry is reaping numerous benefits from BIM adoption, however, BIM implementation in developing countries still faces significant challenges, such as a lack of support and guidance from clients and the government, thus more challenging for SMEs which form the backbone of the construction industry. Other challenges construction SMEs face in implementing BIM are limited resources and poor organisational structure [34].

## 6 Level of Adoption of Building Information Modelling in Construction Small and Medium-Sized Enterprises

The emergence of building information modelling represents a comprehensive innovation in managing the entire building lifecycle, spanning from the design phase to the ongoing control and management of the building itself [39]. With the continuous advancement of technology, the construction industry undergoes transformation, reaping the advantages of inventive solutions that reshape the way buildings and infrastructure are designed, built, and maintained [4]. Construction SMEs are rapidly embracing BIM adoption, which is reflected in current studies on adoption rate when compared with studies in six years past, with 42% of Australian SMEs using BIM at levels 1 and 2, while 5% utilising BIM at level 3 [21]. According to Anifowose et al. [6], the awareness and understanding of BIM among professionals have steadily increased via collective endeavour. However, there is a noticeable insufficient awareness among management professionals, resulting in a shallow understanding of BIM applications in the post-construction stage of the building. Also, BIM awareness has a noticeable decline from the design phase to the construction stage. According to Monejo and Makinde [26], the level of awareness and acceptance of BIM is moderate in the Nigeria construction industry, mainly in the use of BIM software, which has demonstrated a significant impact in essential aspects of project performance such as improved collaboration, conflict resolution, and reduction in labour.

However, many SMEs find BIM adoption unattractive due to several challenges, including a lack of motivation and resistance to change. Additionally, the availability of multiple BIM platforms that do not cater to the specific requirements of SMEs adds to their reluctance [25]. Furthermore, BIM has been recognised as a cutting-edge technological advancement, revolutionising the construction industry, which serves as a collaborative platform, employing advanced computer software that seamlessly integrates with all project tasks. BIM enhances work performance significantly throughout the project lifecycle, thus minimising project complexity and conflicts [37].

BIM adoption is at the infancy stage in Uganda, with high usage primarily for modelling. However, the importance of BIM and considered benefits towards productivity can improve its adoption in the Ugandan construction industry [2]. In addition, BIM has offered invaluable significance in the construction industry through the effective collaboration of team members in the course of construction works and the BIM technology usage in actualising construction projects [15]. In addition, Liu et al. [23] identified factors that aid the adoption of BIM in the architectural, engineering, and construction (AEC) industry, which are perceived benefits of BIM, internal readiness of construction organisations through BIM training and external forces in the form of competitive strength, influence from stakeholders and competitors.

## 7 Importance of Building Information Modelling Adoption in the Nigeria Construction SMEs

According to Saka et al. [36], ensuring the sustainable integration of building information modelling (BIM) is crucial to bridging the gap between construction SMEs and large construction firms that have already embraced BIM practices, thus empowering SMEs to compete in diverse construction projects effectively. Olugboyega [31] noted that BIM adoption is remarkably high for designing modern and complex buildings, particularly those with extensive project information. Prominent examples of such projects include the Eko Corporate Tower, Eko Boulevard, Le Reve Tower, Afren Tower, Eko Pearl Towers in Lagos state, and various other intricate developments that were successfully realised through the implementation of BIM during both the design and construction phases. Encouraging BIM adoption among SMEs can profoundly impact the construction industry, thus, construction SMEs can improve productivity, increase economic profits, and mitigate risk by embracing BIM and departing from traditional construction methods [25]. According to Vidalakis et al. [40], the integration of BIM by construction SMEs can facilitate effective information management, communication, and collaboration among supply chain actors in diverse construction operations. Furthermore, this proves highly beneficial in maintaining existing facilities, as BIM enables the streamlined maintenance of building components, making the process more efficient and manageable [35].

Additionally, building information modelling serves its purpose by delivering a multitude of benefits in all stages of construction projects; this includes improved design quality, ease of implementation, enhanced information sharing capabilities, reduced construction costs and design errors, accelerated work progress, and shorter construction timelines, increased energy efficiency, support for construction and project management, and enabling building owners to achieve greater operational efficiency throughout the lifecycle of the structure [32, 15]. According to Blair [9], BIM serves as a valuable tool for construction management professionals to proactively mitigate disruptions and prevent potential failures even before the construction process begins, its significance for construction SMEs lies in its capacity to efficiently manage collaborations with other industry professionals and seamlessly integrate project planning during handover processes. Also, construction SMEs can take advantage of project monitoring by tracing work progress with an accurate timeline to achieve tremendous success [9].

According to Kouch et al. [22], implementing BIM can facilitate the sharing and distribution of data, enabling its utilisation across various applications to manage multiple tasks and activities in the construction sectors throughout the building lifecycle. Embracing BIM technology is essential for construction SMEs operating in the construction sector and imperative for firms aiming to enhance their competitiveness and remain relevant in the industry [22]. BIM adoption by construction SMEs can facilitate predictable project duration, less disruption towards handover, less rework, and a better-quality asset and data valid for the entire lifecycle of the project [17]

## 8 Implication of the Study

The study has reviewed extant literature on the level of building information modelling adoption by construction SMEs and the importance of BIM to various construction works towards improving construction production management, majorly done by construction SMEs. The practical usage of this study will aid construction SMEs in developing countries to harness the importance of BIM, facilitating the implementation of the same at all levels of construction work. This will improve SMEs' job performance and the return on investment. Implementing BIM tools by construction SMEs will enable them to compete with large construction companies, improving their collaboration with relevant stakeholders and companies, thus improving product output and effective project monitoring to the point of delivery.

## 9 Conclusion and Further Research

This study examines the adoption level of building information modelling in construction SMEs. The extant literature reviewed divulged the paradigm shift from regular construction practices towards adopting digital construction, such as building information modelling, including the level of adoption of BIM and implementation of BIM tools at different stages of construction works, ranging from design to actual construction and maintenance of buildings. Developed countries prioritised BIM adoption, while not in developing countries due to challenges such as government support, poor awareness, lack of client support, limited resources, poor organisation structure, and inadequate research on BIM implementation. Typical challenges deterring construction SMEs from adopting SMEs were identified as lack of motivation, resistance to change, and lack of specific requirements for BIM adoption and implementation. Previous studies further showed that BIM can bridge the digital divide between construction SMEs and large construction firms, enabling SMEs to compete with big construction companies in carrying out various construction projects to achieve quality output, while construction SMEs can effectively collaborate with relevant stakeholders, including information sharing and management at all stages of construction works.

The study used relevant literature from developed and developing countries to put the study in the apt context of understanding the level of adoption of BIM adoption in construction SMEs. The study identified gaps between developed and developing countries in building information modelling adoption and implementation in various construction operations, while the feasibility of implementing BIM by construction SMEs was identified through the importance of BIM adoption to construction SMEs.

In synopsis, the findings in this study are relevant to the construction industry in developing countries and suggest further research on the adoption level and implementation of BIM by construction SMEs in all stages of work. The study review is limited due to few relevant publications on BIM adoption and implementation in developing countries; thus, further research is required to establish this study.

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## References

1. Abdalla SB, Rashid M, Yahia MW, Mushtaha E, Opoku A, Sukkar A, Maksoud A, Hamad R (2023) Comparative analysis of building information modeling (BIM) patterns and trends in the United Arab Emirates (UAE) with developed countries. Buildings 13(3):695
2. Acheng PO, Kibwami N, Mukasa TJ, Odongkara BB, Birungi R, Semanda J, Manga M (2022) Building information modelling adoption in Uganda's construction industry. Int J Constr Manage, pp 1–24
3. Ahiawodzi AK, Adade TC (2012) Access to credit and growth of small and medium scale enterprises in the Ho municipality of Ghana. Br J Econ Fin Manage Sci 6(2):34–51
4. Akinradewo O, Aigbavboa C, Aghimien D, Oke A, Ogunbayo B (2023) Modular method of construction in developing countries: the underlying challenges. Int J Constr Manag 23(8):1344–1354
5. Ametepey SO, Junior EYF, Cobbina JE (2022) Barriers to the growth of small and medium scale construction enterprises in Ghana. Open J Civ Eng 12(1):38–55
6. Anifowose OM, Babarinde SA, Olanrewaju OI (2018) Adoption level of building information modelling by selected professionals in Kwara state
7. Aranda-Mena G, Crawford J, Chevez A, Froese T (2009) Building information modelling demystified: does it make business sense to adopt BIM? Int J Manag Proj Bus 2(3):419–434

8. Azhar S (2011) Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry. Leadersh Manag Eng 11(3):241–252
9. Blair A (2022) BIM in construction management: 4 benefits for SMEs. GetApp. https://www.getapp.com.au/blog/2750/bim-construction-management-advantages#:~:text=BIM%20is%20a%20handy%20tool,integrate%20project%20planning%20in%20handovers
10. Bui N, Merschbrock C, Munkvold BE (2016) A review of building information modelling for construction in developing countries. Procedia Eng 164:487–494
11. Chong HY, Lee CY, Wang X (2017) A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. J Clean Prod 142:4114–4126
12. Dainty A, Leiringer R, Fernie S, Harty C (2017) BIM and the small construction firm: a critical perspective. Build Res Inf 45(6):696–709
13. Doan D, Ghaffarianhoseini A, Naismith N, Zhang T, Tookey T (2019) What is BIM?: a need for a unique BIM definition
14. Doan D, Ghaffarianhoseini A, Naismith N, Zhang T, Rehman A, Tookey T (2018) What is BIM? A need for a unique BIM definition. In: IConBEE2018: inaugural international conference on the built environment and engineering, p 88
15. Doumbouya L, Gao G, Guan C (2016) Adoption of the Building Information Modeling (BIM) for construction project effectiveness: the review of BIM benefits. Am J Civ Eng Archit 4(3):74–79
16. Egwunatum SI, Oboreh JC (2022) Factors limiting knowledge management among construction small and medium enterprises. J Eng Proj Prod Manage 12(1):1
17. Electricbloomhosting (2019) Digital construction and the opportunities for SMEs. BIM+. https://www.bimplus.co.uk/digital-construction-and-opportunities-smes/
18. Fai S, Graham K, Duckworth T, Wood N, Attar R (2011) Building information modelling and heritage documentation. In: Proceedings of the 23rd international symposium, international scientific committee for documentation of cultural heritage (CIPA), Prague, Czech Republic, pp 12–16
19. Ganah AA, John GA (2014) Achieving level 2 BIM by 2016 in the UK. Comput Civ Building Eng 2014:143
20. Hamma-Adama M, Kouider T, Salman H (2018) State of building information modelling (BIM) adoption in Nigeria
21. Hosseini M, Banihashemi S, Chileshe N, Namzadi MO, Udaeja C, Rameezdeen R, McCuen T (2016) BIM adoption within Australian small and medium-sized enterprises (SMEs): an innovation diffusion model. Constr Econ Build 16(3):71–86
22. Kouch AM, Illikainen K, Perälä S (2018) Key factors of an initial BIM implementation framework for small and medium-sized enterprises (SMEs). In: ISARC. Proceedings of the international symposium on automation and robotics in construction, vol 35. IAARC Publications, pp 1–9
23. Liu R, Issa R, Olbina S (2010) Factors influencing the adoption of building information modeling in the AEC Industry. In: Proceedings of the international conference on computing in civil and building engineering, pp 139–145
24. Lu SL, Sexton M (2008) Key characteristics of small construction firms: a United Kingdom perspective
25. Makowski P, Kamari A, Kirkegaard PH (2019) BIM-adoption within small and medium enterprises (SMEs): an existing BIM-gap in the building sector. In: Advances in ICT in design, construction and management in architecture, engineering, construction and operations (AECO), Northumbria University, Newcastle
26. Monejo TB, Makinde JK (2020) Assessment of the adoption of building information modelling (BIM) in the Nigerian construction industry. In: Proceedings of the school of environmental technology international conference (SETIC2020), FUT Minna
27. Ogunbayo BF, Aigbavboa CO, Thwala WD, Akinradewo OI (2022) Assessing maintenance budget elements for building maintenance management in Nigerian built environment: a Delphi study. Built Environ Proj Asset Manag 12(4):649–666. https://doi.org/10.1108/BEPAM-06-2021-0080

28. Ogundipe KE, Olaniran HF, Ajao AM, Ogunbayo BF (2018) Assessing the impact of quality supervision on construction operatives 'project delivery in Nigeria. Int J Civ Eng Technol 9(9):426–439
29. Organization for Economic Cooperation and Development (2017) Enhancing the contributions of SMEs in a global and digitalized economy. Paris. Available at: https://www.oecd.org/industry/C-MIN-2017-8-EN.pdf. Accessed 10 Dec 2022
30. Olanrewaju OI, Babarinde SA, Chileshe N, Sandanayake M (2021) Drivers for implementing building information modeling (BIM) within the Nigerian construction industry. J Fin Manage Prop Constr
31. Olugboyega O (2016) Building information modelling-based projects in nigeria evidence from Eko Atlantic City. PM World J 5(10):1–14
32. Adekunle SA, Ejohwomu O, Aigbavboa C, Ikuabe M, Ogunbayo B, John IB (2022) Achieving macro-level bim adoption in the South African construction industry: key stakeholders and constraints. In: International conference on computing in civil and building engineering. Springer International Publishing, Cham, pp 545–552
33. Russell R (2009) Systematic review methods. Issues and challenges in conducting systematic reviews to support development of nutrient reference values: workshop summary—NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK44088/#:~:text=A%20systematic%20review%20is%20a,to%20formulate%20specific%20key%20questions
34. Saka AB, Chan DW, Siu FM (2019) Adoption of building information modelling in small and medium-sized enterprises in developing countries: a system dynamics approach. In: Proceedings of the CIB world building congress
35. Seiso MP, Ogunbayo BF, Aigbavboa CO (2023) Joint ventures in the South African construction industry: factors militating against success. Buildings 13(5):1299
36. Saka AB, Chan DW, Siu FM (2020) Drivers of sustainable adoption of building information modelling (BIM) in the Nigerian construction small and medium-sized enterprises (SMEs). Sustainability 12(9):3710
37. Shibani A, Awwad KA, Ghostin M, Siddiqui K, Farji O (2020) Adopting building information modelling in small and medium enterprises of Iraq's construction industry. In: International conference on industrial engineering and operations management, March edn. IEOM Society, pp 457–470
38. Singh V, Holmström J (2015) Needs and technology adoption: observation from BIM experience. Eng Constr Archit Manage
39. Ullah K, Lill I, Witt E (2019) An overview of BIM adoption in the construction industry: benefits and barriers. In: 10th Nordic conference on construction economics and organization, vol 2. Emerald Publishing Limited, pp 297–303
40. Vidalakis C, Abanda FH, Oti AH (2020) BIM adoption and implementation: focusing on SMEs. Constr Innov 20(1):128–147
41. Wang Y (2016) What are the biggest obstacles to growth of SMEs in developing countries?–An empirical evidence from an enterprise survey. Borsa Istanbul Rev 16(3):167–176
42. Wong AK, Wong FK, Nadeem A (2010) Attributes of building information modelling implementations in various countries. Archit Eng Des Manage 6(4):288–302
43. World Bank (2022) Small and medium enterprises (SMEs) finance: improving SMEs' access to finance and finding innovative solutions to unlock sources of capital. Retrieved 18 June 2023, from https://www.worldbank.org/en/topic/smefinance
44. Zahrizan Z, Ali NM, Haron AT, Marshall-Ponting A, Hamid ZA (2013) Exploring the adoption of Building Information Modelling (BIM) in the Malaysian construction industry: a qualitative approach. Int J Res Eng Technol 2(8):384–395

# Conceptualizing Hard and Soft Benefits of Adopting BIM in Construction Projects: A Systematic Review

**Tusdid Sabur Tohfa, Abdelrahman M. Farouk, and Rahimi A. Rahman**

## 1 Introduction

The construction industry contributes significantly to the socioeconomic growth of any nation. The construction industry faces numerous challenges, such as diminished efficiencies, subpar quality, escalating expenses, generation of construction waste, project delays, and insufficient communications among stakeholders, owing to its intricate nature. Modern innovations of BIM are a strategic solution aimed at addressing challenges such as inferior productivity levels within the construction industry. By adopting BIM, the construction sector can streamline workflows, improve collaboration, reduce errors and rework, enhance cost estimation and scheduling precision, and ultimately increase productivity [44]. It has the potential to revolutionize the industry by using technology to address long-standing issues and enhance overall project outcomes [7]. BIM is defined by the National Institute of Building Sciences (NIBS) as: "Building Information Model or BIM utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and it is intended to be a repository of information for the facility owner/operator to use and maintain throughout the life cycle of a facility [42]."

The main obstacle regarding adopting BIM in construction projects pertains to the resistance exhibited by professionals within the industry. This resistance stems from concerns surrounding potential disruptions, associated costs, safeguarding of data, and the necessity for upskilling [57]. Professionals may express concerns regarding the potential disruption of established workflows, the need for supplementary training, and the initial financial implications associated with implementing

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BIM. Data security and privacy concerns arise due to the inclusion of sensitive information within the comprehensive digital models employed in BIM. There may be concerns regarding unauthorized access and data breaches. In addition, professionals may experience apprehension regarding the learning curve entailed by BIM tools and software as they express concerns about the potential obsolescence of their existing skill sets [26]. The presence of these apprehensions serves as a contributing factor to the hesitancy observed in the adoption of BIM within construction endeavors.

The successful adoption of BIM has the potential to foster enhanced productivity among all stakeholders, thereby conferring benefits to the entire construction value chain [28, 47]. While the primary focus of managers regarding BIM adoption is market competitiveness, they have yet to establish a comprehensive approach to fully optimize the benefits of BIM integration [12]. The adoption of BIM by an entity may not lead to the full realization of the associated benefits due to specific challenges. This may result in a loss of investment and a reversion to traditional approaches [12]. However, to realize the critical benefits of BIM is vital for an organization to properly transition to this modern edge technology [23].

This study aims to identify and discuss the key benefits of BIM adoption by comprehensively reviewing the existing literature. The main aim of this review is to address the following research questions: What soft and hard benefits can construction professionals consider when deciding to adopt BIM? To achieve this aim, a comprehensive analysis of the existing literature pertaining to the benefits of BIM adoption in construction projects was carried out. The study identified the most critical benefits of BIM and emphasized their potential impact to clarify their influence on BIM adoption. The outcomes of the review have the potential to enhance the comprehensive comprehension of the benefits of BIM and identify the critical advantages that facilitate the adoption of BIM in construction projects. The outcomes of this study can be valuable resources for academics, practitioners, and the general public who aim to deepen their understanding of BIM and determine its significant benefits. The identification of significant BIM benefits carries substantial economic implications, rendering it imperative to make informed decisions regarding BIM adoption.

## 2 Research Background

### *2.1 Definition of BIM*

Van Nederveen defines BIM as “A model of information about a constructed facility that comprises complete and sufficient information to support all life-cycle processes, which can be interpreted directly by computer applications. It comprises information about the constructed facility and its components, and information about properties such as function, shape, material and processes for the project life cycle”. According to McGraw-Hill's publication titled "The Business Value of BIM", BIM is characterized as the utilization of digital models in the creation, construction, and operation phases of projects [5]. The primary focus of this report is to present the perspectives of contractors regarding the definition of BIM. Succar defines BIM as a set of interacting policies, processes, and technologies generating a methodology to manage the essential design and project data in digital format throughout the facility's life cycle [53]. BIM goes beyond mere software, it encompasses both a process and software. Expanding on this, it becomes apparent that effective utilization of BIM necessitates three key factors: (1) process, (2) technology, and (3) behavior.

### *2.2 Development of BIM*

Professor Charles Eastman developed the BIM concept at the Georgia Tech School of Architecture in the late 1970s [33, 50]. From the mid-2000s onward, the architecture, engineering, and construction (AEC) sector has embraced the incorporation of BIM in construction projects. Initially conceptualized in 2000, BIM was defined as a structured model representing architectural elements. The use of BIM has progressed from the pre-construction to the post-construction phases. In 2008, BIM found application as a project simulation, encompassing a three-dimensional (3D) model of a project component. This model was connected to and amalgamated with essential information across various project phases. Over the period spanning from 2008 to 2013, BIM underwent an expansion, evolving into a technological revolution that played a transformative role in the construction industry.

### *2.3 BIM Levels*

According to the British Standard (BS), the BIM Task Group has adopted the concept of "BIM Levels." The chart below and the four defined levels (Level 0 to Level 3) have widely become the accepted criteria for determining BIM compliance in projects [20]. **Level 0** is described as unmanaged CAD, a stage that most industries have already surpassed. **Level 1** typically involves a combination of 3D CAD for conceptual work and 2D for drafting statutory approval documentation and production information, which is the current operational level for many companies. **Level 2** is characterized by collaborative working, where all parties use their 3D models without working on a single, shared model. **Level 3** signifies complete collaboration across all disciplines using a unified project model stored in a centralized repository, usually an object database in cloud storage. This is known as "Open BIM" [20].

The primary advantages of BIM encompass enhanced and simplified coordination among project personnel, increased productivity, elevated project quality control, and improved communication [13]. BIM users encounter diverse challenges akin to obstacles on their journey. Typically, BIM users must balance the advantages derived from enhanced productivity and coordination and the challenges posed by BIM-related costs, training issues, and associated problems.

BIM has transformed the construction sector by enabling greater collaboration among project stakeholders, which fosters improved teamwork and communication. BIM may help the construction industry in several ways, notably by simplifying systematic categorization and evaluation processes. BIM enables stakeholders to communicate, visualize, evaluate, and manage different project components effectively during the project's whole life cycle because it is a digital depiction of a construction or infrastructure project.

### *2.4 Definition and Categories of Benefits*

The first step to success is defining what success looks like for a particular project—the so-called success criteria. Finding out precisely what a project is anticipated to achieve and enable is the goal of the success criterion. Project deliverables are clearly defined and must be provided within a specific time range [51]. These outputs are goods, functions, or services anticipated to bring about improvements and help organizations accomplish their goals (APM 2012, PMI® 2013d). According to [51], the enhancement to the business brought about by these adjustments is referred to as a benefit. It increases the value of the company to the shareholders [58].

Benefits can be defined as follows [14].

Benefits refer to tangible and measurable enhancements, typically articulated financially, to rationalize any potential business investment. So, every benefit should have a monetary value.

Benefits can be categorized into various types, like tangible and intangible benefits.

- **Tangible benefits** are measured objectively based on evidence. A direct cost reduction, return on investment, and market share change are examples of tangible benefits.
- **Intangible benefits** are those that lack direct and objective measurability, instead depending on a proxy or representative measure for evaluation**.** Customer satisfaction, employee morale, and brand or image perceptions are examples of intangible benefits.

Benefits can be further categorized as planned and emergent benefits.

- **Planned benefits** are anticipated advantages for a chosen beneficiary, identified and sanctioned through the organization's benefit realization management system.
- **Emergent benefits** are unexpected benefits that arise during or after a program, project, or within the context of a portfolio.

Benefits can also be further categorized as direct and indirect benefits.

- **Direct benefits** are unambiguous, measurable gains realized as planned by defined beneficiaries.
- **Indirect benefits** refer to secondary or unintended gains, whether planned or unplanned, experienced by designated beneficiaries or others following the achievement of a direct benefit.

Tangible and intangible, planned and emergent, and direct and indirect are considered non-functional with respect to the benefit realization of BIM. Nevertheless, in general, the benefits are widely categorized as hard benefits and soft benefits.

- **Hard benefits** are the project outputs that any tangible measure can directly measure.
- **Soft benefits** are project outputs that can be represented or substituted by a tangible measure.

In this analysis, we will examine the different benefits associated with BIM adoption, encompassing both hard and soft benefits. This comprehensive approach allows for a thorough exploration of the wide-ranging benefits that BIM adoption can offer.

## *2.5 Knowledge Gap*

The above literature review illustrates that BIM benefits construction projects. In addition, most works focus on BIM adoption benefits, precisely hard benefits, rather than others. A significant knowledge gap exists in the broader conceptualization of the hard and soft benefits of various technological innovations and advancements across industries [8]. The absence of consensus in defining and classifying these benefits hinders the evaluation, comparison, and communication of the value proposition associated with adopting these. While hard benefits, such as increased efficiency and cost savings are frequently measurable and tangible, there is a lack of research on the conceptualization and comprehension of soft benefits, which include intangible, qualitative outcomes such as improved user experience, increased customer satisfaction, and organizational agility [40]. In addition, the interplay between hard and soft benefits, as well as the contextual factors that influence their realization, remains understudied. Understanding the interrelationships between these benefits and the contextual factors influencing their outcomes is essential for informed decision-making, practical adoption, and optimal utilization of emergent technologies across various industries. By bridging this knowledge gap, stakeholders can maximize the potential of technological innovations and generate transformational change in their respective domains. Therefore, this study fills that gap by analyzing the critical hard and soft benefits of adopting BIM in the construction industry.

## 3 Methodology

This study aims to identify the critical soft and hard benefits of adopting BIM in construction projects. Therefore, this study systematically reviews the soft and hard benefits of adopting BIM. The objectives of this SLR may encompass establishing a theoretical foundation for future research endeavors, comprehending the scope of research conducted on a particular subject of interest, or addressing pragmatic queries by assimilating the insights offered by extant research. The form of literature review comprises a unique and valuable contribution to research. It establishes a firm point of departure for other individuals in the academic sphere interested in a specific subject matter [43]. Therefore, an SLR is deemed appropriate for establishing a comprehensive overview of the benefits of adopting BIM. This approach provides valuable insights into the critical benefits of the research topic while also addressing significant gaps in the existing literature. Furthermore, the present study employs the systematic approach outlined in the PRISMA guidelines. According to Moher et al. [40, 41], the PRISMA guidelines consist of a flow diagram divided into four phases: phase 1 involves identification, phase 2 covers screening, phase 3 pertains to eligibility, and phase 4 concerns inclusion. The transparency of the PRISMA approach enhances the clarity and accuracy of the methodological and analytical procedures [41]. Therefore, the utilization of evidence-based research in this study contributes to enhancing the overall quality of the review.

The articles for the SLR were retrieved from the Scopus database. Scopus was used for SLRs in past works in construction and other domains (e.g., engineering, management, and operations) because it contains the largest abstract and citation databases [24, 52]. Compared with others, like Google Scholar and Web of Science, Scopus offers the most comprehensive coverage of construction management research [27]. Scopus has also grown in popularity due to its extensive coverage, interdisciplinary approach, quality control, citation tracking, search capabilities, metrics, and analysis for researchers [22, 49]. As the review encompasses both the soft and hard benefits of BIM, potentially leading to a reduced number of articles, this study employed broad keywords for the search, i.e., "BIM," "Building Information Modeling," and "Benefits." In addition, the search was limited to journal articles in English. According to Palmatier et al. [45], the constraints associated with relying solely on high-impact journal articles for review papers are noteworthy, as they can impede the ability to effectively synthesize existing research and provide a comprehensive overview of knowledge and insights. Consequently, the scope of the inquiry was restricted to scholarly publications in the form of journal articles, excluding conference proceedings, to ensure a comprehensive and rigorous synthesis of the literature. The search approach was: (TITLE-ABS-("building information model*" OR "BIM" AND "benefits" AND (LIMIT-TO) (SRCTYPE, "j") AND (LIMIT-TO (LANGUAGE, "English")). The search yielded a total of 354 articles in academic journals.

In Fig. 1, given the limited results of the initial search, this study incorporated articles citing the initial 354 articles to ensure the thoroughness of the review, resulting in the selection of 44 articles. Out of these, 11 articles with duplicates were excluded, leaving 98 citing articles. During the screening phase, the abstracts of these articles were scrutinized, leading to the removal of 6 more articles. Consequently, a total of 42 initial and 16 citing articles were retained after eliminating duplicates upon combining both sets. The eligibility phase involved a detailed examination of the full articles to identify those with distinguishable soft and hard benefits, culminating in the selection of 19 articles. Subsequently, a further review led to the removal of 2 more articles, leaving a total of 17 articles deemed suitable for subsequent analysis.

The number of articles that were identified was comparable with other SLRs published on the topic of the advantages of BIM. For example, in similar research by

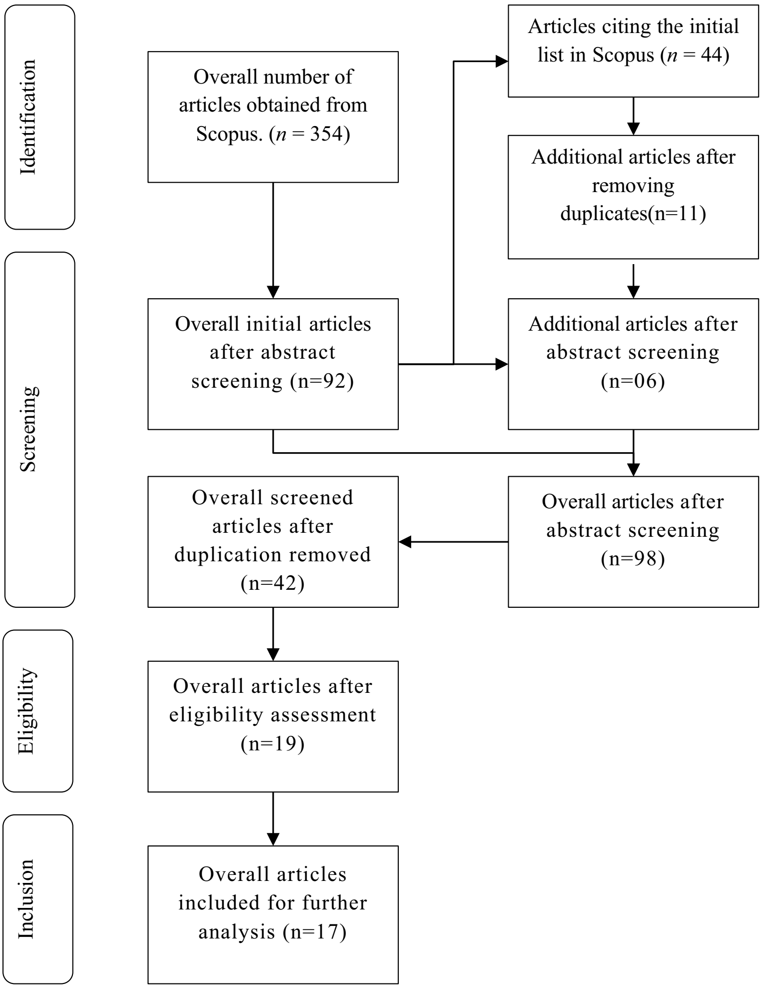


**Fig. 1** SLR procedure

Abbasnejad et al. [1], out of 382 identified articles from the database, only 80 were relevant. Moreover, the present study has a narrower scope than previous literature reviews on BIM, as it specifically examines the benefits of BIM. Thus, the adequacy of the sample size may be deemed sufficient for providing an overview of the present research trends on the benefits of adopting BIM.

The thematic analysis method is an inductive technique that aims to reveal significant patterns of information, interpretations, and fundamental concepts that arise from the data [30]. The methodology offers a rigorous and systematic framework for examining qualitative data and producing valuable insights. It is recommended that a thematic analysis be conducted on the conclusive set of articles obtained through SLR.

# 4 Results

The SLR findings indicate that 34 journals have published more than four articles on the subject matter, as presented in Table 1. The prominent journal on the subject matter is Automation in Construction, which accounted for 48 articles. Sustainability and Engineering, Construction, and Architectural Management held the second highest position among journals dedicated to the subject matter.

The following primary topics emerged from the thematic analysis of the final compilation of articles in this study: Hard and Soft benefits. As seen in Table 2, each theme has several subthemes. The theme and its subthemes are discussed in the following subsections.

The findings of the analysis have culminated in the creation of a framework that facilitates the determination of the importance of pivotal advantages associated with adopting BIM. Consequently, a framework of hard and soft benefits of BIM is depicted in Fig. 2. The subsequent section describes the influence of each benefit on the adoption of BIM in construction projects, along with a classification of these benefits into soft and hard categories.

# 5 Discussion

## *5.1 Hard Benefits of Adopting BIM*

### 5.1.1 Clash Management

Adopting BIM offers significant benefits for managing construction project conflicts [16]. Adopting BIM, conflict location and objective can be determined during the planning phase, reducing the likelihood of costly adjustments during construction. By creating 3D models of constructed facilities and components, prospective conflicts

**Table 1** Distribution of the articles based on publication source

| Name of journal | Count |
|---|---|
| Automation in construction | 48 |
| Sustainability (Switzerland) | 29 |
| Engineering, construction, and architectural management | 29 |
| Buildings | 28 |
| Journal of information technology in construction | 24 |
| Applied sciences (Switzerland) | 16 |
| Journal of building engineering | 15 |
| Malaysian construction research journal | 14 |
| Journal of construction engineering and management | 14 |
| Journal of cleaner production | 10 |
| Advances in civil engineering | 10 |
| Journal of management in engineering | 9 |
| Journal of engineering, design, and technology | 8 |
| International journal of construction management | 8 |
| Energies | 7 |
| Journal of computing in civil engineering | 6 |
| International journal of sustainable construction engineering and technology | 6 |
| Energy and buildings | 6 |
| Construction innovation | 6 |
| Built environment project and asset management | 6 |
| Sustainable cities and society | 5 |
| Smart and sustainable built environment | 5 |
| Frontiers in built environment | 5 |
| Proceedings of institution of civil engineers: management, procurement, and law | 4 |
| Journal of legal affairs and dispute resolution in engineering and construction | 4 |
| Journal of facilities management | 4 |
| Journal of construction in developing countries | 4 |
| Journal of civil engineering and management | 4 |
| Journal of Asian architecture and building engineering | 4 |
| International journal of sustainable development and planning | 4 |
| Infrastructures | 4 |
| Asian journal of civil engineering | 4 |
| Architectural engineering and design management | 4 |
| Ain Shams engineering journal | 4 |

**Table 2** Themes, subthemes, and codes of the reviewed articles

| Themes | Subthemes | Codes |
|---|---|---|
| Hard benefits | Clash management | Clash detection |
| | | Clash elimination in design |
| | | Efficient communication |
| | | Construction complexity |
| | | Predictive performance analysis (energy/code analysis) |
| | Quality | Construction quality |
| | | Enhanced construction productivity |
| | | Improved safety performance |
| | Construction process improvement | Integration of design and construction |
| | | Construction task sequencing and scheduling |
| | | Assembly methods |
| | | Accuracy increase |
| | | Reduced project duration |
| | | Real-time updates |
| | | Construction activity tracking and progress monitoring |
| | | Schedule compliance in construction project delivery |
| | Cost control | Cost estimation and quantity take-off |
| | | Cost-effectiveness |
| | | Better cost estimates and control |
| | | Reduction in as-built drawings cost |
| | | Reduced construction cost |
| | | Simplified cost checking and updating |
| | | Automatic BOQ preparation |
| | Data management | Single source of truth |
| | | Provision of life-cycle data |
| | | Centralized data storage in coordinated model |
| | | Reliable and accurate quantities and cost estimates |
| | | Construction cost reduction and cost performance improvement |
| | | Reduction of errors |
| | Innovation | Increased global competitiveness |
| | | Speeding up the design process |
| | | Innovation encouragement and new construction methods introduction |
| Soft benefits | Collaboration and communication | Stakeholder involvement |
| | | Multi-party communication |
| | | Better communication platform |

(continued)

**Table 2** (continued)

| Themes | Subthemes | Codes |
|---|---|---|
| | | Multi-disciplinary design coordination |
| | | Rapid identification of design changes |
| | | Effective collaboration |
| | Efficiency and productivity | Decision-making |
| | | Consistency and reliability |
| | | Project knowledge management |
| | | Single platform for project information |
| | | Better construction planning and monitoring |
| | | Time and cost assessment for design changes |
| | | Construction scheduling |
| | Project performance | Design alternatives |
| | | Conflict prediction |
| | | Project perspective |
| | | Time-based clashes identification |
| | | Integrated construction scheduling and planning |
| | | Project progress tracking |
| | Improved information management | Component details for better understanding |
| | | Scope clarification |
| | | Improved cost database management |
| | | Facilitation of project information and data sharing, exchange, and management |
| | | Improved visualization |
| | Sustainability | Organizational image enhancement |
| | | Operations and maintenance improvement of project infrastructure |
| | | Financial and investment opportunities improvement |
| | | Client services |

can be identified and resolved before construction [25]. This strategy promotes improved quality, decreased costs, expanded project outcomes, and improved communication and collaboration among project stakeholders.

### 5.1.2 Quality

BIM may be exceedingly beneficial for construction project quality management. BIM enables better quality control and early problem identification through more accurate and comprehensive project representation [13]. Adopting BIM, construction teams can rapidly evaluate and scrutinize design decisions, construction techniques,

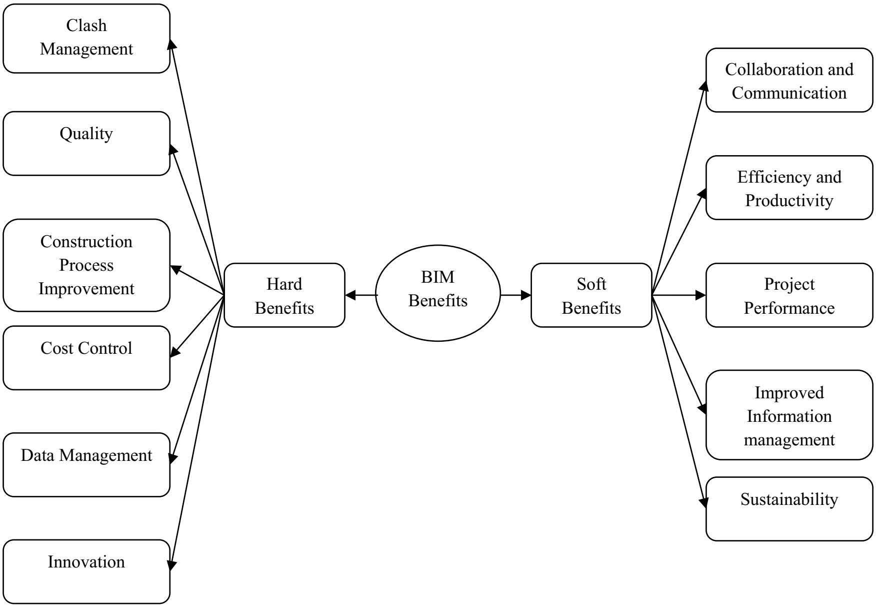


**Fig. 2** BIM benefit framework

and material selections to ensure compliance with regulations. Changes to a project can also be documented using BIM, enabling precise documentation and the detection of potential problems [35]. Utilizing BIM for quality management could enhance project outcomes and reduce error and rework rates.

### 5.1.3 Construction Process Improvement

Adopting BIM can offer significant benefits for enhancing the construction process. BIM's capacity to facilitate proper planning, coordination, and communication among project stakeholders results in improved project outcomes and shorter project duration [2]. By creating a precise 3D model, BIM can identify and resolve potential problems before construction begins, resulting in fewer errors and less remediation. BIM also facilitates more accurate resource allocation and cost estimation, which reduces the likelihood of budget overruns. BIM's capacity to monitor and manage project changes encourages increased collaboration and fewer stakeholder disagreements [7].

#### 5.1.4 Cost Control

Integration of BIM may have a significant positive effect on construction cost management. BIM's ability to estimate costs more precisely and thoroughly reduces the likelihood of budget overruns. BIM's 3D modeling capabilities enable stakeholders to view and evaluate the entire project, enabling them to identify cost-cutting opportunities [36]. In addition, BIM enables real-time cost monitoring and analysis, which makes it easier to identify budget variances and make timely adjustments. By adopting BIM, stakeholders can simulate multiple design and construction scenarios to determine the most cost-effective course of action [21]. Adopting BIM to accelerate the construction process and reduce the need for rework can also result in significant cost reductions.

#### 5.1.5 Data Management

BIM may be of tremendous benefit for data management on construction projects. BIM enables the creation of a comprehensive digital representation of the entire construction process, serving as a single source of information [19]. As a result, data administration is streamlined, and it is now simpler to access, communicate, and update data in real time. BIM also enables integrating data from multiple sources, providing a more comprehensive view of the project and facilitating more informed decisions [56].

#### 5.1.6 Innovation

Integration of BIM may benefit construction projects in novel ways. BIM provides advanced capabilities such as 3D modeling, visualization, and virtual reality simulations, enhancing stakeholder cooperation and communication [48]. BIM's real-time project monitoring enables stakeholders to make rapid adjustments, enhancing project outcomes. By providing a digital model of the project, BIM can identify potential issues early and reduce the need for costly rework. BIM enables prefabrication and modular construction techniques, significantly reducing time and expenses [4].

### *5.2 Soft Benefits of Adopting BIM*

#### 5.2.1 Collaboration and Communication

BIM offers significant benefits to construction project collaboration and communication. BIM enables stakeholders to share project data and modifications in real time, enhancing team communication and collaboration [39]. The utilization of BIM to generate a digital representation of the project ensures that all stakeholders have access to a consistent source of project information, thereby reducing the likelihood of communication errors or misunderstandings. BIM's 3D modeling capabilities enable stakeholders to view the project's design and scope, fostering greater comprehension and communication among project participants [38].

### 5.2.2 Efficiency and Productivity

BIM can result in significant efficiency and productivity gains. BIM generates a digital model of the project, enabling stakeholders to envisage and organize construction operations more precisely and efficiently [3]. The 3D modeling and simulation capabilities of BIM allow stakeholders to optimize construction plans before the commencement of actual construction work, thereby eradicating the possibility of expensive rework. In addition, BIM promotes using lean construction techniques, such as modular construction and prefabrication, which can help reduce construction time and costs [18].

### 5.2.3 Project Performance

BIM significantly improves the efficacy of construction projects. BIM creates a digital model of the project that contains all relevant data and information in a single location. For improved project performance, stakeholders can use this centralized source of information to monitor various project parameters, such as budgets, schedules, and quality indicators. BIM simplifies the management of project milestones, enabling stakeholders to anticipate potential delays and implement corrective actions to keep the project on track [55].

### 5.2.4 Improved Information Management

BIM may substantially improve construction project information management. Because BIM-based construction management centralizes project information, stakeholders can communicate and collaborate more effectively [17]. BIM eliminates errors and duplication by exchanging and managing real-time project data and information. Additionally, it ensures that everyone is working with the most recent information. BIM enables stakeholders to access project information from any location and at any time, increasing the overall efficacy of the project [37].

### 5.2.5 Sustainability

BIM can provide significant sustainability benefits for construction projects. By simulating and analyzing multiple project scenarios, BIM can help reduce waste, enhance material consumption, and increase energy efficiency [31]. This enables stakeholders to make well-informed decisions with minimal environmental impact. BIM's 3D modeling component enables stakeholders to visualize the project's design and identify any issues impacting sustainability [11]. BIM can also aid in selecting sustainable materials by analyzing their environmental impact and supplying statistics on their life cycle [15].

### 5.2.6 Study Implications

Studying the soft and hard benefits of adopting BIM has enormous ramifications and enables a thorough assessment of its influence. Researchers can evaluate measurable cost reductions, increased productivity, and efficiency through less rework and better resource allocation. Researchers can also consider the soft benefits of improved stakeholder communication, decision-making, and collaboration. The value of BIM can be maximized when an understanding of these benefits informs decision-making.

### 5.2.7 Limitations and Future Research Directions

Conceptualizing the hard and soft benefits of adopting BIM in construction projects has been a topic of extensive research, but several limitations must be acknowledged. However, it is imperative to recognize and address certain constraints within this research body. To begin with, it is worth noting that numerous research conducted within this domain exhibit limited sample sizes, thereby constraining the extent to which the findings can be extrapolated. To address this issue, it is imperative for forthcoming research to make a concerted effort to incorporate more extensive and more diverse participant samples. This will help ensure that the findings obtained apply to a broader array of projects and contexts. Furthermore, it is worth noting that the research conducted on the benefits of BIM often concentrates on geographic areas, such as the United States or Europe. Consequently, the findings may not be directly transferable to construction projects in other regions with distinct regulatory frameworks, cultural norms, and industry practices [44]. To address this constraint, future investigations should strive to incorporate a broader international outlook to accommodate regional disparities. Furthermore, a considerable number of research have predominantly concentrated on immediate consequences, such as financial and temporal benefits during the construction period, while disregarding the enduring effects of BIM adoption across the entirety of the project's lifespan [46].

It is imperative to comprehend the comprehensive advantages of BIM throughout its entire life cycle, encompassing its influence on maintenance, operations, and facility management. Organizational factors significantly influence the adoption of BIM. Further investigation is warranted to explore the impact of leadership support, change management strategies, and organizational culture on the practical adoption and attainment of BIM benefits [6]. Gaining an understanding of these factors can facilitate the identification of obstacles and the formulation of strategies aimed at promoting the successful adoption of BIM. By addressing these limitations and exploring these future research directions, the comprehension of the soft and hard benefits of adopting BIM in construction projects can be significantly augmented. The outcome will result in a higher level of decision-making knowledge and a more effective integration of BIM within the industry. Consequently, this will contribute to the enhancement of project results, the promotion of sustainability, and the augmentation of economic value.

## 6 Conclusion

This study intends to review existing literature on the critical soft and hard benefits of adopting BIM in construction projects and identify gaps in the current pool of knowledge. For the SLR, the PRISMA approach was used to thoroughly assess 17 journal articles, which were then thematically analyzed. The articles were divided into two themes based on the analysis: soft and hard benefits. The articles also contributed to the following eleven subthemes: There are six subthemes under the hard benefits, including conflict management, quality, cost control, data management, and innovation. The five subthemes under the soft benefits include collaboration and communication, productivity and efficiency, project performance, improved information management, and sustainability. The analysis points to a knowledge gap in identifying the significant benefits of implementing BIM. Most works concentrated on the evaluation of BIM adoption in construction projects instead of presenting its significant soft and hard benefits.

The first SLR of research trends on the benefits of BIM adoption was carried out in this study. The study identified research limitations, knowledge gaps, future research paths for BIM, and the benefits of BIM adoption, which goes deep into research trends and article classifications. This study still has a few limitations despite significant attempts. First, the assessment only looks at the latest publications discussing the benefits of BIM adoption. As a result, this study cannot represent other BIM-related research areas. Another limitation is that the literature search was carried out utilizing Scopus. Consequently, articles that are not listed in Scopus could be disregarded. Nevertheless, the methodology is suitable because the chosen database is frequently used by SLR research in construction fields. Moreover, the snowballing technique also enhances the existing data. Another minor limitation of this study is that all the articles evaluated are in the English language. Despite these limitations, the study's aim was satisfactorily achieved.

The study provides theoretical contributions by shedding insight into the benefits of adopting BIM, assisting future researchers in conducting comparable assessments and identifying research gaps. Researchers can follow the study's conclusions regarding limitations and future directions. When applying BIM in construction projects, industry professionals can use the results to help them grasp its benefits and apply it most effectively. As a result, this study has substantial theoretical implications that will help researchers better understand the benefits of BIM and assist practitioners in the industry.

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## References

1. Abbasnejad B, Nepal MP, Ahankoob A, Nasirian A, Drogemuller R (2021) Building Information Modelling (BIM) adoption and implementation enablers in AEC firms: a systematic literature review. Archit Eng Des Manag 17(5–6):411–433. https://doi.org/10.1080/17452007.2020.1793721
2. Al-Ahbabi M, Alshawi M (2015) BIM for client organisations: a continuous improvement approach. Constr Innov 15(4):402–408
3. Al-Ashmori YY, Othman I, Rahmawati Y, Amran YHM, Sabah SHA, Rafindadi AD, Mikić M (2020) BIM benefits and its influence on the BIM implementation in Malaysia. Ain Shams Eng J 11(4):1013–1019. https://doi.org/10.1016/j.asej.2020.02.002
4. Alfred O (2011) A preliminary review on the legal implications of BIM and model ownership. 16:687–696
5. Analysis MT (2012) SmartMarket report the business value of BIM in North America SmartMarket report
6. Aranda-Mena G, Crawford J, Chevez A, Froese T (2009) Building information modelling demystified: does it make business sense to adopt BIM? Int J Manag Projects Bus 2(3):419–434. https://doi.org/10.1108/17538370910971063
7. Arayici Y, Coates P, Koskela L, Kagioglou M, Usher C, O'reilly KJSS (2011) BIM adoption and implementation for architectural practices. Struct Surv 29:7–25
8. Arto K, Ricardo C (2014) Challenges in the implementation of BIM for FM? Case Manchester town hall complex. In: Computing in civil and building engineering, pp 665–672. https://doi.org/10.1061/9780784413616.083
9. Azhar S (2008) Building information modeling (BIM): a new paradigm for visual interactive modeling and simulation for construction projects. 1
10. Azhar S (2011) Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry. Lead Manag Eng 11:241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127
11. Azhar S, Brown J (2009) BIM for sustainability analyses. Int J Constr Educ Res 5(4):276–292
12. Brooks TJ, Lucas JD (2014) Computing in civil and building engineering ©asce 2014 243. Fitch 2012:243–250
13. Bryde D, Broquetas M, Volm JM (2013) The project benefits of building information modelling (BIM). Int J Project Manag 31(7):971–980. https://doi.org/10.1016/j.ijproman.2012.12.001
14. Carlos Eduardo Martins Serra (2017) Benefits realization management
15. Carvalho JP, Bragança L, Mateus R (2019) Optimising building sustainability assessment using BIM. Autom Constr 102:170–182. https://doi.org/10.1016/j.autcon.2019.02.021
16. Chahrour R, Hafeez MA, Ahmad AM, Sulieman HI, Dawood H, Rodriguez-Trejo S, Dawood N (2021) Cost-benefit analysis of BIM-enabled design clash detection and resolution. Constr Manag Econ 39(1):55–72

17. Demian P, Walters D (2014) The advantages of information management through building information modelling. Constr Manag Econ 32(12):1153–1165
18. Doumbouya L, Gao G, Guan C (2016) Adoption of the building information modeling (BIM) for construction project effectiveness: the review of BIM benefits. Am J Civil Eng Archit 4(3):74–79
19. Dowsett RM, Harty CF (2013) Evaluating the benefits of BIM for sustainable design: a review. In: Proceedings of the 29th annual ARCOM conference, pp 13–23
20. Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook a guide to building information modeling for owners, managers, designers, engineers, and contractors, 2nd edn. Wiley, Amsterdam
21. Enshassi AA, Hamra LAA, Alkilani S (2018) Studying the benefits of building information modeling (BIM) in architecture, engineering and construction (AEC) industry in the Gaza strip. Jordan J Civil Eng 12(1):144285
22. Farouk AM, Rahman RA, Romali NS (2023) Non-revenue water reduction strategies: a systematic review. Smart Sustain Built Environ 12(1):181–199
23. Farouk AM, Rahman RA, Zakaria ZB (2023) Design coordination in BIM: decision criteria for determining tolerances. https://doi.org/10.1063/5.0111777
24. Farouk AM, Zulhisham AZ, Lee YS, Rajabi MS, Rahman RA (2023) Factors, challenges and strategies of trust in BIM-based construction projects: a case study in Malaysia
25. Fawaz M, Ibrahim R, Rashidi A, Ghafar MA (2021) From modelling to management of project delivery: review on clash management process with BIM in Malaysia. Malaysian Constr Res J 35(3):57–70
26. Gamil Y, Rahman IAR (2019) Awareness and challenges of building information modelling (BIM) implementation in the Yemen construction industry. J Eng Des Technol 17(5):1077–1084. https://doi.org/10.1108/JEDT-03-2019-0063
27. Ghaleb H, Alhajlah HH, Bin Abdullah AA, Kassem MA, Al-Sharafi MA (2022) A scientometric analysis and systematic literature review for construction project complexity. Buildings 12(4):1–20. https://doi.org/10.3390/buildings12040482
28. Grilo A, Jardim-Goncalves R (2010) Value proposition on interoperability of BIM and collaborative working environments. Autom Constr 19(5):522–530. https://doi.org/10.1016/j.autcon.2009.11.003
29. Hardin B (2009) BIM and construction management: proven tools, methods, and workflows. Wiley, Amsterdam
30. Hindiyeh RI, Ocloo WK, Cross JA (2023) Systematic review of research trends in engineering team performance. Eng Manag J 35(1):4–28. https://doi.org/10.1080/10429247.2022.2030178
31. Kivits RA, Furneaux C (2013) BIM: enabling sustainability and asset management through knowledge management
32. Kymmell W (2008) Building information modeling: planning and managing construction projects with 4D CAD and simulations (McGraw-Hill construction series). McGraw-Hill Education, New York
33. Latiffi AA, Brahim J, Fathi MS (2014) The development of building information modeling (BIM) definition. Appl Mech Mater 567:625–630
34. Latiffi AA, Mohd S, Kasim N, Fathi MS (2014) Building information modeling (BIM) application in Malaysian construction industry. https://doi.org/10.5923/s.ijcem.201309.01
35. Leygonie R, Motamedi A, Iordanova I (2022) Development of quality improvement procedures and tools for facility management BIM. Develop Built Environ 11:100075. https://doi.org/10.1016/j.dibe.2022.100075
36. Li X, Wang C, Alashwal A (2021) Case study on BIM and value engineering integration for construction cost control. Adv Civil Eng 2021:8849303. https://doi.org/10.1155/2021/8849303
37. Lin YC (2014) Construction 3D BIM-based knowledge management system: a case study. J Civil Eng Manag 20(2):186–200
38. Liu Y, van Nederveen S, Hertogh M (2017) Understanding effects of BIM on collaborative design and construction: an empirical study in China. Int J Project Manag 35(4):686–698. https://doi.org/10.1016/j.ijproman.2016.06.007

39. Lu W, Zhang D, Rowlinson SM (2013) BIM collaboration: a conceptual model and its characteristics. In: Proceedings of the 29th annual association of researchers in construction management (ARCOM) conference
40. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Reprint—preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Phys Therapy 89(9):873–880. https://doi.org/10.1093/PTJ/89.9.873
41. Moher D, Liberati A, Tetzlaff J, Altman DG, Altman D, Antes G, Atkins D, Barbour V, Barrowman N, Berlin JA, Clark J, Clarke M, Cook D et al (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Internal Med 151(4):264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135
42. National Institute of Building Sciences (2007) National building information modeling standard, version 1, Part 1: overview, principles, and methodologies, vol 1
43. Okoli C, Schabram K (2010) A guide to conducting a systematic literature review of information systems research. Electr J. https://doi.org/10.2139/ssrn.1954824
44. Olatunji OA, Sher WD, Gu N, Ogunsemi DR (2010) Building information modelling processes: benefits for construction industry. In: Proceedings of the W078-special track 18th CIB world building congress May 2010 Salford, United Kingdom, p 137. http://cibworld.xs4all.nl/dl/publications/w078_pub361.pdf#page=142
45. Palmatier RW, Houston MB, Hulland J (2018) Review articles: purpose, process, and structure. J Acad Market Sci 46(1):1–5. https://doi.org/10.1007/s11747-017-0563-4
46. Papadonikolaki E, van Oel C, Kagioglou M (2019) Organising and managing boundaries: a structurational view of collaboration with building information modelling (BIM). Int J Project Manag 37(3):378–394. https://doi.org/10.1016/j.ijproman.2019.01.010
47. Papadonikolaki E, Verbraeck A, Wamelink H (2017) Formal and informal relations within BIM-enabled supply chain partnerships. Constr Manag Econ 6193:1–22. https://doi.org/10.1080/01446193.2017.1311020
48. Poirier E, Staub-French S, Forgues D (2015) Embedded contexts of innovation: BIM adoption and implementation for a specialty contracting SME. Constr Innov 15:42–65
49. Radzi AR, Rahman RA, Doh SI (2023) Decision making in highway construction: a systematic review and future directions. J Eng Des Technol 21(4):1083–1106
50. Reddy KP (2011) BIM for building owners and developers: making a business case for using BIM on projects. Wiley, Amsterdam
51. Serra CEM, Kunc M (2015) Benefits realisation management and its influence on project success and on the execution of business strategies. Int J Project Manag 33(1):53–66. https://doi.org/10.1016/j.ijproman.2014.03.011
52. Shafei H, Radzi AR, Algahtany M, Rahman RA (2022) Construction 4.0 technologies and decision-making: a systematic review and gap analysis. Buildings 12(12):2206
53. Succar B, Kassem M (2015) Macro-BIM adoption: conceptual structures. Autom Constr 57:64–79. https://doi.org/10.1016/j.autcon.2015.04.018
54. van Nederveen S, Reza Beheshti WG (2010) Modelling concepts for BIM. Handbook of research on building information modeling and construction informatics: concepts and technologies
55. Van Tam N, Quoc Toan N, Phong VV, Durdyev S (2023) Impact of BIM-related factors affecting construction project performance. Int J Build Pathol Adapt 41(2):454–475
56. Valinejadshoubi M, Bagchi A, Moselhi O (2019) Development of a BIM-based data management system for structural health monitoring with application to modular buildings: case study. J Comput Civil Eng 33(3):98–127
57. Vass S, Gustavsson TK (2017) Challenges when implementing BIM for industry change. Constr Manag Econ 35(10):597–610. https://doi.org/10.1080/01446193.2017.1314519
58. Zwikael O, Smyrk JR (2011) Project management for the creation of organisational value. Springer, London

# Trust in Robotics and Automation in the Construction Industry: The Case of Malaysia

**Nur Aliah Hani Saiful Amir, Ahmad Rizal Alias, Lee Yong Siang, and Abdul Rahimi Abdul Rahman**

## 1 Introduction

Diverse workforce-related challenges and productivity issues currently need to be solved in the construction industry, partially due to its heavy reliance on human tasks. They are frequently hampered by a shortage of skilled labour, a high incidence of safety risks, potential accidents and injuries, time constraints, location, and safety factors [22]. Emerging Industry 4.0 innovations, such as the use of virtual human applications in the construction industry, digital software for optimizing construction data, cyber-physical systems, collaborative robots, health and safety, and site monitoring have created opportunities for a better-enhanced construction environment [10]. Robots have been regarded as critical to supplementing human productivity difficulties and retooling traditional workflow procedures in the construction field. Nevertheless, what this implies in practice is ambiguous and continually evolving [4]. Concerns about the implications of robots and automation on construction sites have sparked sociocultural and economic discussions, raising questions about the type of intervention robots would have and what this would imply: fewer human employees or no human workers on sites [27]. To alleviate some of these agitations and concerns, trust must be built for the construction sector to accept and adapt to robotics and automation.

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In the case of Malaysia, many problems have hampered the construction industry's growth and expansion, resulting in low productivity levels compared with other industries, such as manufacturing. In reality, Malaysia's construction industry is still far left behind in the digital area, with most industry practitioners admitting to a long-standing culture of opposition to change. The industry's slow progress regarding digitalization has caused the construction industry to rely heavily on manual work, causing the management of construction projects in Malaysia to be much more intricate and time-consuming than in other progressive countries. As Malaysia is working towards becoming a developed country, an increase in the economy will rapidly result in the need for more infrastructure. Hence, time-consuming projects may hinder this progress which can cause Malaysians to face many difficulties, such as high housing market prices and traffic jams, which is now a primary problem in the major city centres of Malaysia such as Kuala Lumpur and George Town [1]. These problems may not only affect the economy, but they can also harm the health of Malaysians and cause a spike in stress level and mental illness. This can further be proven by the Ministry of Health (MOH) research in 2022 on 336,900 individuals [34]. The study has found that the Federal Territories in Malaysia have the highest cases of depression and anxiety. The reason for this increase is mainly because the cost of living in the Federal Territories is rather high compared with the rural areas [8]. Thus, through this, we can see that the effect of outdated project management and handling can cause a major effect on society [26].

To further discuss the issue at hand, Malaysian construction industry practitioners' work culture and business models are also one of the primary reasons why the utilization of robotics and automation in the industry is less than in other industries [15]. This is because many contractors need to see the importance of implementing robotics and automation in their projects as they feel comfortable with their companies' current work culture and business models. There is also no urge from their clients or the government for them to change their business models, which makes them feel secure in using manual work to manage and handle their projects [9]. It is undeniable that changing the mindset of these industry practitioners is hard, especially when the manual work method has been used for ages, and trust is built with manual work. Most contractors want to avoid risks by applying automation and robotics in their projects due to the high initial investments and out-of-the-ordinary work culture. In addition, concerns about the implications of robots and automation on construction sites have sparked sociocultural and economic discussions, raising questions about the type of intervention robots would have and what this would imply: fewer human employees or no human workers on sites. The fear of job loss and change has made industry practitioners stick to the old work culture instead of moving towards progressive changes. To alleviate some of these agitations and concerns, trust must be built for the construction sector to accept and adapt to robotics and automation.

However, there are several companies that have adopted robotics and automation in design and construction in Malaysia [20, 23, 24, 33]. The prime example is Gamuda Berhad. One of the most famous robotics used in their projects is the Autonomous Tunnel Boring Machine (A-TBM). A-TBM was created entirely by local engineers at Gamuda Berhad. It employs artificial intelligence (AI) control algorithms to autonomously drive the TBMs, resulting in proven, measurable increases in productivity, safety, and tunnel building quality. Tunnel boring machine data insights improved A-TBM performance, increased 360° awareness, and improved risk management in tunnelling by avoiding mistake and rework, decreased resources, shortened production time, increase safety and reduced human reliance [14].

Thus, one of the ways to negotiate this issue is by strategy formulation rather than solving the issue at hand through method as "getting from A to B" [13]. Therefore, this study aims to identify the issue and strategies that need to be taken to build trust towards using robotics and automation in the Malaysian construction industry. With this study, it is hoped to bring light to the issue to ensure that there will be more incentives and policies to help the construction industry move towards Industrial Revolution 4.0. It also hopes to further improve the livelihood of Malaysian by strategizing the steps that can be taken to build further trust towards the implementation of robotics and automation in the construction industry. Nevertheless, this study differs from prior works as it is one of the pioneer studies that critically analyzes the strategies for building trust using robotics and automation through interviews and thematic analysis.

## 2 Literature Review

Trust is "the attitude that an agent will assist in attaining an individual's aims in a setting marked by ambiguity and vulnerability" and "the reliance by an agent that influential individuals will not perform activities harmful to their well-being" [18]. Past research has demonstrated that mutual trust helps to smooth the project implementation, provides flexibility in the face of uncertainty, boosts efficiency, and maintains long-term connections [24]. Such long-term ties are critical for a company seeking to acquire deals and establish itself in a new location [5].

The usage of robotics in the construction industry started in the 1980s with the introduction of single-purpose robots to perform specific jobs such as concrete finishing or welding. The robots' primary focus is performing complex, dirty, or dangerous work in the field. In the construction industry, autonomous robots are re-programmable, multipurpose manipulator that moves materials, components, tools, or special devices through varied programmed movements to perform several tasks in building industry production processes [39, 41].

According to Malaysian construction industry workers, they still need to be made aware of the existence of automation and robotics technologies despite new technology progressing in building engineering, construction, and design from time to time [38]. This is because Malaysian construction industry players want to refrain from using robotics and automation, as it raises the question of trust in data security, reliability, and ethics [37]. Robotics and automation depend on computing systems and datasets to operate safely. These data are necessary to conduct everyday operations and assist management in reaching their objectives and making the best choices according to the information obtained from them. In this case, the question of the safety of the data involved not just the quantity or variety of data but also the data's quality, privacy, and security [17].

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One of the crucial ethical issues raised by using robotics and automation is when robots take on responsibility in the circumstances previously guided by human judgement. Examining ethical challenges from various viewpoints, such as those of operators and machines, should be part of these considerations [7].

Due to the problems stated, most construction players continue using the traditional technique in their projects as a safe play [3]. As a result, the project's primary goals are to identify the issues and strategies creating trust in robotics and automation in construction projects.

### *2.1 Issues on Building Trust in Robotics and Automation in the Construction Industry*

There are several studies that discuss the issues on building trust in robotics and automation in the construction industry [20, 21]. One of the issues discussed is cultural issues. In the construction industry, conventional methods of doing things are preferred over innovative but untested technology that promise big returns [11]. As a result, the construction sector is hesitant to adapt new technology. Construction sites, unlike other industries, are typically distinct and varied, necessitating automation and robotics that can learn and adapt quickly in changing conditions [16]. This might involve utilizing other digital technologies such as blockchain to promote trust and transparency [2].

The ethics and governance of a country deeply affect the matter at hand. In this context, to create and maintain industry practitioners' trust in automation and robotics, a transparent, involved and adaptable governance is needed [25]. This is a critical problem that is vital to the society as a whole. While automation technologies promise wonderful results, it cannot be properly adopted if not strictly governed [40].

### *2.2 Strategies on Building Trust in Robotics and Automation in the Construction Industry*

The scenario of robotics and automation in construction is always evolving, and it is predicted that as these technologies mature, the potential will far exceed the obstacles [29]. This is due to robotics and automation which require a large quantity of data for algorithm training, large-scale businesses will likely be more advantageous in the short run [25]. However, these advantages will quickly extend to medium and small-scale businesses as they see the cost and time savings. The exponential expansion of innovation and technical developments is creating new opportunities in urban development and construction. Automation is a key component of the Industrial Revolution 4.0 and will continue to grow in the construction sector. In the long term, the construction sector will regard AI as a primary driver of change to increase efficiency, productivity, work processes, precision, consistency, and dependability [32]. Furthermore, it reduces expenses, unanticipated hazards, and accidents on construction sites [35]. In 5–10 years, the problems and prospects of AI applications for the construction sector will give a fresh perspective for future investigation.

Strategic partnerships with high-tech businesses were the best way to increase the deployment of construction robots' technologies in Malaysia [41]. Partnership strategies will boost technology transfer between two parties, where the partnership may enhance the transfer of information and technologies, allowing enterprises to raise their profit and performance. New technology and talents may be introduced into the corporation and integrated into the operations. As a result, organizations that form alliances might seize more opportunities for new ventures.

### *2.3 Knowledge Gap*

The above literature review shows that though there are major issues in building trust towards applying robotics and automation, there are certainly ways to countermeasure those issues. However, for current body of knowledge, there is a lack of research in regard with the case study in Malaysia. Furthermore, there is also a lack of studies that researches into trust regarding the utilization of robotics and automation, with most of the research done for the cases in Malaysia are about industrialized building system IBS [21, 31] or building information modelling (BIM) [12]. There is a study that discusses on the challenges of the implementation of construction robotics technologies in the construction, however the research uses quantitative method through distribution of questionnaire questions. The study also only distributes the questionnaire to few selected companies in Kuala Lumpur [41]. A crucial aspect of addressing this gap is the need to gather insights from industry practitioners spanning across different regions of Malaysia, as the challenges and implications are pertinent to the entire nation rather than being localized to Kuala Lumpur alone. To effectively fill this void, a comprehensive approach is vital. This approach entails the utilization of qualitative research methods, engaging a diverse array of industry professionals and conducting insightful analyses. By doing so, this research endeavour aims to pave the way for a better understanding of the dynamics of trust within the rapidly evolving landscape of robotics and automation. The current state of research underlines the hurdles and prospects of trust-building in the realm of robotics and automation. However, this understanding remains insufficient in the case of Malaysia. By employing a comprehensive approach that includes qualitative methodologies, wide-ranging participant involvement, and thorough analyses, this research seeks to bridge the gap left by prior studies. Ultimately, the goal is to shed light on the intricate dynamics of trust, empowering decision-makers to make informed choices and ensuring the successful integration of innovative technologies within the industry.

## 3 Methodology

Figure 1 depicts the study methodological process, from establishing the interview procedure along analyzing the interview data. The data was gathered by questioning industry practitioners from various backgrounds about their perspectives on trust in applying robots and automation in Malaysia. The acquired interview data was analyzed using a thematic analysis approach [19].

### *3.1 Developing Interview Protocol*

The first major step for this study is by developing an interview protocol. In order to develop the interview protocol, the study objectives and aim must be clearly defined. This study aims to identify the Malaysian construction industry practitioners on their confidence in robotics and automation applied in the industry. Once the study aims and objectives are identified, suitable data collection is then considered. For this study, a prevalent data gathering format through qualitative research is used. Unstructured interviews are adapted for this research because they allow respondents

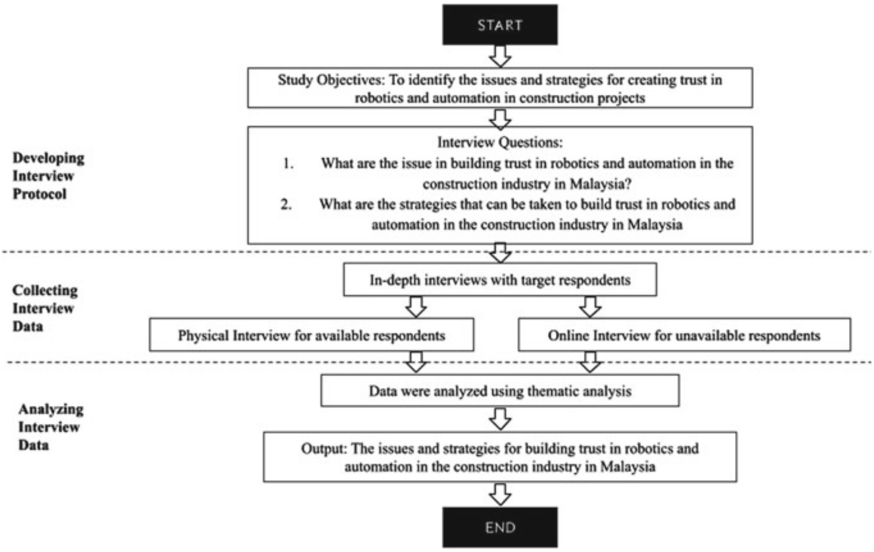


**Fig. 1** Methodology

to express themselves in their own manner and at their own speed, with little influence on respondents' responses. Thus, an interview survey of the industry players was made to collect the data and information required for this study. Next, the interview questions is then developed. The following sets of questions in the questionnaire are as listed below:

a. What is the issue in building trust in robotics and automation in the construction industry in Malaysia?
b. What are the strategies that can be taken to build trust in robotics and automation in the construction industry in Malaysia?

### *3.2 Collecting Interview Data*

The sample size for this study consists of 14 respondents from various backgrounds, which include engineers, clients, and consultants. This study has adopted the digital revolution and chooses two methods for data collection which are physical and online in-depth interview. This method is used to classify the issues in building trust in the utilization of robotics and automation in the construction industry and determine their strategies for further improving the implementation of robotics and automation. For physical in-depth interview, the procedure starts by contacting respondents that fit the criteria and an in-depth interview date that was deemed suitable is then set up. Another method of reaching more significant respondents is by distributing the in-depth interview questions via Google Forms for respondents who are not able to meet physically, in conjunction with digital revolution [28]. The in-depth interview question was based on the industry practitioners' views on issues and strategies that can be applied to build trust in robotics and automation in the construction industry. The respondents' background information was captured immediately in the research area as a result of this interview survey. In this context, respondents' education level, profession, and experience were collected for more precise data, which suits this study's aim. The form is then distributed by posting and promoting on LinkedIn. To achieve a realistic view of the issue, the target demographic comprises industry practitioners from the primary construction project stakeholders. The target respondents must fit into three primary criteria to be a sample for this study [30]. The three primary criteria are:

a. Respondents must have at least minimum of 5 years working in the construction industry
b. Respondents must be contractors registered under BEM and use robotics and automation in the projects they are working with/have worked with.
c. Respondents must have experience in applying robotics and automation in the construction industry in Malaysia.

### 3.3 Analyzing Interview Data

This is the step in which the information gathered is analyzed. An analysis is critical due to where judgements and solutions were created. To help with the analysis, a thematic analysis method was used to further understand the data collected. Thematic analysis is a qualitative data analysis process that involves reading over a set of data and looking for patterns in the meaning of the data to find themes. It is an active reflexive process in which the researcher's subjective experience is essential to making meaning of the facts. Following the theme analysis technique, there are six-steps of an iterative process, which are: (1) familiarizing oneself with the data, (2) developing coding categories, (3) developing themes, (4) evaluating themes, (5) defining and identifying themes, and (6) discovering exemplars. Getting acquainted with the data may entail transcribing or (re)reading the data [6]. Coding entails noting interesting elements of data in a methodical manner and then combining the data. The researcher must compile initial codes into probable themes before acquiring all data pertinent to the specific issue. The process of reviewing themes involves determining if the themes operate in connection to the coded extracts and the complete dataset. Once the themes and subthemes were reviewed, a map of the themes then can be made to further see the data collected clearly.

## 4 Results and Discussion

Based on the research done following the methodology steps, this study analyzes the data collected and discusses how to achieve the research's aim and objectives. In this study, two main subjects can be obtained to understand the level of trust among industry practitioners towards robotics and automation. The main subjects are the core in answering the objectives of this research which is to identify the main issues and strategies in building trust towards using robotics and automation in Malaysia's construction industry. The two main subjects are represented below.

### 4.1 Issues in Building Trust to Implement Robotic and Automation in Malaysia's Construction Industry

This issue has three main themes: economy, promotion, and enforcement. The main themes are concluded from a series of subthemes that are analyzed from respondents' statements. The respondents' statements following their attributes are as given in Table 2.

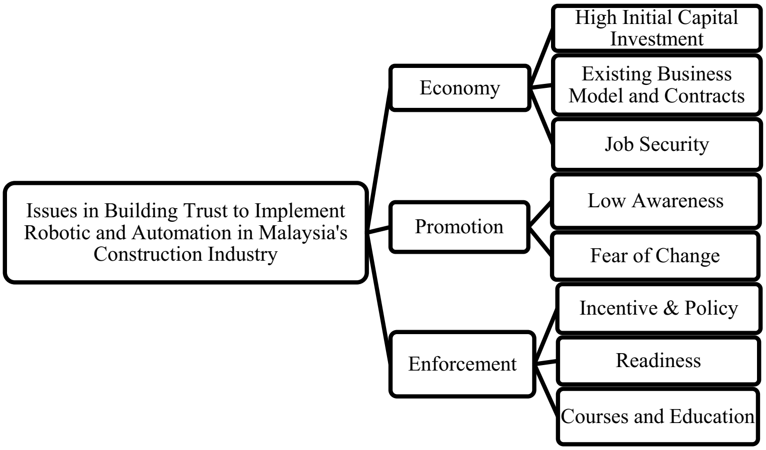


**Fig. 2** Issues in building trust to implement robotic and automation in Malaysia’s construction industry

**Table 1** Issues in building trust to implement robotic and automation in Malaysia’s construction industry. Source: Created by authors

| No | Theme | Subtheme | Respondent | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
| 1 | Economy | High capital investment | √ | √ | √ | | √ | √ | √ | √ | √ | | √ | √ | | √ | 11 |
| | | Existing business model and contracts | | | | | √ | | | | | √ | | | | | 2 |
| | | Job security | | √ | | √ | | | | | √ | | | | | | 3 |
| 2 | Promotion | Low awareness | √ | | √ | √ | √ | √ | √ | | | √ | | √ | √ | | 9 |
| | | Fear of change | | | | | | | | | | √ | | | √ | | 2 |
| 3 | Enforcement | Incentive and policy | | | | | | | | √ | | √ | | | √ | √ | 4 |
| | | Readiness | | | | | √ | | √ | | | | √ | | √ | | 4 |
| | | Courses and education | | | | | √ | | √ | | | | √ | √ | | | 4 |

**Table 2** Respondents' statements on issues in implementing robotics and automation. Source: Created by authors

| Attributes | Respondents statements |
|---|---|
| High capital investment | "The main issues for Malaysia are the lacks of funding or financial to support robotic and automation in Malaysia." (R6) |
| Existing business model and contracts | "Additionally, to make full use of automation a broader diverse group of people and companies need to collaborate, over multiple projects for many years. Our industry is too fragmented to achieve this." (R9) |
| Job security | "Fear of job loss" (R4) |
| Low awareness | "Insufficient exposure & awareness to the industry players" (R11) |
| Fear of change | "Many people don't understand how, or believe that, new technologies, automation, etc., will improve construction. They are not willing to change their ways of working and try new ideas." (R9) |
| Incentive and policy | "The government should come with the initiative by offering incentive to those who play roles in introducing & practising the new technology in the industries." (R12) |
| Readiness | "The readiness of the application of the robotics itself." (R10) |
| Courses and education | "Provide education not only for the university level, but also in schools." (R1) |

### 4.1.1 Economy

One of the main issues in building trust to implement robotics and automation in Malaysia's construction industry is Malaysia's fluctuating economy. In order to use robotics and automation, a high initial capital investment is needed. Due to the fluctuation of the Ringgit in Malaysia due to inflation, many contractors choose to cut costs in the projects they have handled. Thus, many contractors refuse to invest in new automation and use old technologies as it is much more cost-saving.

Next, due to existing business models and contracts, many industry practitioners feel safe not using robotics and automation as it is a risk to change old business models and existing contracts. For example, in Malaysia, we can see there are only a few significant contractors in Malaysia that use robotics and automation, as these contractors often take on big and major projects with high bidding costs and revenue. Due to the high amount in revenue thanks to handling mega projects, these significant companies can take risks in changing their business models. Meanwhile, other smaller industry practitioners must compete with said companies in bidding for these projects. As a result, many smaller contractors choose to stick with old business models as there is less risk taken compared with using robotics and automation.

Additionally, job security is one of the main issues in establishing robotics and automation in the construction industry. Due to the belief that by using automation, many workers will lose their jobs to robots, many industry practitioners refuse to use robotics and automation for fear of losing their job.

#### 4.1.2 Promotion

Another prominent theme issue in building trust to implement robotics and automation in Malaysia's construction industry is promotion. The main subtheme in the theme of the promotion is low awareness. As the implementation of robotics and automation in Malaysia is not diverse, there is a low percentage of awareness about the utilization of robotics and automation among Malaysia's construction industry practitioners.

Next, the fear of changing the old project management and handling methods causes these industry practitioners to refrain from implementing robotics and automation in their projects. As these industry practitioners have more experience in using common project management, they feel comfortable with the current manual work used and refuse to change their method as it is much more time-consuming and riskier.

#### 4.1.3 Enforcement

The enforcement of using robotics and automation in Malaysia's construction industry still needs improvement. This can be seen through three significant subthemes: incentive and policy, readiness, and courses and education.

Most incentives and policies for the construction industry in Malaysia do not initiate the utilization of robotics and automation in the construction industry. As Malaysia is a developing country, most of the incentives and policies do not go to the construction industry but instead go towards strengthening the economy. There's also the stigma of construction industry which performs well with the manual work, which causes most of the incentives and policies for implementation of robotics and automation to go towards other industries such as manufacturing. Thus, there needs to be stern enforcement by the government for the utilization of robotics and automation in the construction industry.

Next, the readiness to implement robotics and automation in the construction industry still needs to improve because industry practitioners are still comfortable using the old project management and handling methods compared with robotics and automation. Furthermore, the implementation of robotics and automation in current projects needs to be improved, which shows that changes are still far for this implementation in Malaysia.

Moreover, there needs to be more courses and education regarding robotics and automation for the construction industry in Malaysia. Most courses and education for robotics and automation are highlighted in the technology and communication industry. Additionally, the course and education for construction industries often emphasize using traditional ways of handling construction projects, with only a few subjects highlighting robotics and automation. Furthermore, Malaysia needs more experts to teach robotics and automation to civil students who will be future industry practitioners.

### 4.2 *Strategies in Building Trust to Implement Robotic and Automation in Malaysia's Construction Industry*

The thematic analysis above discusses the strategies that need to be taken to build trust in implementing the utilization of robotics and automation in Malaysia's construction industry. The data analysis of the interview survey is given in Table 3 (Fig. 3).

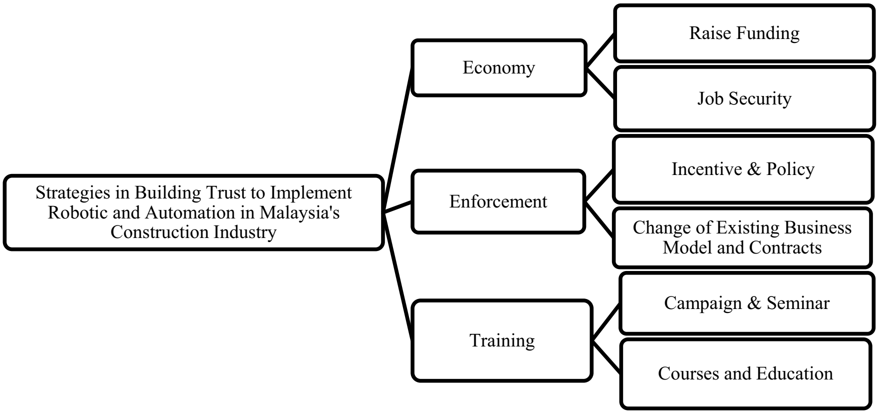


**Fig. 3** Strategies in building trust to implement robotic and automation in Malaysia's construction industry

**Table 3** Strategies in building trust to implement robotic and automation in Malaysia's construction industry

| No | Theme | Subtheme | Respondent | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
| 1 | Economy | Raise funding | √ | | | | | √ | √ | | | | | √ | | √ | 4 |
| | | Job security | | | | | | | | | | | | | √ | | 1 |
| 2 | Enforcement | Incentive and policy | | | | | | √ | √ | √ | | | | √ | √ | | 5 |
| | | Change of existing model and contracts | | | | | | | | | √ | | | | | | 1 |
| 3 | Enforcement | Campaign and seminar | √ | √ | | √ | √ | √ | √ | | | √ | √ | | √ | √ | 10 |
| | | Courses and education | √ | | | √ | | | | | | | √ | √ | | √ | 5 |

**Table 4** Respondents' statements on strategies in implementing robotics and automation

| Attributes | Respondents statements |
|---|---|
| Raise funding | "Funds and grants from the government can help expand interest in using robotics and automation." (R4) |
| Job security | "Training for interested individuals can help create new job opportunities." (R14) |
| Incentive and policy | "Introduction to new incentive and policies on work implementation where 60/40 method were used. Division of 60% manual work and 40% automation is advised for contractors that wants to start implementing automation." (R8) |
| Change of existing business model and contracts | "A different approach to project procurement is needed. Rather than always bidding for work, companies need to negotiate long-term contracts to enable them to invest properly in automation." (R9) |
| Campaign and seminar | "By organizing roadshow, seminar, etc." (R11) |
| Courses and education | "Educate the new generation on the technology and at the same time expose it to the available industry players for them to adopt." (R10) |

This issue has three main themes: economy, enforcement, and training. The main themes are concluded from a series of subthemes that are analyzed from respondents' statements. The respondents' statements following their attributes are as given in Table 4.

### 4.2.1 Economy

A few countermeasures can be taken regarding the economy to boost the implementation of robotics and automation in the construction industry. The first step that can be taken is to raise funding for the utilization of robotics and automation in the construction industry. In this context, as the utilization of robotics and automation needs high capital initial investments, the governments can take the initiative by providing funds for contractors to invest in robotics and automation in their projects.

In addition, by applying robotics and automation in Malaysia, more job opportunities can be opened, especially in the robotics and automation industries. The stigma that more workers will lose their jobs by utilizing robotics and automation must be challenged; in contrast, more job opportunities are available for job seekers in the new and improved, progressive construction industry.

#### 4.2.2 Enforcement

Through this research, it has been found that most contractors feel that there are fewer incentives and policies for the utilization of robotics and automation in the construction industry in Malaysia. Thus, the Malaysian government should establish more incentives and policies for using robotics and automation to rise in the construction industry. One of the countermeasures that can be taken is applying the 60/40 work policy, where the division of automation and manual work are separated by 60% manual work and 40% automation.

Furthermore, the work culture of old business models and contracts must be averted to ensure that the implementation of robotics and automation is successful. One of the ways to avert this crisis is by lowering contract bidding and introducing a new approach to project procurement to negotiate long-term contracts so that contractors can invest appropriately in automation.

#### 4.2.3 Training

As Malaysia still has low awareness of the implementation of robotics and automation in the construction industry, one of the ways to increase awareness is by holding campaigns and seminars concerning the issues. More job opportunities can be found through this seminar, and research and studies on this subject matter can be emphasized to gain trust in robotics and automation in the construction industry.

Moreover, more courses and education regarding robotics and automation can be invested in to train more experts on robotics and automation in the construction industry. Additionally, education on this matter can be applied even to students in school so that an increase in robotics and automation interest can be seen.

### *4.3 Study Implications*

From this study, it can be seen that the implementation of robotics and automation in Malaysia's construction industry still has a long way to go. Through this study, other researchers can further understand the level of trust in Malaysia's industry practitioners, where most of them are interested in applying robotics and automation in the industry, but is rather afraid of taking risk with the high initial investments costs. There are also several strategies that can be taken to further increase industry practitioners' trust towards implementing robotics and automation in Malaysia. Those strategies include higher incentives and stern policies from the government to gain the public interests towards robotics and automation.

### 4.4 Limitations and Future Directions

Despite the findings, a few things could be improved during this research. First, the respondents for this research are only 14. A higher number of respondents can achieve broader view on the subject matter. Next, this study only reviews respondents that have already applied robotics and automation in their projects. For further studies, an interview of industry practitioners that still have not applied robotics and automation can be made to further understand the view of all industry practitioners from different backgrounds. However, the theme's applied data saturation and redundancy have been reached. The aim and objectives of the study are satisfied.

## 5 Conclusion

In overall, all the aims of this study have been achieved. Based on the analyzed data, several issues and strategies for creating trust in robotics and automation in construction projects have been identified. Through this study, Malaysia construction players demanded more awareness to create trust in utilizing robotics and automation in the construction industry. Based on the interview, most of the respondents believe that there is a bright future for implementing robotic and robotics in the construction industry in Malaysia, though much more countermeasure steps need to be taken to build trust in contractors to invest in this new technology. Therefore, through this study, the views of contractors in the subject matter between positive and negative output are clearly explained. This research has many economic, enforcement, and awareness ramifications. This study finds that though industry practitioners are eager and interested in utilizing robotics and automation in the construction industry, most are still afraid to risk applying robotics and automation due to fear of the high cost and risk of investing in new technologies. Through this study, more awareness on the subject matter can be achieved and act as a proof to the government to invest in incentives and policies that push robotics and automation in Malaysia's construction industry as many contractors are interested in changing their old business models to further progress towards the industrial revolution. Furthermore, the study's emphasis on knowledge, governmental incentives, and policy support as essential components for trust-building can also be especially relevant in many worldwide contexts. Countries on the verge of embracing robots and automation in construction should use these findings to develop their own strategies for successful implementation. International stakeholders may foresee obstacles and establish proactive methods by recognizing the universal features found in this research, therefore expediting the integration of robots and automation into their building environments. In essence, this study has the ability to transcend regional boundaries and serve as a guiding light for the worldwide building industry. The lessons learned from Malaysia provide a framework for tackling obstacles and capitalizing on possibilities in the field of trust-building while using robots and automation. By accepting the study's tactics and recommendations, other countries may pave a path to a future of construction that is not just technologically sophisticated, but also founded on trust and successful innovation.

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## References

1. Abdul Rashid MA, Zuhair Q (n.d.) Challenges persist in Malaysia's real estate market despite dominance of residential properties. thesun.my. https://thesun.my/local_news/house-ownership-still-beyond-reach-of-many-OH12046293
2. Abioye S, Oyedele LO, Akanbi L, Ajayi AO, Bilal M, Akinade OO, Ahmed AM (2021) Artificial intelligence in the construction industry: a review of present status, opportunities and future challenges. J Build Eng 44:103299. https://doi.org/10.1016/j.jobe.2021.103299
3. Amin MM, Abas NH, Shahidan S, Rahmat MH, Suhaini NA, Nagapan S, Rahim RA (2017) A review on the current issues and barriers of Industrialised Building System (IBS) adoption in Malaysia's construction industry. IOP Conf Ser Mater Sci Eng 271:012031. https://doi.org/10.1088/1757-899X/271/1/012031
4. Automation and Robotics in the Architecture, Engineering, and Construction Industry (n.d.) Google Books. https://books.google.com.my/books?hl=en&lr=&id=ZptXEAAAQBAJ&oi=fnd&pg=PP5&dq=Trust+in+Robotics+and+Automation+in+the+construction+industry&ots=JggfU66iXv&sig=Tcy_w1FZIcvts8Yw3VUgcy9_5ng&redir_esc=y#v=onepage&q&f=false
5. Binastra Land—Lifestyle Developer (n.d.) Binastra land—lifestyle developer. https://binastra.com.my/
6. Braun V, Clarke V (2006) Using thematic analysis in psychology. Qual Res Psychol 3(2):77–101. https://doi.org/10.1191/1478088706qp063oa
7. Burton E, Goldsmith J, Koenig S, Kuipers B, Mattei N, Walsh T (2017) Ethical considerations in artificial intelligence courses. AI Magazine 38(2):22–34. https://doi.org/10.1609/aimag.v38i2.2731
8. CodeBlue (2023) Zaliha: depression and anxiety rates highest in federal territories. CodeBlue. https://codeblue.galencentre.org/2023/03/08/zaliha-depression-and-anxiety-rates-highest-in-federal-territories/
9. Davies R, Coole T, Smith A (2017) Review of socio-technical considerations to ensure successful implementation of industry 4.0. Procedia Manuf 11:1288–1295. https://doi.org/10.1016/j.promfg.2017.07.256

10. Delgado JL, Ajayi AO, Akanbi L, Akinade OO, Bilal M (2019) Robotics and automated systems in construction: understanding industry-specific challenges for adoption. J Build Eng 26:100868. https://doi.org/10.1016/j.jobe.2019.100868
11. Emaminejad N, Akhavian R (2022) Trustworthy AI and robotics: implications for the AEC industry. Autom Constr 139:104298. https://doi.org/10.1016/j.autcon.2022.104298
12. Farouk AM, Zulhisham AZ, Lee YS, Rajabi MS, Rahman RA (2023) Factors, challenges and strategies of trust in BIM-based construction projects: a case study in Malaysia. Infrastructures 8(1):13. https://doi.org/10.3390/infrastructures8010013
13. Galliers RD, Sutherland AR (1991) Information systems management and strategy formulation: the 'stages of growth' model revisited. Inf Sys J 1:89–114. https://doi.org/10.1111/j.1365-2575.1991.tb00030.x
14. Gamuda B (2020) What does it take to automate a tunnel boring machine?. https://gamuda.com.my/2020/03/what_does_it_take_to_automate_tunnel_boring_machine/blog/
15. Grabowska S, Saniuk S, Gajdzik B (2022) Industry 5.0: improving humanization and sustainability of Industry 4.0. Scientometrics. 127:1–28. https://doi.org/10.1007/s11192-022-04370-1
16. Hancock PA, Billings DL, Schaefer KE, Chen JYC, De Visser EJ, Parasuraman R (2011) A meta-analysis of factors affecting trust in human-robot interaction. BUJ J Technol 53(5):517–527. https://doi.org/10.1177/0018720811417254
17. Hassan NH, Ismail Z, Maarop N (2015) Information security culture: A systematic literature review. In: 5th International conference on computing and informatics (ICOCI). Istanbul, Turkey
18. Hoff KA, Bashir M (2014) Trust in automation. Hum Factors 57(3):407–434. https://doi.org/10.1177/0018720814547570
19. Jamshed SQ (2014) Qualitative research method-interviewing and observation. National Library of Medicine 5(4):87. https://doi.org/10.4103/0976-0105.141942
20. Joe (2022) Borneo gets first 3D printed house. Global Construction Review. https://www.globalconstructionreview.com/borneo-gets-first-3d-printed-house/
21. Kamaruddin SS, Mohammad MA, Mahbub R, Ahmad K (2013) Mechanisation and automation of the IBS construction approach: a Malaysian experience. Proced Soc Behav Sci 105:106–114. https://doi.org/10.1016/j.sbspro.2013.11.012
22. Kok AC, De Bakker F, Groenewegen P (2017) Sustainability struggles: conflicting cultures and incompatible logics. Bus Soc 58(8):1496–1532. https://doi.org/10.1177/0007650317703644
23. Latiffi AA, Brahim J, Fathi MS (2016) Transformation of Malaysian construction industry with building information modelling (BIM). MATEC Web Conf 66:00022. https://doi.org/10.1051/matecconf/20166600022
24. Lau E, Rowlinson S (2010) Trust relations in the construction industry. Int J Manag Proj Bus 3(4):693–704. https://doi.org/10.1108/17538371011076127
25. Moreno J, Serrano M, Fernández-Medina E (2016) Main issues in big data security. Fut Internet 8(3):44. https://doi.org/10.3390/fi8030044
26. Nasir SRM, Isa CR, Ali K (2014) Application of automation technology in Malaysian construction industry. Springer, New York, pp 871–883
27. Onososen A, Musonda I (2022) Research focus for construction robotics and human-robot teams towards resilience in construction: scientometric review. J Eng Des Technol 21(2):502–526. https://doi.org/10.1108/jedt-10-2021-0590
28. Preston V (2009) Questionnaire survey. Elsevier, Amsterdam, pp 46–52
29. Regona M, Yigitcanlar T, Xia B, Li RYM (2022) Opportunities and adoption challenges of AI in the construction industry: a PRISMA review. J Open Innov 8(1):45. https://doi.org/10.3390/joitmc8010045
30. SME Definition (2020) https://www.smecorp.gov.my/index.php/en/policies/2020-02-11-08-01-24/sme-definition?id=371
31. Saad SM, Alaloul WS, Ammad S, Altaf M, Qureshi AR (2022) Identification of critical success factors for the adoption of industrialized building system (IBS) in Malaysian construction industry. Ain Shams Eng J 13(2):101547. https://doi.org/10.1016/j.asej.2021.06.031

32. Schia MH (2019) The introduction of AI in the construction industry and its impact on human behavior. https://iglc.net/Papers/Details/1730
33. Steel R-Z (n.d.) Manufacturing. Zamil Steel. https://zamilsteel.com/ped/en/manufacturing
34. Tan ESS, Chin SAFX, Sathapan MSP, Dewi AD, Amini F, Bustami NA, Tan PY, Ho YB, Tan CK (2023) Mental health and the COVID-19 pandemic: observational evidence from Malaysia. Int J Environ Res Public Health 20(5):4046. https://doi.org/10.3390/ijerph20054046. PMID: 36901057; PMCID: PMC10001641.
35. Tayib MA, Bakhary NA, Ibrahim CK (2022) Industry 4.0 in the Malaysian construction industry and its adoption challenges. https://doi.org/10.1007/978-981-16-7924-7_79
36. Vaduva-Sahhanoglu AM, Calbureanu-Popescu MX, Smid S (2019). Automated and robotic construction-a solution for the social challenges of the construction sector.
37. Vee C, Skitmore M (2003) Professional ethics in the construction industry. Eng Constr Archit Manag 10(2):117–127. https://doi.org/10.1108/09699980310466596
38. View of The Influence of Government Regulation on Waste Reduction Among Kuantan Malaysian Construction Industry (n.d.) https://akademiabaru.com/submit/index.php/araset/article/view/1949/1524
39. What is Industrial Automation and Robotics? (n.d.) https://www.twi-global.com/technical-knowledge/faqs/what-is-industrial-automation-and-robotics
40. Winfield AFT, Jirotka M (2018) Ethical governance is essential to building trust in robotics and artificial intelligence systems. Phil Trans R Soc A 376(2133):20180085. https://doi.org/10.1098/rsta.2018.0085
41. Yahya MY, Hui Y, Yassin AM, Omar R, Robin ROA, Kasim N (2019) The challenges of the implementation of construction robotics technologies in the construction. MATEC Web Conf 266:05012. https://doi.org/10.1051/matecconf/201926605012

# Applicability of Building Information Modelling (BIM) to Structural Design Workflow

**Steve Penney and Hossein Askarinejad**

## 1 Introduction

Building information modelling (BIM) is a digital representation of the characteristics of a building or infrastructure. It involves the creation and management of a 3D model of a project, integrating different aspects of the design and construction process, including architectural, structural, and mechanical, electrical, and plumbing (MEP) systems. Adoption of BIM by various stakeholders in a project can enhance the project coordination and communication process. BIM goes beyond 3D modelling, as it also includes information about various components of the building which can be used for the complete lifecycle of a building, from design and construction to operation and maintenance.

Structural engineering comprises a wide range of skills which can apply to different project types from minor slope strengthening, to large-sized structures of tall buildings [4]. Structural engineers are responsible for finding solutions for the efficient use of structural elements and materials in order to make a building and its systems safe, sustainable, and durable [19]. Structural engineers can leverage building information modelling (BIM) in various ways. BIM offers significant benefits including conceptual design, structural analysis, layout, and detailing. These advantages encompass the reduction of errors in design and drafting, potentially lowered direct costs associated with engineering design and drafting due to enhanced

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productivity, and the facilitation of more insightful situation analysis through simulation. The BIM provides a holistic view and models can be frequently updated to reflect any alterations in the design or general specifications, ensuring data accuracy [2]. Normally, structural designs should be integrated with the outputs generated by other disciplines such as architects and engineers of different building services [17].

However, the current uptake of BIM by structural engineers and adoption of BIM as a workflow in the structural design context has been reasonably slow [8]. Additionally, it is unclear from existing literature whether structural engineers who use BIM are fully working to the BIM philosophy of a single source of truth, or whether they are working to their interpretation of BIM which could vary between engineers. In general, BIM for structural engineering has remained an overlooked area in the extant literature, compared against other applications of BIM [10].

The aim of this research was to attempt to quantify the use of BIM by civil/structural engineers in New Zealand and discover the reasons for or against adopting BIM. The research looked into identifying the factors for the relatively slow uptake and what the real or perceived business risks are. For this purpose, an online survey was developed and distributed to structural engineers across New Zealand and the collected data were systematically analysed. The survey was structured to provide data on geographic location, company size, and type of work, plus the details about the participants' knowledge and use of BIM. The findings are expected to contribute to various organisations, in particular those involved in structural engineering that are aiming to improve their digitisation through adoption of BIM.

## 2 Literature Review

There have been a number of studies on different aspects of building information modelling (BIM) in general, such as those by Becerik-Gerber and Kensek [5] and Eastman et al. [7]. Additionally, the barriers or challenges to BIM adoption has been studied by a number of researchers such as [9, 11, 15]. For instance, Hall et al. [9] studied the barriers to BIM implementation for small and medium-sized enterprises (SMEs) in the New Zealand construction industry. The authors evaluated the importance of different criteria items including the knowledge, resources, governmental and technological barriers. While above studies provide a good overview of the BIM implementation, but the papers look holistically at the broad construction sector rather than looking at a specialised field or industry such as civil engineering or structural engineering.

Few researchers have focused on civil engineering in particular [6] and some limited studies can be found promoting the benefit of BIM in structural engineering [12, 13], however, as argued by Hoseini et al. [10] and Vilutiene et al. 21], research on the integration of BIM within civil or structural engineering is still in its infancy. Considering the broad range of structural engineering tasks and its significant potential for utilising BIM in various structural applications, there are considerable research gaps to be addressed in this field.

Vilutiene et al. [21] presented a bibliometric analysis of BIM literature published between 2003 and 2018 incl. The article is an in-depth analysis of published articles related to BIM. Out of the 369 published articles reviewed in this paper, it was observed there was a lack of attention paid to structural engineering within published BIM literature. The study found that < 20% of studies on BIM referred to structural engineering applications. Even these studies have been mainly concerned with generic issues of BIM like information management and significant unexplored capacity currently exists for solving complex technical issues in regard to fully utilising BIM in specialised areas of structural engineering.

Hunt [12] reported that ~ 50% of structural engineers are actively using BIM, however there is no data to indicate if BIM is being used for purely design documentation or if it is also being used for structural analysis purposes. Additionally, in this paper, a simple structural analysis was carried out using Autodesk Revit and Nemetschek Risa 3D to assess the applicability of BIM workflow. The BIM model was created in Revit and needed to be exported to RISA for structural analysis. The RISA file then needed to be re-merged with the original Revit model. It was shown, the workflow relies on the import/export functions being carried out for all iterations of the design and does not support the core BIM philosophy of using a common platform.

Baran and Bartosz [3] described the process of modelling a building in Autodesk Revit and carrying out the structural analysis on the same model using Autodesk Robot. This was more a comparison between different methods of analysis than a study of the BIM workflow itself. The study showed the successful interoperability between the design authoring tool (Revit) and the structural analysis tool (Robot), using a single platform. Sacks and Barak [18] reported that, using BIM, the process to prepare a project to input it into structural analysis software is more efficient, since all the data can be directly transferred from the building model. The design results are stored in the building information model, becoming easily available for the detailing process.

Kaner et al. [13] outlines four case studies conducted on two projects from two mid-sized structural engineering consultants, one in Canada and one in Israel. The study focused specifically on the use of BIM for structural precast applications. The study found that both engineering consultancies experienced a difficult transition period from a traditional 2D CAD workflow to a 3D BIM workflow. The transition required absolute buy-in from top level management, professional training for technicians and an expectation that there would be a productivity decline as technicians came up to speed with BIM. The subject consultancies found that while there was no immediate change in hours spent, there was a marked reduction in drawing and construction errors for precast elements.

## 3 Method

As this research attempts to evaluate the use of BIM in the structural engineering context, a suitable survey questionnaire was developed and the civil/structural engineers working in the consulting companies in New Zealand, were invited to participate in the survey. Of the 112 contacts made, there were a total of 55 responses received which represented a 49% response rate.

The survey was constructed using Google Forms and was distributed online. The questions presented to participants were dependent on previous answers to drill down into the reasons for or against engineers using BIM workflows. The questionnaire comprised of three sections. The first section of the questionnaire was to do with demographic background of the participants, including the participants' region, company size, and main draughting tools used. The second section aimed to evaluate the level of BIM knowledge and awareness. This allowed the authors to analyse the respondents' level of exposure to BIM in their usual tasks. Additionally, this section combined with the demographic data obtained in section one, allowed the authors to analyse, and compare the BIM awareness of structural engineers in different regions and work environments.

The third section aimed to identify the key drivers and barriers to the adoption of BIM in the structural engineering context. In this section, the respondents were asked to provide their agreement/disagreement with different items based on their experience, using the five-point rating scale from strongly agree (1) to strongly disagree (5). This allowed the authors to analyse the respondents' views on different barriers in their work context. It also aimed to identify the respondents' opinions on the potential benefits of BIM and why they believe it is important to consider adopting BIM workflow in future. This information is invaluable for the industry, in particular the structural consulting sector, as it provides an insight on the structural engineers' thoughts and perceptions about the current state, barriers and future potential of BIM implementation in their specialised field and work environment.

## 4 Results and Discussion

The survey results were systematically analysed and compared. Figure 1 shows the regional distribution of respondents and Fig. 2 presents an indication of the size of respondents' companies from different regions. Canterbury accounts for a large portion of the responses (32%), followed by Wellington (13%), Otago (13%), and Auckland (9%). This is likely due to the large number of structural engineers operating in the Canterbury region due to the Christchurch rebuild following the 2011 earthquake sequence. It can also be observed that the majority of respondents work in the companies with a number of staff ranging from 11 to 50.

All 55 respondents indicated that they were involved in structural engineering and design works in different roles. 30 out of 55 participants (54%) indicated their job

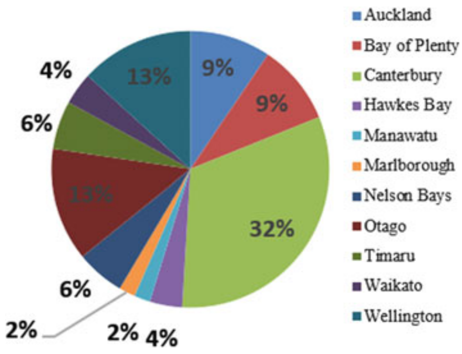



**Fig. 1** Survey respondents by NZ region

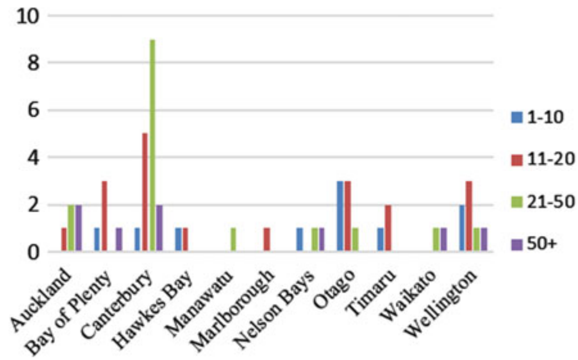



**Fig. 2** Respondents company sizes (staff numbers)

title as "Structural Engineer/Designer", 13 participants (24%) had "Director/Manger/team leader" role (in the structural engineering teams), and 12 participants (22%) were in a "Structural Draughtsman/Technician" role. This shows that there was a good range of participants involved in different capacities within the structural design work stream from technician level to the team management level. Figure 3 provides an insight into the current structural draughting tools used by those participated in this study. As shown in this figure, the primary draughting tool is Autodesk Revit with more than twice the usage level as AutoCAD. Autodesk Revit is one of the main applications under BIM umbrella. This suggests the market is moving towards using BIM tools and 3D modelling as the common workflow. AutoCAD is still a popular tool used as a supplement to Revit.

### *4.1 BIM Knowledge and Awareness*

As shown in Fig. 4, 57% of respondents reported they were aware of and were/are using BIM. This is consistent with the percentage of participants using Autodesk Revit in their workflow as discussed in previous section. The percentage is slightly

**Fig. 3** Main draughting tools currently used in structural works

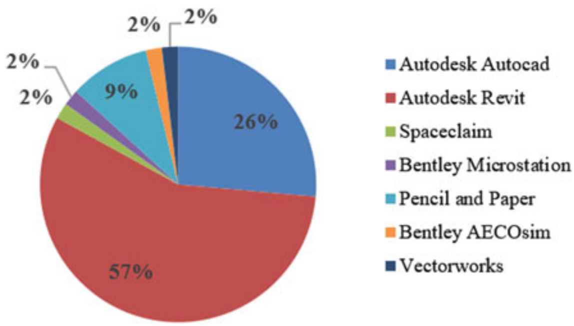
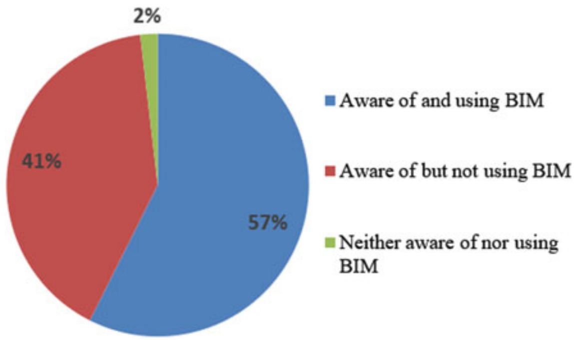



**Fig. 4** BIM awareness/use by structural engineers/ designers




higher than the value showed by [12] where it was reported approximately 50% of structural engineers were actively using BIM. Additionally, Fig. 4 shows 41% of the respondents indicated that they were aware of BIM but not currently using that.

Figures 5 and 6 show the respondents' awareness of BIM by both region and company size. While almost all respondents are aware of BIM, there appears to be a regional trend showing structural engineers or technicians in the main centres are using BIM more than those in the regions. Company size does not appear to be much of an influence in terms of BIM usage. However, it should be noted that the larger companies generally have their offices in the main centres. Also, larger consultancies normally have greater resources available in terms of IT and training budgets and are more likely to have BIM specialists employed.

Figure 7 shows respondents' understanding of BIM to be mostly "using 3D intelligent, computable data for project collaboration" (44%) and "3D modelling analysis and documentation for the building lifecycle" (34%). This shows the majority of participants (78%) see BIM as a holistic platform used for modelling, documentation, and collaboration rather than a computer programme/dataset with merely visualisation and internal applications. However, having only 34% of the participants choosing the second definition which highlights the "building lifecycle", shows a relatively low appreciation of BIM as a platform for the entire building lifecycle.

**Fig. 5** BIM awareness of structural engineers by NZ regions

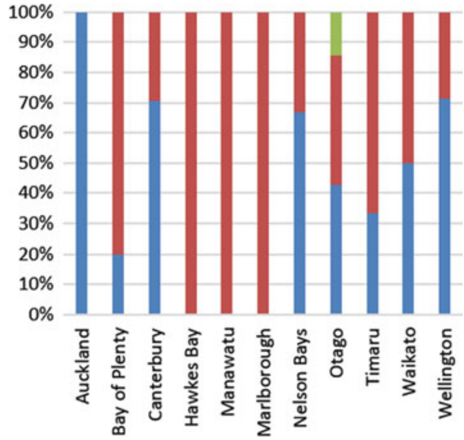
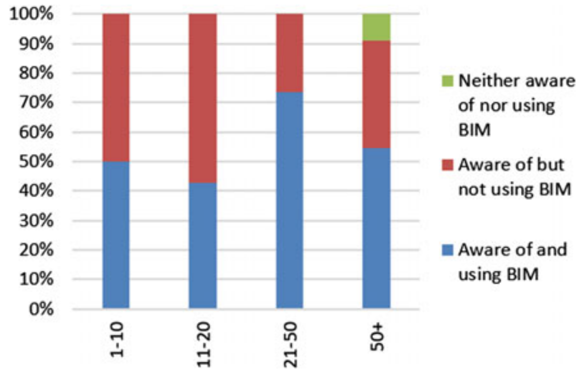



**Fig. 6** BIM awareness by company size




This indicates a possible gap in the current training and education of BIM in the engineering consulting sector.

## *4.2 Use of BIM for Structural Design Workflow*

The results show that from those respondents who currently use a BIM workflow, 83% do not use the BIM models specifically for their "structural analysis and design" workflow. Out of this 83%, about half have considered using BIM models for structural analysis but have chosen not to while the remaining half have not considered it. The reasons given were summarised into six key reasons shown in Fig. 8. Approximately 2/3 of respondents cited interoperability and knowledge as the main reasons for not using BIM models specifically for structural analysis. This is reasonably consistent with the wider engineering/construction sector. The interoperability issue was also highlighted in the study conducted by Hall et al. [9] as one of the major

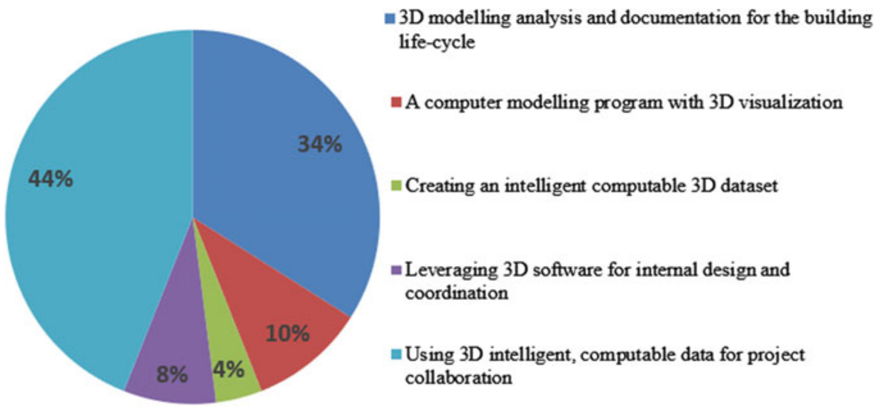


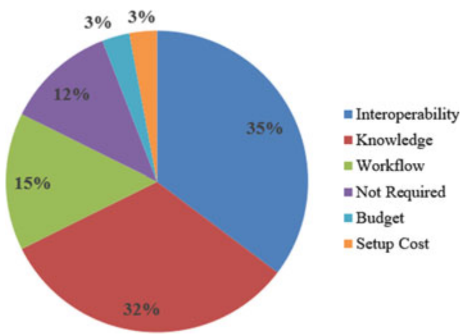

**Fig. 7** Respondents' understanding of BIM

barriers to BIM implementation for small and medium-sized enterprises (SMEs) in New Zealand construction industry. Ayinla and Adamu [1] also raised the technology and interoperability as a serious problem that requires significant attention to promote BIM adoption. The wide variety of file formats and multiple project platforms in use at one time demands a wide skillset to manage the different packages, along with an increased software subscription cost [20].

In Fig. 8, along with "Interoperability" issue, "Knowledge" is observed as the next major contributor. This can include the lack of knowledge around the benefits of BIM, and how BIM can be leveraged to adapt to new and more efficient procedures. This is in line with the previous studies on wider BIM implementation where lack of BIM knowledge and expertise was found as one of the significant barriers [14].

Additionally, the results show from those respondents who currently use a BIM workflow, about 55% restrict their use of BIM to certain projects. Figure 9 shows the main reasons identified for this restriction. It can be observed that the reasons were predominantly budget and client needs. The predominant responses suggested BIM

**Fig. 8** Reasons for not using BIM for structural analysis



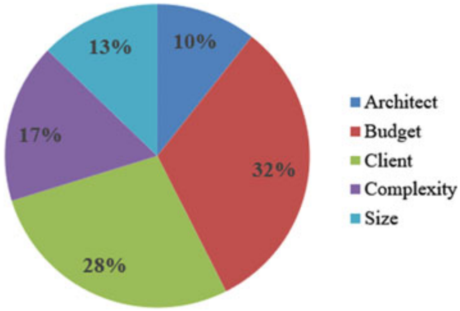



**Fig. 9** Reasons for restricting BIM to selected projects

projects cost more and clients are unwilling to pay for the additional cost of a BIM project.

To further evaluate the key drivers and barriers for using BIM in structural engineering context, the respondents were asked to provide their agreement/disagreement with different items based on their experience, using the five-point rating scale from strongly agree (1) to strongly disagree (5). Figure 10 shows the respondents' opinions on the key drivers and why they believe it is important to consider adopting BIM workflow in future.

Figure 10 shows that there is a reasonable consensus about the importance of two factors as the key reasons for future adoption of BIM including the "improvement in visualisation", plus the "improvement in coordination of design documents and process". It can be seen that 50% of the participants have indicated that they strongly agree (1) that adopting BIM would improve visualisation. Additionally, 50% of the

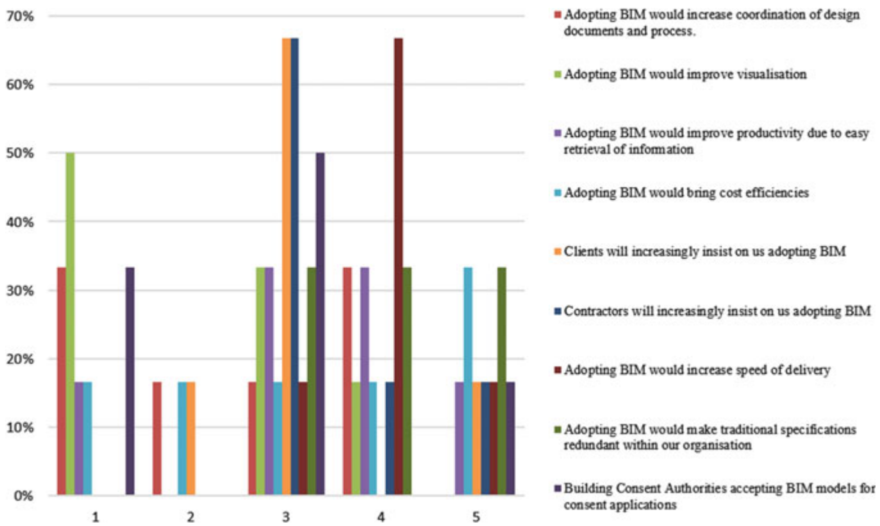



**Fig. 10** Reasons to consider adopting BIM workflow in future

respondents either strongly agree (1) or agree (2) that adopting BIM would improve the coordination of design documents and process. However, it is interesting to note about 30% of the respondents have disagreed with that. Additionally, there seems to be a good consensus on the possible effect of BIM adoption on speed of project delivery where 80% of the participants have either disagreed (4) or strongly disagreed (5) that adopting BIM would increase the speed of delivery.

Figure 11 provides the respondents' views on current barriers for adoption of BIM in the structural engineering context. It can be observed in this figure that 100% of the participants who are not currently using BIM in their structural design workflow have indicated they either strongly agree (1) or agree (2) that adopting BIM would require changes in the workflow and procedures that they are not currently prepared to do. This highlights that there are still a lot of works to be done in terms of staff training, documentation, and overall procedural matters to increase the use of BIM by structural engineers. Also, the results shows that 60% of the participants who are not currently using BIM in their structural design have agreed (2) that there are too much custom contents in their current workflow. This further highlights the interoperability issue that was raised earlier. For instance, there are various custom structural analysis software or design programmes currently used by the structural consultants and these software packages and the associated contents may not be compatible with the BIM platform.

The requirement by building consent authorities to receive 2D drawings to grant consent is raised as another major barrier where 60% of the participants strongly agree (1) that this requirement is a reason for not adopting BIM in their workflow. This shows the importance of governmental and legal initiatives and policies in regard to BIM requirements. The governmental procedures in particular, regarding

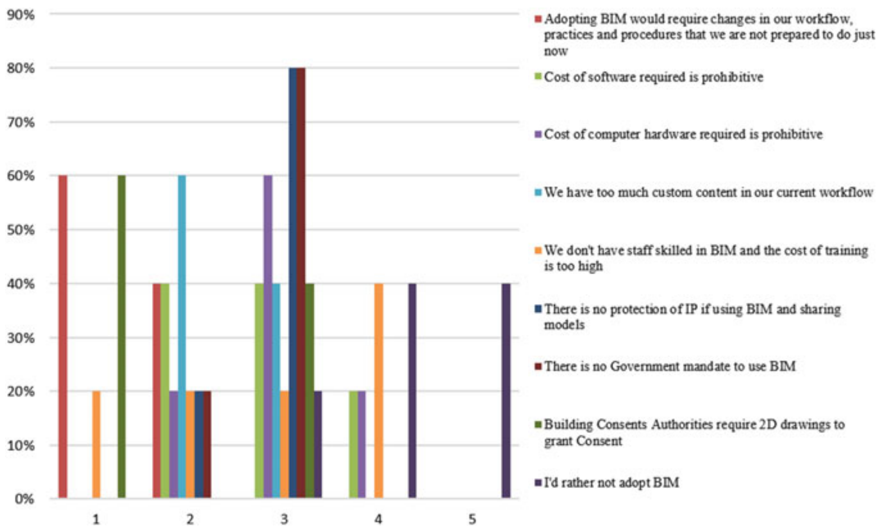



**Fig. 11** Current barriers to adopting BIM workflow

the building consents process should be amended to facilitate and promote the use of BIM. However, it should also be noted that such changes or mandates have to be implemented carefully to avoid possible divide in the engineering and construction market between early adopters of BIM and those that are relatively behind in adopting BIM workflow.

While there is a reasonable consensus about a number of potential barriers to BIM adoption in structural engineering context as discussed above, there seems to be scattered views about some other possible factors. For instance, 40% of the participants have indicated that they either strongly agree (1) or agree (2) that the staff's skills and cost of training are major barriers, but on the other hand, 40% have disagreed with that. This scattered view can also be observed about the software cost and if the cost is a major barrier. This shows that, overall software and training costs are not necessarily a significant barrier for adopting BIM in many structural consulting companies and that is likely to depend on the company size and resources. This is consistent with the findings reported by Makowski et al. [16] on the BIM use by construction companies which suggest that the financial aspect of the BIM transformation is one of the least concerning issues. Having said that, it should also be noted that large software companies such as Autodesk tend to design several products for complex projects usually undertaken by large consultants and contractors, and they generally dedicate more resources to satisfy the needs of larger clients compared with small consulting or contractors.

## 5 Conclusions

The purpose of this research was to attempt to evaluate the overall awareness and current BIM usage in the specific field of structural engineering and determine the main barriers to adoption of BIM in the structural design workflow. A questionnaire survey was administered and the civil/structural engineers and technicians working in the consulting companies in New Zealand were invited to participate in the survey. In total, 55 responses were received. The questionnaire comprised of three main sections, including the demographic information, BIM knowledge/awareness section, and a section on possible benefits and barriers to BIM adoption in the structural engineering context. The survey results were then systematically analysed and compared. Below is a summary of the main findings:

- The results show that 57% of the participants currently use BIM in their work. However, only 17% use BIM specifically for their "structural analysis and design" workflow. This shows there is a significant challenge for adoption of BIM as a single common platform for creating models throughout the structural design workflow, from concept design, structural analysis, detailed design, and draughting to final documentation.

- While almost all respondents were aware of BIM, there appears to be a regional trend showing structural engineers in the main centres are using BIM more than those in the regions.
- The majority of the respondents cited interoperability and knowledge as the two most significant reasons for not using BIM models for structural analysis and design.
- The results showed that, the two main benefits or key reasons for future adoption of BIM in the structural engineering context are viewed to include the "improvement in visualisation", and the "improvement in coordination of design documents and process". Additionally, the majority of respondents believe that adopting BIM would not necessarily increase the speed of project delivery.
- The majority of the participants, who are not currently using BIM in their structural design workflow, have indicated that adopting BIM would require changes in their existing workflow and procedures that they are not currently prepared to do. This highlights that there are still a lot of works to be done in terms of staff training, documentation and overall procedural matters to increase the use of BIM by structural engineers and technicians.
- Additionally, the majority of the participants have identified the custom contents in their current workflow, plus the requirement by building consent authorities to receive 2D drawings, as other most significant barriers to adoption of BIM in the structural engineering context. This further highlights the importance of interoperability issue, plus the significance of governmental initiatives and policies.

This research provides valuable insight on the current status, awareness, and barrier to adoption of BIM in the specific field of structural engineering. Further research in this area is required to investigate detailed strategies to overcome the raised issues. Future studies should look into addressing the gaps and resolving the technical issues of implementing BIM in the structural design workflow.

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## References


1. Ayinla KO, Adamu Z (2018) Bridging the digital divide gap in BIM technology adoption. Eng Constr Architect Manag 25(10):1398–1416
2. Azhar S (2011) Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry. Lead Manag Eng ASCE 11:241–252
3. Baran W, Bartosz Ż (2018) Structural engineering by way of BIM. In: Proceedings of the 3rd scientific conference environmental challenges in civil engineering (ECCE 2018)
4. Bartley T (2017) BIM for civil and structural engineers. British Standards Institution (BSI), London. https://www.bsigroup.com/en-GB/our-services/standards-subscription-services/Eurocodes-Plus/
5. Becerik-Gerber B, Kensek K (2010) Building information modeling in architecture, engineering, and construction: emerging research directions and trends. J Profess Issues Eng Educ Pract 136:139–147
6. Cheng JCP, Lu Q, Deng Y (2016) Analytical review and evaluation of civil information modelling. Autom Constr 67:31–47
7. Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors. Wiley, New Jersey
8. EBOSS (2021) BIM in New Zealand: an industry-wide view. EBOSS, Wellington
9. Hall AT, Durdyev S, Koc K, Ekmekcioglu O, Tupenaite L (2022) Multi-criteria analysis of barriers to building information modeling (BIM) adoption for SMEs in New Zealand construction industry. Eng Constr Architect Manag 30:3798–3816. https://doi.org/10.1108/ECAM-03-2022-0215
10. Hosseini MR, Maghrebi M, Akbarnezhad A, Martek I, Arashpour M (2018) Analysis of citation networks in building information modeling research. J Constr Eng Manag 144:04018064
11. Hosseini M, Banihashemi S, Chileshe N, Namzadi MO, Udaeja C, Rameezdeen R, McCuen T (2016) BIM adoption within Australian small and medium-sized enterprises (SMEs): an innovation diffusion model. Constr Econ Build 16(3):71–86
12. Hunt CA (2013) The benefits of using building information modelling in structural engineering. Masters thesis, Utah State University
13. Kaner I, Sacks R, Kassian W, Quitt T (2008) Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms. Electr J Inform Technol Constr 13:303–323
14. Khosrowshahi F, Arayici Y (2012) Roadmap for implementation of BIM in the UK construction industry. Eng Constr Architect Manag 19(6):610–635
15. Li P, Zheng S, Si H, Xu K (2019) Critical challenges for BIM adoption in small and mediumsized enterprises: evidence from China. Adv Civil Eng 2019:1–14
16. Makowski P, Kamari A, Kirkegaard PH (2019) BIM-adoption within small and medium enterprises (SMEs): an existing BIM-gap in the building sector. In: Proceedings of the 36th CIB W78 2019 conference, Northumbria University, Newcastle
17. Pezeshki Z, Ivari SAS (2018) Applications of BIM: a brief review and future outline. Arch Comput Methods Eng 25(2):273–312
18. Sacks R, Barak R (2007) Impact of three dimensional parametric modelling of buildings on productivity in structural engineering practice. Autom Constr 17:439–449
19. Sun M, Staszewski WJ, Swamy RN (2010) Smart sensing technologies for structural health monitoring of civil engineering structures. Adv Civil Eng 2010:724962
20. Vidalakis C, Abanda FH, Oti AH (2020) BIM adoption and implementation: focusing on SMEs. Constr Innov 20(1):128–147
21. Vilutiene T, Kalibatiene D, Hosseini M, Pellicer E, Zavadskas EK (2019) Building information modeling (BIM) for structural engineering: a bibliometric analysis of the literature. Adv Civil Eng 2019:5290690

# Effective Digital Leadership Among Construction Industry Professionals: Analysis of Core Competencies

**Shakil Ahmed, Rahimi A. Rahman, Yong Siang Lee, and Syafizal Shahruddin**

## 1 Introduction

The construction industry, one of the largest employment sectors globally, has been steadily growing at a rate of 1.3% per year, with 111.9 million individuals directly and indirectly involved [12]. Despite its significant economic contribution, the industry lags behind in modernization, digitization, and adopting state-of-the-art technology and processes. This heavy reliance on manual or semi-manual systems poses numerous challenges. Traditionally resistant to change, the construction industry now faces critical issues such as safety hazards, quality deficiencies, project delays, budget overruns, and sustainability challenges. According to

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Megheirkouni and Mejheirkouni [37], the root concern lies in the traditional leadership culture and its management approach. It is evident that the construction sector must change its traditional method of leadership and adopt a new smart system to overcome these long-standing issues. With the current wave of digital transformation in almost all manufacturing sectors, it is crucial to embrace and implement a new effective leadership system in the construction industry. While other manufacturing industries have already benefited from digital transformation in leadership culture, the construction industry has been slow to adopt these advancements [27]. By transitioning into a smart, effective, and digital system, the construction industry can overcome its existing challenges, leading to increased production rates, improved quality standards, enhanced safety measures, greater sustainability practices, and better control over budgets and schedules [64]. As a result, the construction industry is actively discussing and seeking reliable leadership systems to usher in a new era of digitally equipped construction, effectively addressing current limitations and setting the stage for future success.

To address the concerns in the construction industry, a new concept of leadership has emerged called "Digital Leadership." This term recognizes the need for a system that overcomes the limitations of traditional project management and provides desired outcomes [42]. Digital leadership offers several notable features, such as seamless real-time data delivery, enabling digital leaders to make quick and informed decisions [11]. Additionally, it improves communication, collaboration, and information sharing among project stakeholders, which are crucial factors for project success [44]. The implementation of a digital leadership culture can significantly enhance project management in terms of safety, quality, schedule, budget, and sustainability [50]. Consequently, the construction industry will enter a new era in the digital world. However, the challenge lies in effectively adopting and implementing the digital leadership system, ensuring it runs smoothly. The responsibility for understanding, adopting, implementing, providing training to team members, and supervising the system lies with the digital leader. The digital leader plays a crucial role and can solely determine the success or failure of digital leadership in any construction project. Thus, a skilled digital leader is essential for proper adoption and implementation of this concept, and to yield the best results. The question then arises: what attributes make a leader a good digital leader? Researchers and industry experts have identified specific skills and competencies that differentiate an ordinary leader from an effective digital leader. However, these competencies are not cumulative or structural in nature. Therefore, it is vital to explore and analyze the competencies of a digital leader for effective digital leadership.

Thus, this study aims to investigate and analyze the competencies of a digital leader for effective digital leadership. The research involved conducting interviews with professionals in the construction industry, and the collected data was analyzed using thematic analysis. The findings of this study will provide valuable insights for policymakers, researchers, and industry practitioners, helping them understand the concept of digital leadership and identify the key competencies necessary for becoming an effective digital leader in the construction industry.

## 2 Background

### *2.1 Digital Leadership Concept*

Digital leadership in the construction industry refers to the application of digital technologies and strategies to effectively lead and manage construction projects. It involves leveraging digital tools, data, and processes to enhance communication, collaboration, decision-making, and overall project performance [16]. Digital leadership is a term used in various contexts, and its definition can vary depending on the field. In the context of construction, it focuses on utilizing technology and digital platforms such as BIM, cloud-based project management systems, IoT devices, drones, virtual reality, and augmented reality to streamline workflows, improve efficiency, increase productivity, enhance safety measures, and optimize resource allocation [40].

Digital leaders in construction must possess the necessary skills and competencies to navigate and leverage these digital technologies effectively. They play a crucial role in driving digital transformation within their organizations By embracing digital leadership, the construction industry can overcome traditional challenges, improve project outcomes, and remain competitive in an increasingly digitalized world [36]. The concept of digital leadership does not have a single, standardized definition, but it encompasses the ability to create a clear and meaningful vision for digitalization and execute strategies to achieve it.

### *2.2 Digital Leadership in Construction*

The introduction of digital leadership in the construction sector is a recent development, representing a relatively new concept in the field of construction. Researchers are currently exploring the features and opportunities of digital leadership in construction projects. Zupancic et al. [66] investigated the competencies of digital leaders in the architecture sector, identifying six key areas: technological ecologies, creativity, knowledge processes, and experimentation; design and research; human resources and leadership; collaborative and explorative environments; and the impact of digital leadership. Hossain and Nadeem [24] highlighted the importance of digital leaders collaborating with universities and research organizations to accelerate digital innovation and improve the outcomes of adopted digital technologies. Morgan and Papadonikolaki [40] provided an overview of digital leadership in the construction sector, exploring the soft skills required in this context and discussing the application of this concept within firms, supply chains, and projects.

Zulu and Khosrowshahi [63] analyzed the taxonomy of digital leadership types, identifying six themes: proactive and forward-thinking; supportive; uncoordinated; cautious; resistant and visionless; and undriven leaders. These themes shed light on how leaders influence digital transformation paths within organizations. In a separate study, Zulu et al. [65] shed light on the barriers to enacting digital leadership in the construction industry, grouping their findings into five themes: leadership characteristics, management and organizational issues, resource constraints, technological issues, and risk perceptions.

Johari and Hendra [25] discussed the dimensions of digital leadership capabilities within their organization, identifying four specific dimensions: (a) competency of digital leaders, (b) capacity of digital leaders, (c) organizational structure, and (d) organizational strategy. They claimed that these findings provide valuable insights for improving overall digitalization among leaders and organizations. Soehaditama et al. [51] explored the impact of digital leadership on digital transformation in the construction sector, while Ekechukwu and Lammers [19] discussed the shift from project management to project leadership in the context of digital transformation in the construction industry. Lastly, Guzman et al. [22] analyzed the skills required for digital leadership within the context of Industry 4.0.

### *2.3 Study Positioning*

Digital leadership, as a relatively new concept in the construction sector, has not been extensively explored in research. There is a shortage of literature available on different themes related to digital leadership specifically in the context of the construction sector. Only a few publications can be found on the Internet. For instance, Guzman et al. [22] discuss the characteristics of digital leadership, while Zulu and Khosrowshahi [63] and Zulu et al. [65] focus on the taxonomy and barriers of adopting digital leadership. Hossain and Nadeem [24] emphasize the benefits of collaboration in digital leadership, and Morgan and Papadonikolaki [40] provide an overview of digital leadership in the construction sector. Other studies generally analyze the existing literature or focus on more general aspects. However, there is a significant gap in research that specifically addresses the competencies of digital leadership among construction professionals. This study aims to fill this gap by analyzing the core competencies of digital leadership in a systematic and structured manner. It will contribute significantly to the existing knowledge base by addressing this important question.

## 3 Methodology

This study adopted a qualitative research method to assess the competencies of effective digital leadership among construction professionals and analyze qualitative data. There are several ways to collect qualitative data from participants, and in this research, the authors chose to use open-ended interviews. The authors selected this method for the following reasons: (i) it allows for in-depth exploration of experiences, context, opinions, and perspectives of individuals or groups; (ii) direct engagement with participants promotes open communication, trust, and honest sharing of personal perspectives, facilitating comprehensive understanding through follow-up questions and clarification; (iii) it allows for unexpected insights and new directions to emerge during the data collection process; and (iv) tailored interview questions enable in-depth investigation of specific areas of interest, enhancing the researcher's understanding of the topic [14, 23, 47, 54].

Figure 1 provides an overview of the research methodology used in this study. It starts with creating the interview questions and ends with analyzing the interview data. Before conducting the interviews with construction professionals, the authors invited participants who met predefined specific criteria. The collected data was then analyzed using thematic analysis to gain insights and understand the findings.

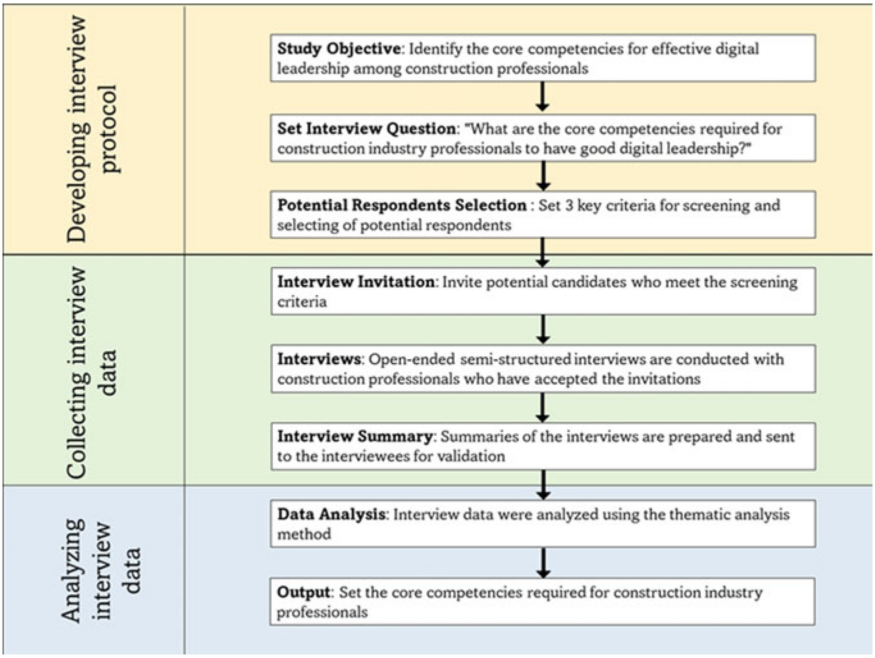


**Fig. 1** Research methodology

## 3.1 Data Collection

### 3.1.1 Semi-Structured Interview Protocol

The qualitative data for this study was collected through an open-ended semi-structured interview with construction professionals. To design this interview process, an interview protocol was developed. The protocol consisted of a main question, with the interviewer having the option to ask follow-up questions based on the situation, experiences, and initial responses of the participants. The main question asked to the participants was, "What do you consider to be the key competencies required for effective digital leadership in the construction industry?" This question aimed to gather information about the key competencies of effective digital leadership in the construction sector from individuals familiar with the concept of relevant smart construction. The interviews were conducted using various mediums such as in-person meetings, video and audio calls on platforms like WhatsApp, Skype, or Zoom, and telephone calls, depending on the preferences of the participants. All the information exchanged during the interviews was recorded through note-taking. These notes will later be summarized and shared with the participants for validation purposes.

### 3.1.2 Selection of Study Participants

For the qualitative data collection, interviews with construction professionals form the foundation of this research. Therefore, selecting the participants for these interviews is a crucial factor. The authors of this study employed a conscious screening process to identify potential participants. The screening criteria included the following: (i) working in a construction company, (ii) holding a valid professional license/position, (iii) possessing a minimum of 2 years of experience, and (iv) being familiar with concepts such as smart construction, digital twin, BIM, and AI in construction. After screening and selecting potential participants, the authors sent ~ 33 invitations to participate in the interviews. Ultimately, the final number of participants reached 20, marking the completion of the interview phase of this study. Dworkin [15] has affirmed that this number is sufficient for conducting qualitative research. The participants were drawn from various construction organizations and represented different professional levels and designations.

### 3.1.3 Respondent Profile

The demographic information of the respondents is presented in Table 1. Among the respondents, 65% are male and 35% are female. It is worth noting that the representation of females in the construction industry is relatively low, accounting for only 10.9% based on the NAWIC [41] report. However, there has been a recent

**Table 1** Demographics information of respondents

| Demographic characteristics | Frequency | Percentage (%) |
|---|---|---|
| *Gender* | | |
| Male | 13 | 65 |
| Female | 7 | 35 |
| *Designation* | | |
| BIM modeler | 2 | 10 |
| Architect | 2 | 10 |
| Engineer | 8 | 40 |
| BIM coordinator | 2 | 10 |
| Project coordinator | 1 | 5 |
| Academic faculty | 2 | 10 |
| BIM-GIS operator | 1 | 5 |
| Project manager | 2 | 10 |
| *Academic qualification* | | |
| Diploma degree | 3 | 15 |
| Bachelor's degree | 7 | 35 |
| Post graduate | 10 | 50 |
| *Work experience (years)* | | |
| 2–4 years | 4 | 20 |
| 4–6 years | 5 | 25 |
| 6–8 years | 5 | 25 |
| 8–10 years | 3 | 15 |
| More than 10 years | 3 | 15 |

increase, particularly in IT and managerial positions within the construction sector. The participant proportion in this research aligns with this trend. In Table 1, it can be observed that 50% of the respondents hold either a master's or PhD degree in their respective field of work, while 35% have a bachelor's degree, and the remaining 15% have a diploma degree. Additionally, the table indicates that 20% of the respondents have 2–4 years of working experience, while 50% have 4–8 years. The remaining 30% have more than 8 years of experience in the construction sector.

## *3.2 Data Analysis*

The collected qualitative data have been analyzed using the thematic analysis approach in this research to investigate the key competencies required in digital leadership for the effective implementation of digital strategies in the construction sector. Among various qualitative research methods, the authors chose thematic analysis due to its flexibility in aligning with the research objectives, providing rich and detailed data [9]. Additionally, it offers comparable accessibility without requiring extensive theoretical or technological knowledge compared with other qualitative approaches [30]. Thematic analysis allows for clear and organized reporting by effectively summarizing key features of large datasets through a structured approach to data handling [10]. Several studies [6, 20, 35, 61] have also adopted this approach for analyzing qualitative data collected through interviews.

The collected data in this study underwent a six-phase thematic analysis process, following the approach introduced and developed by Braun and Clarke [9]. An overview of the six-phase process is provided below.

1. Familiarizing with the data: The authors immersed themselves in the data, transcribed it into a written summary, and read it repeatedly to become familiar with its content.
2. Generating initial codes: The authors identified and labeled initial codes or patterns within the data that were relevant to the research question.
3. Searching for themes: The authors explored and grouped codes into potential subthemes and themes based on similarities and patterns observed in the initial codes and summary.
4. Reviewing themes: The authors reviewed and refined the identified subthemes and themes, ensuring they accurately represented the initial codes and reflected the research objectives.
5. Defining the themes: The authors developed clear and meaningful descriptions for each subtheme and theme, capturing their essence and relevance to the research question.
6. Reporting the final themes: The authors integrated the identified themes into a coherent and comprehensive narrative, presenting the findings (final themes) of the thematic analysis.

The adopted thematic analysis in this study involves six phases. Firstly, the interview data from 20 respondents was transcribed multiple times to gain initial insights. Secondly, each sentence of the transcript was analyzed to generate initial codes. These codes were then reviewed to identify potential subthemes. In the third phase, subthemes were identified based on the initial codes. The next step involved reviewing the themes and grouping the subthemes from the previous phase to create overarching themes. The authors ensured that the initial codes and raw data aligned with the research objectives. In the fifth phase, the themes were defined and named. The authors considered the context of the construction sector and the competencies of digital leadership to generalize the naming of the new themes. Lastly, in the sixth phase, the developed and categorized themes were reported, providing explanations based on the issues and feedback provided by the respondents.

## 4 Result

The study focuses on exploring and investigating the competencies of effective digital leadership in the construction sector. Twenty construction professionals from diverse backgrounds were interviewed to gather their feedback. After a six-phase thematic analysis of the qualitative data, the study presents the final findings in the form of initial codes, subthemes, and themes. The two main themes are hard and soft skills. Competencies of digital leaders are categorized into two main themes and these are hard and soft skills. Previous studies [5, 34, 55] also followed the same approach to categorize the individual skill and competency to group them with the wider themes.

Figure 2 and Table 2 summarize the final findings of the thematic analysis, which identified five subthemes (technical skill, attitude and mindset, leadership skill, knowledge and expertise, and interpersonal skill) and two main themes (hard skill and soft skill) based on the content of the initial codes derived from the interview summary.

### *4.1 Hard Skills*

Hard skills play a vital role in digital leadership within the construction industry. These skills are indispensable for implementing and practicing digital leadership concepts, requiring a deep understanding and proficiency in various technical areas to navigate the complexities of the digital world effectively. The study identified two subthemes, namely technical skill and knowledge and expertise, which encompass

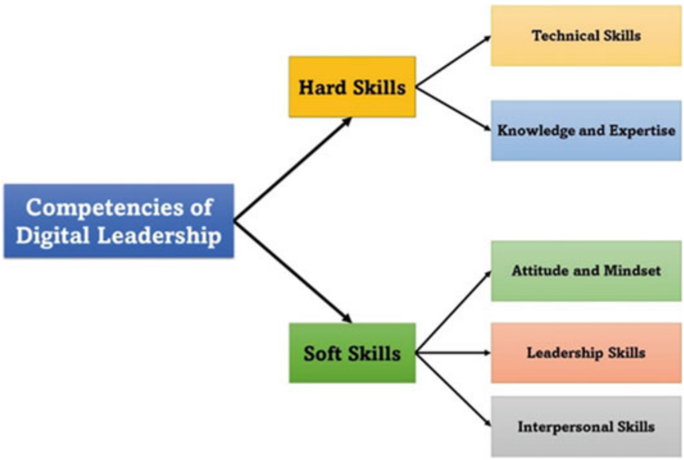


**Fig. 2** Overview of the themes and subthemes of the digital leadership competencies

**Table 2** Competencies of effective digital leadership in the construction projects

| | Interviewee 02 | Interviewee 03 | Interviewee 04 | Interviewee 06 | Interviewee 08 | Interviewee 09 | Interviewee 10 | Interviewee 11 | Interviewee 13 | Interviewee 14 | Interviewee 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hard skills* | | | | | | | | | | | |
| Technical skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Knowledge and expertise | | | ✔ | ✔ | | ✔ | | ✔ | | ✔ | |
| *Soft skills* | | | | | | | | | | | |
| Attitude and mindset | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Leadership skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Interpersonal skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ |

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Hard skills* | | | | | | | | | | |
| Technical skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 100 |
| Knowledge and expertise | | ✔ | | | ✔ | ✔ | ✔ | | | 45 |
| *Soft skills* | | | | | | | | | | |
| Attitude and mindset | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 100 |

(continued)

**Table 2** (continued)

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Leadership skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 100 |
| Interpersonal skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 95 |

competencies such as BIM expertise, programming skills, construction process experience, technical tool proficiency, formal education, relevant training, cybersecurity expertise, and more, as revealed through thematic analysis of respondent feedback. Table 3 shows the status of theme "Hard Skills" and competencies within it.

### 4.1.1 Technical Skills

Technical skills encompass specific competencies and expertise gained through education, training, or practical experience within a particular industry. Table 2 underscores the unanimous agreement among respondents, with 100% concurring on the essentiality of these skills for digital leadership. This study, through interviews, identifies five critical technical skills vital for effective digital leadership in the construction domain: programming skills, proficiency in contemporary digital tools and technologies (technical/digital literacy), mastery of BIM-related software, knowledge of cybersecurity measures, and appropriate education and training. In Table 3, the core competencies for digital leadership are assessed, with BIM proficiency (90%) and digital/technical literacy (75%) emerging as highly significant, while cybersecurity skills (50%) and relevant education and training (60%) are deemed moderately important. Programming skills (45%) are considered somewhat less critical. The responses based on the summary of the interviews are as following:

> I strongly believe that BIM technology is an integral part of digital construction, and proficiency in BIM is essential for professionals involved in any digital processes within the construction industry. (Interviewee No. 27)

> In my view, programming languages is essential for leveraging tools and achieving project success in digital leadership culture. (Interviewee No. 14)

> As data serves as the backbone of digital construction, cyber-security skills are also important to ensure the security and protection of data in the digital system. (Interviewee No. 20)

> Technical literacy is essential, including a solid understanding of technology like software, hardware, and networking. (Interviewee No. 23)

> Formal education and training are essential for digital leaders, providing them with the necessary knowledge, skills, and foundation to navigate technology landscapes, drive innovation, and lead successful digital transformation initiatives. (Interviewee No. 18)

### 4.1.2 Knowledge and Expertise

The study emphasizes the significance of knowledge and expertise in digital leadership within the construction sector. Table 2 indicates that 45% of respondents agree on their importance. Within this theme, two specific competencies emerged: understanding the technical construction process (rated at 40% importance in Table 3) and expertise in industry standards and regulations (rated at 20% importance). The higher importance assigned to understanding construction processes highlights the need for practical project management knowledge, while the 20% rating for standards and

**Table 3** Hard skills of effective digital leadership in the construction projects

| | Interviewee 02 | Interviewee 03 | Interviewee 04 | Interviewee 06 | Interviewee 08 | Interviewee 09 | Interviewee 10 | Interviewee 11 | Interviewee 13 | Interviewee 14 | Interviewee 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Technical skills* | | | | | | | | | | | |
| BIM proficiency | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Programing skills | ✔ | | | | ✔ | | ✔ | ✔ | | ✔ | ✔ |
| Cybersecurity skills | ✔ | | | ✔ | | | | ✔ | ✔ | | ✔ |
| Digital/ technical literacy | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ | |
| Relevant education and training | ✔ | | ✔ | ✔ | | ✔ | | ✔ | | ✔ | |
| *Knowledge and expertise* | | | | | | | | | | | |
| Understanding of construction process | | | ✔ | ✔ | | | | ✔ | | ✔ | |
| Expertise in standard and regulations | | | | ✔ | | | | | | | |

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Technical skills* | | | | | | | | | | |

(continued)

**Table 3** (continued)

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| BIM proficiency | ✔ | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ | 90 |
| Programing skills | | | ✔ | | | ✔ | | | ✔ | 45 |
| Cybersecurity skills | ✔ | ✔ | ✔ | ✔ | | | | | ✔ | 50 |
| Digital/technical literacy | ✔ | ✔ | ✔ | ✔ | ✔ | | | ✔ | | 75 |
| Relevant education and training | ✔ | ✔ | | | | ✔ | ✔ | ✔ | ✔ | 60 |
| *Knowledge and expertise* | | | | | | | | | | |
| Understanding of construction process | | ✔ | | | ✔ | ✔ | ✔ | | | 40 |
| Expertise in standard and regulations | | ✔ | | | ✔ | ✔ | | | | 20 |

regulations underscores the importance of compliance in this regulated industry. The responses from the interviews can be summarized as follows:

> Leaders in construction need a detailed understanding of the construction process to predict and address challenges, as well as maximize opportunities. (Interviewee No. 18)

> In addition to having a deep understanding of the construction process, a digital leader should also possess knowledge about industry standards and compliance to help them adopt digital culture easily and enhance the benefits. (Interviewee No. 06)

## 4.2 *Soft Skills*

Soft skills are essential for implementing digital leadership in the construction industry. Table 4 in the study identifies three subthemes within the "Soft Skills" category: leadership skills, attitude and mindset, and interpersonal skills. These subthemes encompass 10 key competencies of digital leadership, including creativity, communication, risk management, adaptability, digital vision, teamwork, and quick decision-making. These competencies form the foundation for fostering digital leadership in construction, vital for successful digital transformation in the sector. Table 4 presents the status of the "Soft Skills" theme and its competencies.

### 4.2.1 Leadership Skills

Leadership skills, including effective leadership, risk management, and decision-making abilities are pivotal in digital leadership. Table 2 shows that 100% of study respondents acknowledge the importance of these skills for effective digital leadership. Table 4 illustrates leadership-related competencies, with 85% emphasizing effective leadership skills, 60% considering decision-making skills important, and 50% rating risk management skills as moderately important. ***Effective***. The responses from the interviews can be summarized as follows:

> Effective leadership skills are vital for managing teams and mitigating project risks. Leaders should inspire and motivate team members, provide clear guidance, and make informed decisions to ensure project success. (Interviewee No. 31)

> Effective risk management is essential in digital construction, considering the potential risks involved, such as data breaches. (Interviewee No. 23)

> Digital leaders must manage risks associated with the adoption of new technologies and processes and have to be strategic. (Interviewee No. 06)

> The ability to make quick decisions based on data is an important skill for digital leaders in the construction industry. This involves collecting and analyzing data to inform strategic decision-making and drive project success. (Interviewee No. 08)

**Table 4** Soft skills of effective digital leadership in the construction projects

| | Interviewee 02 | Interviewee 03 | Interviewee 04 | Interviewee 06 | Interviewee 08 | Interviewee 09 | Interviewee 10 | Interviewee 11 | Interviewee 13 | Interviewee 14 | Interviewee 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Leadership skills* | | | | | | | | | | | |
| Effective leadership skills | ✔ | ✔ | ✔ | | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ |
| Risk management skills | | | ✔ | | ✔ | | | ✔ | ✔ | ✔ | ✔ |
| Decision-making skills | | | ✔ | ✔ | ✔ | | ✔ | | ✔ | | ✔ |
| *Attitude and mindset* | | | | | | | | | | | |
| Creative and innovative | ✔ | ✔ | | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Adaptive and flexible to new/change | | ✔ | | ✔ | ✔ | | ✔ | | | ✔ | ✔ |
| Strategic mindset | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ |
| Continuous learning | ✔ | ✔ | ✔ | ✔ | | | ✔ | | | ✔ | |
| Digital vision | ✔ | | | ✔ | ✔ | | ✔ | | | ✔ | |
| *Interpersonal skills* | | | | | | | | | | | |
| Communication skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ | ✔ | ✔ |
| Team collaboration | ✔ | | ✔ | | ✔ | | ✔ | | ✔ | | ✔ |

(continued)

**Table 4** (continued)

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Leadership skills* | | | | | | | | | | |
| Effective leadership skills | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 85 |
| Risk management skills | ✔ | | | ✔ | ✔ | | | | ✔ | 50 |
| Decision-making skills | ✔ | ✔ | ✔ | ✔ | | | ✔ | | ✔ | 60 |
| *Attitude and mindset* | | | | | | | | | | |
| Creative and innovative | ✔ | ✔ | | ✔ | ✔ | ✔ | | | ✔ | 70 |
| Adaptive and flexible to new/change | ✔ | ✔ | | ✔ | | ✔ | ✔ | ✔ | | 60 |
| Strategic mindset | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | 90 |
| Continuous learning | | | ✔ | | | ✔ | ✔ | ✔ | | 50 |
| Digital vision | ✔ | | ✔ | ✔ | | | ✔ | ✔ | | 50 |
| *Interpersonal skills* | | | | | | | | | | |

(continued)

**Table 4** (continued)

| | Interviewee 18 | Interviewee 20 | Interviewee 22 | Interviewee 23 | Interviewee 24 | Interviewee 27 | Interviewee 29 | Interviewee 30 | Interviewee 31 | Response rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Communication skills | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 90 |
| Team collaboration | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | 65 |

### 4.2.2 Attitude and Mindset

Attitude and mindset play a vital role as competencies in digital leadership. Under the "attitude and mindset" subtheme, the thematic analysis of interview data revealed five key competencies: creative and innovative, adaptive and flexible to new/change, strategic mindset, continuous learning, and digital vision. Table 2 demonstrates the significance of this subtheme, with all respondents (100%) acknowledging its indispensability. Table 4 reflects the perceived importance of various skills for digital leadership. Notably, a strategic mindset stands out as crucial (90%), closely followed by creativity and innovation (70%). Adaptability is important to 60% of respondents. Continuous learning and having a digital vision are seen as moderately important (50%). In summary, strategic thinking and creative skills are highly valued in digital leadership. The responses from the interviews can be summarized as follows:

> An innovative and creative mindset is essential for digital leaders to effectively solve complex problems that arise during digital practices. (Interviewee No. 02)

> As new technologies emerge within a few days, flexibility towards new cultures or any changes in ongoing processes becomes crucial. (Interviewee No. 03)

> Professionals in construction must have a strategic mindset to develop and implement digital strategies aligned with organizational goals. (Interviewee No. 27)

> Professionals in construction must have a strategic mindset to develop and implement digital strategies aligned with organizational goals. (Interviewee No. 27)

> A digital leader should have digital vision which enable to see and understand the impact of technology on various aspects of business in the construction industry. (Interviewee No. 06)

### 4.2.3 Interpersonal Skills

Interpersonal skills are pivotal in digital leadership, encompassing competencies like communication and team collaboration. Table 2 presents a noteworthy finding from the study, with a remarkable 95% of respondents recognizing the necessity of these skills in the construction sector. Additionally, Table 4 reveals that a significant 90% of respondents emphasize the vital importance of communication skills for digital leaders, while team collaboration is considered significant by 65% of respondents. The responses from the interviews can be summarized as follows:

> Great digital leaders should have good communication skills to match their strategic thinking, giving clear messages to stakeholders and team members. Without that skill, their initiatives might never come to fruition. (Interviewee No. 29)

> Team collaboration enables seamless integration and maximizes the benefits of digital solutions. (Interviewee No. 15)

# 5 Discussion

## *5.1 Hard Competencies*

Technical skills are essential for leaders who manage technical teams and aim to achieve the best outcomes. In this study, respondents mentioned several technical skills that have a crucial impact on becoming an effective digital leader. As digital construction is considered the future of the construction industry, and building information modeling (BIM) is the foundation of any digital construction initiative, proficiency in BIM plays a pivotal role. Olugboyega [43] highlighted that expertise in BIM is essential in digital leadership and should be a prerequisite for BIM-based projects. Another study by Morgan and Papadonikolaki [40] listed BIM proficiency as a fundamental competency for digital leaders in construction projects. Another important technical competency is programming skills, which are highly effective in the digital and automated processes of construction projects. Temelkova [52] stated that programming skills play a crucial role in automating tasks, streamlining processes, and enhancing overall efficiency. Furthermore, Weiner et al. [58] concluded their study by noting that with the ability to analyze and visualize large volumes of project data, digital leaders equipped with programming skills can make informed decisions and optimize resource allocation. Additionally, these skills enable the seamless integration of technologies like building information modeling (BIM) and the Internet of Things (IoT), fostering collaboration among stakeholders. Finally, Luecha et al. [33] emphasized that leaders proficient in programming can develop innovative solutions and customize software applications to address unique construction challenges.

In the realm of digital leadership, where workflows and data are managed within digital systems, having proper skills in cybersecurity is crucial, and this study also identifies it as a key competency for digital leaders. Triplett [53] expressed concern that without a strong emphasis on cybersecurity, the advantages of this leadership approach can quickly transform into concerning vulnerabilities for construction projects. Additionally, Lehto and Limnell [32] highlighted that digital leaders with cybersecurity skills play a pivotal role in safeguarding sensitive data, mitigating cyber risks, and protecting critical infrastructure. By implementing robust security measures, adhering to regulations, and effectively managing third-party risks, these leaders ensure the confidentiality, integrity, and availability of information while promoting seamless project operations. Digital/technical literacy is another key competency that enables digital leaders to be effective and efficient, as determined in this study. Zeike et al. [62] mentioned that by leveraging digital literacy, leaders can drive innovation, enhance decision-making processes, and effectively lead their teams toward digital transformation in construction. Relevant education and training are also crucial technical competencies for digital leaders, and other studies have also emphasized their importance in improving the efficiency of a leader's capability. Benitez et al. [7] demonstrated how relevant training influences a digital leader's ability to become more effective and encourages professionals to embrace the digital leadership concept. Chatterjee et al. [13] highlighted the impact of digital training and education for professionals involved in traditional construction methods to create awareness and initiate the practice of digital leadership. Moreover, several research studies [17, 39] concurred that relevant education and training are essential in the transformation process of digital construction.

The study identifies two competencies that are closely related to the knowledge and expertise of a digital leader. The first is a solid understanding of the technical processes in construction, which is considered crucial for becoming a successful digital leader. Gfrerer et al. [21] share this perspective, noting that digital leaders require this knowledge to make informed decisions about technology adoption and implementation, ensuring alignment with industry standards and seamless integration into existing workflows. Furthermore, Promsri [46] emphasizes that understanding the technical processes enables effective communication with both technical and non-technical stakeholders, facilitates risk management, and drives continuous improvement in construction processes. With this understanding, digital leaders can successfully navigate the complexities of digital transformation and lead their organizations toward enhanced efficiency, productivity, and success in the construction sector [17, 52]. The second competency related to knowledge and expertise is expertise in industry standards and regulations. This competency plays a crucial role in ensuring compliance, enhancing safety, improving quality, and instilling stakeholder confidence. Other studies [3, 11] support this view, highlighting that a deep understanding of industry standards and regulations empowers digital leaders to successfully navigate regulatory challenges, drive efficiency, and effectively manage risks throughout the construction industry's digital transformation. Sağbaş and Erdoğan [49] also stress the importance of organizations recognizing and prioritizing this competency to maximize the benefits of digital leadership in construction.

### *5.2 Soft Competencies*

This study identifies three core leadership competencies that are significantly important for the digital leadership concept. The first and foremost competency is effective leadership skills, which are crucial for a digital leader. Promsri [46] and Zeike et al. [62] both emphasize the importance of this skill set, which encompasses various aspects such as inspiring and motivating teams, setting strategic direction, making informed decisions, and fostering a culture of innovation and collaboration. According to Alanazi [3], effective leadership skills enable digital leaders to guide their organizations through the digital transformation journey and achieve sustainable growth and success. Another key leadership-related competency is risk management. Several studies [26, 38, 62] concur with the findings of this study, highlighting the importance of effective digital leaders possessing the ability to identify, assess, and mitigate risks associated with digital initiatives. Bowen [8] suggests that this competency enables proactive decision-making, data analysis, and the implementation of risk mitigation strategies. Robust risk management skills are essential for successfully navigating the complexities of digital transformation in the construction industry. The last leadership-related competency is data-driven decision-making, which is a fundamental requirement for leaders in any sector. According to Oberer and Erkollar [42], in the fast-paced digital landscape, digital leaders must possess strong data-driven decision-making skills to guide successful initiatives, manage risks, and achieve strategic goals. Sağbaş and Erdoğan [49] also highlight the vital nature of this competency, emphasizing that analyzing data, deriving insights, and making informed decisions based on evidence are essential in the face of rapid changes and the increasing reliance on data-driven insights. Strong data-driven decision-making skills are critical for driving transformation and innovation in the digital construction field.

In this study, five core competencies have been identified as crucial skills for digital leaders in the construction industry. These competencies are categorized under the subgroup of attitude and mindset. Among these, creativity and innovation stand out as a significant competency for embracing the concept of digital leadership. Wasono and Furinto [57] also found this competency to be fundamental for leaders involved in digital practices. According to Kiyak and Bozkurt [31], these skills empower leaders to think creatively, find innovative solutions, and effectively leverage emerging technologies. Additionally, [4] believe that embracing creativity and innovation fosters growth, addresses challenges, and maximizes the benefits of digital leadership in construction. Finally, Bresciani et al. [11] emphasized that recognizing and prioritizing these competencies are crucial for driving successful digital transformation in the industry. Another key competency is a strategic mindset, and other studies like [11, 32], and Oberer and Erkollar [42] concur that this skill plays a crucial role in the digital leadership concept. According to Sagbas and Erdogan [49], a strategic mindset enables leaders to think ahead, plan strategically, and make informed decisions that align with digital transformation goals. Benitez et al. [7] suggested that organizations should prioritize the development of this competency to maximize the benefits of digital leadership in the construction industry. Continuous learning is also a crucial competency in digital leadership, as determined in this study, due to the rapidly evolving nature of technology and industry trends. AlAjmi [2] recognized this competency as a significant one among the soft skills of a digital leader and believed that it enables leaders to stay updated, adapt to changes, and drive innovation within the construction sector. Many studies [1, 62] emphasized the need to emphasize and promote the value of continuous learning in the construction industry's digital leadership landscape.

Within the five competencies of the attitude and mindset subgroup, digital vision is fundamental. Without this skill, a digital leader cannot become effective and successful in the construction sector. Promsri [46] stated that having a digital vision is a vital competency for digital leaders, as it allows them to envision and communicate a clear direction for digital transformation initiatives. Ehmig-Klassen and Schallmo [18] believe that a strong digital vision serves as a strategic roadmap, guiding leaders in leveraging technology and driving successful digital initiatives within the construction sector. According to the findings of Yucebalkan et al. [60], it emphasizes the need for digital leaders to prioritize and develop this competency, as it directly impacts the outcome of impactful digital transformation efforts. The last competency in the attitude and mindset subgroup is being adaptive and flexible to change, which is essential for a digital leader in the construction sector to be effective. de Araujo et al. [4] stated that this competency enables leaders to navigate dynamic landscapes, embrace emerging technologies, and effectively manage change, fostering innovation and staying ahead in the industry. Kawiana [29] suggested that digital leaders should prioritize the development of this competency for successful digital leadership and transformation in construction.

One of the key competencies for digital leadership is strong interpersonal skills, and this study has identified two essential competencies within this category. The first competency is effective communication skills, which are crucial for digital leaders to facilitate efficient information sharing, collaboration, and decision-making [49, 67, 59]. Oberer and Erkollar [42] have also acknowledged the pivotal role played by strong communication abilities in successfully leading and navigating digital transformation initiatives within the construction sector. Another vital competency is team collaboration, which holds immense significance not only in the construction industry but also in all manufacturing sectors. As stated by Petry [45] and Saputra et al. [48], team collaboration is a critical competency for digital leaders, as it facilitates effective coordination and synergy within project teams. Vercammen and Burgman [56] believe that teams consisting of members with diverse backgrounds, experiences, and skills can offer a broader range of insights, potentially leading to better decision-making and problem-solving. Furthermore, collaborative teams can foster a culture of continuous learning and improvement within the realm of digital leadership [28].

## 6 Implications and Limitations

The findings of this study hold significant implications for the construction industry, particularly in the context of the ongoing transformation toward digital construction. There are no other studies available on the Internet that have conducted research focusing on the core competencies of digital leaders in the construction sector. The list of determined core competencies of digital leaders constitutes a solid foundation for construction professionals and academicians to investigate these competencies in more depth or with different methodological approaches.

On the other hand, the findings of this study will raise awareness among companies and government entities about the opportunities and advantages of the digital leadership concept in construction. This, in turn, may encourage them to adopt this concept by providing solid information about the essential competencies required for effective digital leadership. Additionally, it will provide a structural analysis of digital leadership competencies for those who struggle to implement this concept. Government bodies and management within the construction sector can receive education and take necessary measures to improve these competencies among construction professionals, allowing them to seamlessly integrate into the flow of digital transformation without any hassles. Furthermore, these findings will assist both the private and public sectors in establishing plans and strategies to embrace the new digital waves in construction.

Despite the numerous implications of this study, the authors have identified a few limitations that could be addressed by future researchers. The first limitation pertains to the sample size, as this study analyzed findings from only twenty responses. Future research with a sufficiently large sample size may more accurately reflect the responses and thoughts of the construction industry. The second limitation arises from the fact that many of the respondents were not directly involved in digital leadership or the digital construction process, or had minimal involvement. Therefore, it is encouraged that future research be conducted in a manner that focuses on respondents who are experienced and directly involved in digital leadership practices within the construction sector.

## 7 Conclusion

There is limited discussion and research on digital leadership specifically in the context of the construction sector, given its novelty. Therefore, the objective of this study is to assess and analyze the core competencies of digital leadership among professionals in the construction industry. To achieve this, interviews were conducted with construction professionals, and the data obtained were analyzed using thematic analysis.

The thematic analysis revealed two main themes of competencies: "Soft Skills" and "Hard Skills," which were further divided into six subthemes: technical skills, knowledge and expertise, attitude and mindset, leadership skills, and interpersonal skills. Several significant core competencies were identified, including proficiency in building information modeling (BIM), programming skills, creativity and innovation, leadership and communication skills, understanding of construction processes and regulations, strategic mindset, adaptability to change and new technologies, digital vision, digital literacy, and training and education, among others. These findings are crucial for construction industry stakeholders and policymakers as they provide insights into the core competencies required for effective digital leadership. The findings can inform the development of strategic plans and policies aimed at enhancing the competencies of digital leaders to maximize the benefits of digital systems in the industry.

Additionally, the qualitative data obtained regarding problems and mechanisms can serve as the basis for developing a questionnaire survey to gather a more comprehensive understanding of the criticality of these issues and the mechanisms involved.

## References


1. Aksal FA (2015) Are headmasters digital leaders in school culture? Egitim ve Bilim 40(182)
2. AlAjmi MK (2022) The impact of digital leadership on teachers' technology integration during the COVID-19 pandemic in Kuwait. Int J Educ Res 112:101928
3. Alanazi AT (2022) Digital leadership: attributes of modern healthcare leaders. Cureus 14(2)
4. de Araujo LM, Priadana S, Paramarta V, Sunarsi D (2021) Digital leadership in business organizations. Int J Educ Admin Manag Leadership 12:45–56
5. Balcar J (2016) Is it better to invest in hard or soft skills? Econ Labour Relat Rev 27(4):453–470
6. Basarir-Ozel B, Turker HB, Nasir VA (2022) Identifying the key drivers and barriers of smart home adoption: a thematic analysis from the business perspective. Sustainability 14(15):9053
7. Benitez J, Arenas A, Castillo A, Esteves J (2022) Impact of digital leadership capability on innovation performance: the role of platform digitization capability. Inform Manag 59(2):103590
8. Bowen G (2021) Digital leadership, ethics, and challenges. Strategy, leadership, and AI in the cyber ecosystem. Elsevier, Amsterdam, pp 23–39
9. Braun V, Clarke V (2006) Using thematic analysis in psychology. Qual Res Psychol 3(2):77–101
10. Braun V, Clarke V (2014) What can "thematic analysis" offer health and wellbeing researchers?, vol 9. Taylor & Francis, Milton Park, p 26152
11. Bresciani S, Ferraris A, Romano M, Santoro G (2021) Digital leadership. In: Proceedings of the digital transformation management for agile organizations: a compass to sail the digital world. Emerald Publishing Limited, pp 97–115
12. BuildOps (2018) The number of employees in the construction Industry in the world—chart. https://buildops.com/commercial-construction/the-number-of-employees-in-the-construction-industry-in-the-world-chart/#:~:text=It%20shows%20that%20the%20number,yearly%20growth%20rate%20of%201.3%25
13. Chatterjee S, Chaudhuri R, Vrontis D, Giovando G (2023) Digital workplace and organization performance: moderating role of digital leadership capability. J Innov Knowl 8(1):100334
14. DiCicco-Bloom B, Crabtree BF (2006) The qualitative research interview. Med Educ 40(4):314–321
15. Dworkin SL (2012) Sample size policy for qualitative studies using in-depth interviews. Springer, New York, pp 1319–1320
16. Eberl JK, Drews P (2021) Digital leadership–mountain or molehill? A literature review. In: Innovation through information systems: volume III: a collection of latest research on management issues, pp 223–237
17. Ehlers U-D (2020) Digital leadership in higher education. J Higher Education Policy and Leadership Studies 1(3):6–14
18. Ehmig-Klassen K, Schallmo D (2021) Digital leadership: approaches and practical insights from the B2B sector. In: Paper presented at the ISPIM conference proceedings
19. Ekechukwu J, Lammers T (2020) Digital technology to enhance project leadership practice: the case of civil construction. Dig Transform Bus Soc Theory Cases, pp 247–271
20. Franz B, Roberts BA (2022) Thematic analysis of successful and unsuccessful project delivery teams in the building construction industry. J Constr Eng Manag 148(3):05022001
21. Gfrerer AE, Rademacher L, Dobler S (2021) Digital needs diversity: innovation and digital leadership from a female managers' perspective. Digitalization: approaches, case studies, and tools for strategy, transformation and implementation. Springer, New York, pp 335–349
22. Guzmán VE, Muschard B, Gerolamo M, Kohl H, Rozenfeld H (2020) Characteristics and skills of leadership in the context of industry 4.0. Proced Manufact 43:543–550
23. Hammarberg K, Kirkman M, de Lacey S (2016) Qualitative research methods: when to use them and how to judge them. Hum Reprod 31(3):498–501
24. Hossain MA, Nadeem A (2019) Towards digitizing the construction industry: state of the art of construction 4.0. In: Paper presented at the proceedings of the ISEC

25. Johari S, Hendra S (2023) An overview of digital leadership dimensions in construction industry. Int J Bus Technol Manag 5(2):49–66
26. Karakose T, Polat H, Papadakis S (2021) Examining teachers' perspectives on school principals' digital leadership roles and technology capabilities during the COVID-19 pandemic. Sustainability 13(23):13448
27. Karmakar A, Delhi VSK (2021) Construction 4.0: what we know and where we are headed? J Inform Technol Constr 26
28. Karneli O (2023) The role of adhocratic leadership in facing the changing business environment. J Contemp Admin Manag (ADMAN) 1(2):77–83
29. Kawiana IGP (2023) Digital leadership: building adaptive organizations in the digital age. J Multidisip Sahombu 3(01):170–179
30. King N, Cassell C, Symon G (2004) Using templates in the thematic analysis of text. In: Cassell C, Symon G (eds) Essential guide to qualitative methods in organizational research, pp 256–270
31. Kiyak A, Bozkurt G (2020) A general overview to digital leadership concept. Uluslararası Sosyal ve Ekonomik Çalışmalar Dergisi 1(1):84–95
32. Lehto M, Limnéll J (2021) Strategic leadership in cyber security, case Finland. Inform Sec J Glob Perspect 30(3):139–148
33. Luecha C, Chantarasombat C, Sirisuthi C (2022) Program development of digital leadership for school administrators under the office of primary educational service area. World J Educ 12(2):15–27
34. Lyu W, Liu J (2021) Soft skills, hard skills: what matters most? Evidence from job postings. Appl Energy 300:117307
35. Manoharan K, Dissanayake P, Pathirana C, Deegahawature D, Silva R (2023) Assessment of critical factors influencing the performance of labour in Sri Lankan construction industry. Int J Constr Manag 23(1):144–155
36. Maruthuvellu SG, Salamzadeh Y, Richardson C (2022) Digital leadership competencies in the malaysian context: a study in manager levels. In: Handbook of research on developing circular, digital, and green economies in Asia. IGI Global, pp 13–41
37. Megheirkouni M, Mejheirkouni A (2020) Leadership development trends and challenges in the twenty-first century: rethinking the priorities. J Manag Develop 39(1):97–124
38. Mihardjo L, Sasmoko S, Alamsjah F, Elidjen E (2019) Digital leadership role in developing business model innovation and customer experience orientation in industry 4.0. Manag Sci Lett 9(11):1749–1762
39. Mohamed SM (2022) Employee performance as affected by the digital training, the digital leadership, and subjective wellbeing during COVID-19. J Posit School Psychol 143:540–553
40. Morgan B, Papadonikolaki E (2021) Digital leadership for the built environment. In: Industry 4.0 for the built environment: methodologies, technologies and skills. Springer, New York, pp 591–608
41. NAWIC (2022) Statistics of women in construction. https://www.nawic.org/statistics#:~:text=Women%20numbered%2010.9%20percent%20of%20the%20entire%20U.S.%20construction%20workforce%20in%202022.&text=Women%20in%20the%20U.S.%20earn,percent%20of%20what%20men%20make
42. Oberer B, Erkollar A (2018) Leadership 4.0: digital leaders in the age of industry 4.0. Int J Organ Lead 7:404–412
43. Olugboyega O (2022) BIM leadership theory for organisational BIM transformation. Front Built Environ 8:1030403
44. Peng B (2022) Digital leadership: state governance in the era of digital technology. Cult Sci 5(4):210–225
45. Petry T (2018) Digital leadership. In: Knowledge management in digital change: new findings and practical cases, pp 209–218
46. Promsri C (2019) The developing model of digital leadership for a successful digital transformation. GPH Int J Bus Manag 2(08):01–08
47. Qu SQ, Dumay J (2011) The qualitative research interview. Qualit Res Account Manag 8(3):238–264

48. Saputra N, Nugroho R, Aisyah H, Karneli O (2021) Digital skill during covid-19: effects of digital leadership and digital collaboration. Jurnal Aplikasi Manajemen 19(2):272–281
49. Sağbaş M, Erdoğan FA (2022) Digital leadership: a systematic conceptual literature review. İstanbul Kent Üniversitesi İnsan ve Toplum Bilimleri Dergisi 3(1):17–35
50. Shamim M (2022) The digital leadership on project management in the emerging digital era. Global Mainstream J Bus Econ Develop Project Manag 1(1):1–14
51. Soehaditama JP, Zen A, Sjarifudin D, Widyastuti T, Karsono B (2023) Digital leadership for agile organization and organizational sustainability. East Asian J Multidiscipl Res 2(5):2165–2176
52. Temelkova M (2018) Skills for digital leadership-prerequisite for developing high-tech economy. Int J Adv Res Manag Soc Sci 7(12):50–74
53. Triplett WJ (2022) Addressing human factors in cybersecurity leadership. J Cybersec Privacy 2(3):573–586
54. Valenzuela D, Shrivastava P (2002) Interview as a method for qualitative research. In: Southern cross University and the Southern cross institute of action research (SCIAR)
55. Vasanthakumari S (2019) Soft skills and its application in work place. World J Adv Res Rev 3(2):066–072
56. Vercammen A, Burgman M (2019) Untapped potential of collective intelligence in conservation and environmental decision making. Conser Biol 33(6):1247–1255
57. Wasono LW, Furinto A (2018) The effect of digital leadership and innovation management for incumbent telecommunication company in the digital disruptive era. Int J Eng Technol 7(2.29):125–130
58. Weiner J, Tanniru M, Khuntia J, Bobryk D, Naik M, LePage K (2016) Digital leadership in action in a hospital through a real time dashboard system implementation and experience. J Hosp Admin 5(4):34
59. Yang K, Sunindijo RY, Wang CC (2022) Identifying leadership competencies for construction 4.0. Buildings 12(9):1434
60. Yücebalkan B, Eryılmaz B, Özlü K, Keskin Y, Yücetürk C (2018) Digital leadership in the context of digitalization and digital transformations. Curr Acad Stud Soc Sci 1:489–505
61. Zamani SH, Rahman R, Fauzi M, Yusof L (2021) Effect of COVID-19 on building construction projects: impact and response mechanisms. In: Paper presented at the IOP conference series: earth and environmental science
62. Zeike S, Bradbury K, Lindert L, Pfaff H (2019) Digital leadership skills and associations with psychological well-being. Int J Environ Res Public Health 16(14):2628
63. Zulu SL, Khosrowshahi F (2021) A taxonomy of digital leadership in the construction industry. Constr Manag Econ 39(7):565–578
64. Zulu S (2022) Barriers to effective digital leadership enactment in the construction industry. In: Paper presented at the proceedings of the CIB international conference on smart built environment (ICSBE)
65. Zulu SL, Saad AM, Ajayi SO, Dulaimi M, Unuigbe M (2023) Digital leadership enactment in the construction industry: barriers undermining effective transformation. Eng Constr Architect Manag
66. Zupancic T, Verbeke J, Herneoja A, Achten H (2017) Competences for digital leadership in architecture. In: Fioravanti A, Cursi S, Elahmar S, Gargaro S, Loffreda G, Novembri G, Trento A (eds) Paper presented at the ShoCK!-sharing computational knowledge!-proceedings of the 35th eCAADe conference
67. Şişu JA (2023) Digital leadership competencies: a systematic literature review. Rev Manag Comp Int 24(1):69–77

# Theme: Sustainability

# Assessment of Energy Consumption in Building Construction Phase: A Case of Sri Lanka

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## 1 Introduction

Energy conservation has become a significant concern in the construction industry for achieving sustainable development [29]. Approximately 9% of the total energy consumption is accounted for building construction [31]. The construction industry has many environmental consequences, including the use of large amounts of energy during material processing, construction processes, and in the use of constructed structures as well as some construction operations [17]. Further, $CO_2$ emissions were predicted to be high in processes that required high-energy consumption due to the use of construction and lifting equipment from the on-site construction phase [24].

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In on-site construction processes, the major forms of direct energy use include diesel, electricity, petrol, and gas [27]. Enshassi et al. [9] reviewed that energy required in the construction process can be divided into two main categories such as fossil fuel and electricity. Diesel fuel and electricity are responsible for the greatest total $CO_2$ emissions among those four energy sources [25]. Most of the fuel used in transport and the equipment during the construction stage is in the form of diesel and petrol for the transportation of construction staff [9]. Electricity is one of the most widely used forms of energy [27]. Further, the authors stated that almost all the power tools or equipment used on-site is run on electricity. Electricity is used in electrical appliances such as lighting appliances used in construction site areas and workplaces for administration, production, storage, maintenance, and heating appliances used for heaters and boilers [18]. Sharrard et al. [25] indicate that in the construction industry, diesel and gasoline fuel are responsible for 62–75% of total energy consumption for the overall construction sector and its sub-sectors, while 10 and 25% of the total energy consumed for electricity.

Arnold [2] mentioned that energy cost affects the cost of construction. Similarly, [25] state that the cost incurred for overall spending on power or fuels represents about 2.5% of total construction industry expenditures. Further, [27] pointed out that efficient utilization and conservation of energy on-site can lead to 10–20% cost savings on energy usage. It would be beneficial for quantity surveyors to concentrate on the most energy-intensive operations to reduce a project's energy consumption. Further, the knowledge regarding the activities that consume the highest energy is a vital step in determining how energy is utilized for the construction processes [27]. Peters and Manley [20] estimated the diesel consumption for specific activities in the housing, retail, mixed-use, and energy project, while [28] predicted the on-site fuel consumption of earthworks in the residential building project. However, there is no specific research which was carried out on the electricity, diesel, and petrol consumption of key construction activities where fuels and electricity represent a significant portion of total construction industry expenditures. Therefore, this research aimed to assess energy consumption during the construction phase of a building and establish the potential contribution made to savings in building construction. To achieve the above-mentioned research aim, the following research objectives were established:

1. Assess the level of energy consumption of key construction activities involved in a building construction.
2. Propose alternative methods for optimizing energy consumption at the construction sites.

There are five sections presented in this paper. Section 1 is the introduction which elaborates background, problem statement, research aim, and objectives. The current literature regarding the energy consumption of building construction is presented in Sect. 2. Section 3 presents the research methodology. Then, Sect. 4 analyzes the collected data on two main aspects: energy consumption and energy-saving measures. Section 5 concludes the study with its limitations and future research directions.

# 2 Literature Review

## *2.1 Energy for On-Site Construction*

On-site construction refers to the final installation or erection of the building at the construction site [8]. The authors further stated that on-site construction can be divided into three categories: on-site activities, off-site construction activities, and extended supply chain. Further, on-site construction energy is considered a part of embodied energy [21]. Construction portion is to be about 7–10% of total embodied energy [6]. Further, this construction component is often ignored as this consumes small energy compared with the embodied energy of the building materials due to the lack of information available [21].

Construction projects require different types of equipment and machinery [16]. Further, various construction equipments are required to complete each activity in the construction process [4]. The type of equipment used in the construction phase varies depending on the characteristics of the construction method or construction site such as soil conditions' change [14]. Further, [16] pointed out that traditional simple machines such as forklifts, backhoes, hauling, and hoisting equipment are used in the construction. On the other hand, heavy construction equipment is also used in many stages of construction [22]. Table 1 represents different types of plants, tools, and equipment that are commonly used in the construction industry and the type of energy source used for each tool, and the purpose of the equipment.

**Table 1** Equipment according to energy type use and its purpose

| Construction activity | Plant, tool, equipment | Energy used |
|---|---|---|
| Grooving, molding other joinery | Placers rebates and routers | Electricity |
| Cutting, grinding | Saws | Electricity, petrol |
| Hoisting | Elevators | Petrol or diesel |
| Hoisting | Cranes | Electricity |
| Keep surfaces free from water | Pumps | Electric motor, petrol, or diesel engine |
| Vibrating, concrete, consolidation of concrete | Poker vibrator, tempers | Electricity, petrol |
| Transporting soil, concrete, or other light materials | Conveyors | Electricity |
| Hammering | Hammers | Electricity |
| Boring | Mechanical auger | Diesel |
| Excavation | Trenching machine, grader, bulldozer, and angle dozer | Diesel |

*Source* Talukhaba et al. [27]

The construction phase of a building involves numerous activities, such as the construction of temporary structures, transportation and installation of building materials and components, and site work [5]. Every activity required by a construction contract consumes a significant amount of energy [23]. Similarly, [10] mentioned that construction activities are assumed to consume small but significant energy on the construction site. The authors further stated that this accounts for 15–35% of the entire embodied energy. Transportation, hoisting, and concreting are the most energy-intensive construction activities [27].

## 2.2 Impact of Site Energy on the Total Cost

Arnold [2] studied several building projects and mentioned that it is difficult to quantify or measure energy costs because these costs are embedded in the materials, equipment, or overhead costs. Further, the author stated that that energy costs have an impact on construction costs and that they are dependent on the use of fossil fuels in a volatile market, where the price of gas and diesel directly correlates with construction costs. Efficient utilization and conservation of energy on-site can lead to 10–20% cost savings on energy usage [27]. According to [2], when considering contractor's resources procurement strategies, an increase in fuel costs may also play a vital role and found that energy costs during construction vary and can be a significant part of the construction operation costs. Compared to total construction industry expenditures, overall spending on power or fuels represents about 2.5% of given costs, specifically, power or fuel spending is approximately 4% of heavy construction, 3.7% of special trade contracting, and 1.2% of building construction costs [25].

## 2.3 Optimizing Energy Consumption

There will be an energy crisis or depletion of energy within the next 40–60 years [1]. Optimizing the consumption of energy has become one of the priorities all around the world due to the scarcity of resources and its impact on the environment [13]. Further, the increasing greenhouse gas emissions and declining fossil fuel reserves have highlighted the need for a sustainable energy transition [15]. Therefore, [3] pointed out that renewable energy sources have the potential to provide a solution for that. Further, implementation of the use of renewable energies will be crucial because of the harmful effects of fossil fuel energy [11].

In addition, efficient site management practices, which include efficient site layout, efficient use of the equipment for which it has been designed, regular maintenance according to the manufacturer's instructions, and the training of staff to be conscious of energy conservation are major energy-saving measures on construction site [27]. Further, specifying fuel-efficient plants, accommodation, and improving on-site logistics and coordination of activities would provide energy and cost reduction benefits for the contractor [7]. Moreover, reducing the usage of the crane, managing nighttime electricity, reducing machine idle times, and switching off office equipment also provide energy-saving measures during construction [12]. Further, Yuksek and Karadayi [30] stated that the building phase is possible by using energy-efficient equipment to consume less energy.

Lean methods that focus on waste disposal are suitable tools for reducing energy consumption and emissions in the construction process [19]. Adopting total productive maintenance is a lean technique based on the improvement of the overall equipment effectiveness of plant equipment, which considerably reduces the fuel consumption of the construction equipment [26]. Further, the authors pointed out that the lean technique is used for generating an adequate environment between operators and equipment, meanwhile, it determines the causes for accelerated worsening and production losses. However, the authors state that electricity consumption has moderately increased due to the implementation of the lean technique.

## 3 Research Methodology

The research was conducted using a quantitative approach where the required data were collected based on the two selected projects with time permits. Justifications for the project selection are described in the following paragraphs.

Initially, the document review [i.e., Bills of Quantities and Method Statements (a document comprised clear methodology of the construction works carried out from the commencement to project completion)] was carried out, and then semi-structured interviews were conducted with the project managers for further clarification. This choice was made because project managers possess the most comprehensive information on projects compared to other professionals involved. Further, conducting one interview per project was deemed sufficient to address project-specific inquiries.

The whole energy consumption related to the construction projects can be obtained from the completed construction project. However, ongoing projects were selected due to the difficulties in obtaining records related to petrol, diesel, and electricity. Further, records related to petrol and diesel can be obtained from the storekeeper on the site and records related to electricity can be obtained from the site office. On the other hand, ongoing projects were selected to observe the progress of the site, and equipment used on the site, to clarify for what purpose the equipment is used in the site, to identify the operating hours of equipment, and to identify the site office facilities.

Further, no concern is considered when selecting a particular context such as residential, commercial, office, hospital, or education. The major reason for that is context did not affect the construction stage but it is a major influence in the operational stage. Construction activities that have taken place on the site are almost similar for all these contexts. Therefore, the context of the building is not considered when selecting the project for this case study.

Accordingly, two ongoing projects were selected for the case study analysis to assess energy consumption during the construction phase of a building and establish the potential contribution made to savings in building construction, and the overview of the selected construction projects is listed in Table 2.

Collected data were analyzed using simple descriptive statistics to assess the total energy consumption of each project reference to each source and the following section will discuss the data analysis with findings.

**Table 2** Profile of the case study buildings

| Details of the project | P1 | P2 |
|---|---|---|
| Gross floor area (GFA) | 18,000 $m^2$ | 6875 $m^2$ |
| No. of storeys | Three (03) | Three (03) |
| Location | Jaffna-town (Sri Lanka) | Jaffna-Point Pedro (Sri Lanka) |
| Date of commencement | 10.10.2019 | 20.11.2019 |
| Intended date of completion | 30.07.2022 | 20.03.2022 |
| Construction period | 34 months | 29 months |
| Function | Shopping complex | Hospital |
| Project | Ongoing | Ongoing |
| Actual progress | 50% | 75% |
| Scope of work at site | Site preparation<br>Excavation<br>Concrete<br>RCC raft with strip foundation<br>Brick walls<br>Timber doors and windows<br>Aluminum partitions<br>Steel roofs<br>Floor tiling<br>Handrail works<br>Ceiling work<br>Painting<br>Mechanical ventilation and air conditioning system<br>Vertical transportation system<br>Fire protection and detection system<br>Electrical systems with lightning protection systems<br>Extra low voltage system<br>internal and external plumbing<br>landscaping and road works | Demolition<br>Excavation<br>Concrete<br>Masonry work<br>Al doors and windows<br>Metalwork<br>Steel roofs<br>Floor tiling<br>Ceiling work<br>Painting<br>Furniture<br>Fire protection and detection system<br>Electrical systems with lighting protection system<br>Passenger lift<br>Extra low voltage system (ELV)<br>internal and external plumbing<br>landscaping and road works |

# 4 Analysis and Findings

## 4.1 Energy Consumption

Electricity bills were not maintained at the site, but payments made were recorded in the base office. The company is used to make payments in a timely way; thus, there were no accruals and prepayments. Therefore, the amount of electricity bills and payments was considered equal. The number of units consumed was calculated based on the payments made. Data were collected for the period covering November 2019–October 2021. First, the total number of days was calculated from the description available in the payment records in the base office. According to the norms issued by the Ceylon Electricity Board (CEB) regarding the units calculating, the total number of days was multiplied by ten. And, if that value is < 270, then take the value 18.30 else take the value 22.85 to proceed into the next step. Then, an amount of Rs. 240 is deducted from the electricity bill for that month as it is a fixed price. Then that amount has to be by 22.85 or by 18.3 as per the condition explained above.

For example, a description stated that the electricity bill for the period from 11.01.2020 to 13.02.2020 is Rs. 82,637.10 in P1.

- Total number of days = 21 days + 13 days = 34 days.
- 34*10 = 340.

  This value will be denoted as $X$.

- Apply condition, if $X < 270$ then take 18.30, else take the value 22.85.
- Number of units = (82,637.10 − 240.00)/22.85 = 3606 units.

Then, the number of units of electricity consumed was taken from electricity bills and converted to kJ by multiplying it by 3600. Accordingly, the consumed electricity amount is equivalent to 12, 981, 600 kJ.

Further, the quantity of petrol and diesel consumption was taken from fuel records and converted to kJ by multiplying it by 34,200. Figure 1 illustrates the consumption of electricity, petrol, and diesel consumed in both construction projects during the considered period.

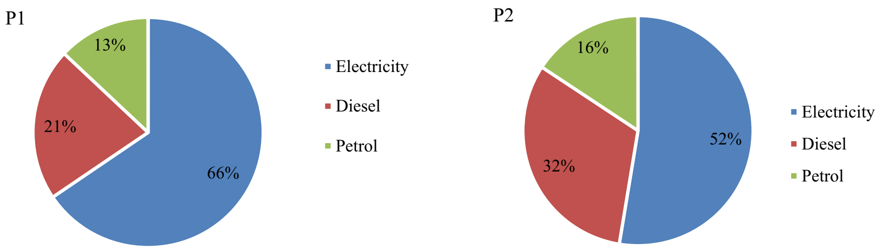


**Fig. 1** Distribution of total energy consumption

Electricity consumption in both construction projects shows the highest contribution than petrol and diesel consumption as the majority of the equipment that is used in construction activities and site office are operated using electricity. Energy consumed by petrol is lower than other energy sources in both cases.

Appendix 1 elaborates on the various sources of energy used in the main construction activities of both projects. It was collected by interviewing the project manager and from the method statement. After the summarized data collection of energy details, electricity was distributed for both site office purposes and the operation of equipment by considering electricity usage approximately in the site office. The construction program is also considered to refer what are the activities that are executed on a particular month to distribute energy consumption in between construction activities. The energy was directly allocated to a particular activity in some months, as it is the only activity that has been undertaken in those months. In some months two or three activities have been performed. However, as only one activity is equipment-intensive, the energy consumption is directly allocated to that activity. In other cases, energy consumption is distributed among all the construction activities by considering the operating hours of equipment.

For example, this calculation is part of the whole calculation of diesel consumption in three months. Table 3 illustrates the distribution of diesel consumed during some construction activities (i.e., backfilling and concreting) for P1. Similarly, the same calculation was followed for other activities as well as P2.

The same calculation was followed to get the energy consumption of petrol and electricity for both projects, and the final summary was taken out for further analysis.

**Table 3** Distribution of diesel consumption

| | Diesel consumption (kJ) | Backfilling | | Concreting | | Remarks |
|---|---|---|---|---|---|---|
| | | % | Diesel | % | Diesel | |
| July | 7,182,000 | (9.3/31.3) * 100 = 60% | 4,309,200 | (22/31.3) * 100 = 30% | 2,154,600 | To drive percentage (operating hours/ total operating hours of total equipment) |
| Aug | 3,762,000 | | | 100% | 3,762,000 | Only concreting activity is executed |
| Sep | 6,215,508 | | | 100% | 6,215,508 | Only concreting activity is executed |

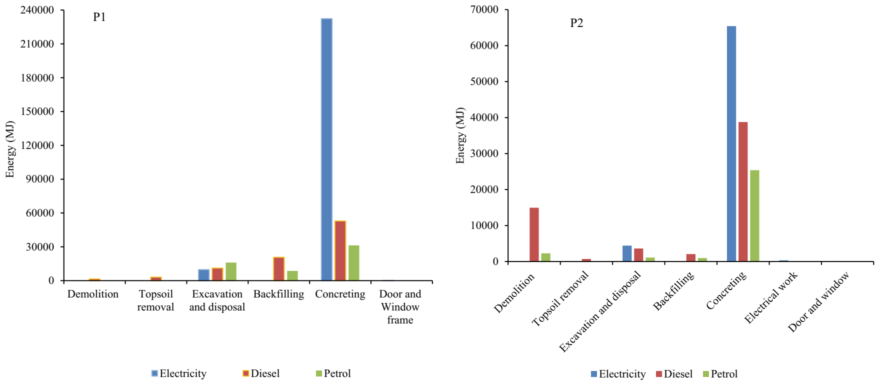


**Fig. 2** Summary of total energy consumption

Accordingly, Fig. 2 demonstrates the electricity, petrol, and diesel consumed for each main construction activity identified in Appendix 1 such as demolition, topsoil removal, excavation, backfilling, concreting, and door and window frame fixing for each project.

Figure 2 shows clearly that concrete work consumed more energy than other construction activities. Further, electricity consumed for concreting activity is significantly higher than the petrol and diesel consumed for concreting activity. Diesel consumed for the backfilling process is higher than for the excavation in P1. However, this situation is the opposite in P2. This is due to the site conditions. However, petrol consumed for backfilling is less than for excavation and disposal activity. Demolition and topsoil removal consumed less diesel compared to other activities.

To calculate energy consumption per unit, quantities involved for each construction activity were taken from Bills of Quantities (BoQ). Table 4 presents the comparison of energy consumed per unit quantity for Projects P1 and P2.

Energy consumed for demolition activity of P2 is significantly higher than P1 due to the following reasons. In the P2 project, a tree cutter that runs on petrol was used for the removal of trees which is not present in Project P1. Further, the P2 project has utilized energy sources such as petrol and diesel, whereas Project P1 has utilized only diesel. Moreover, the P2 project involves the demolition of the existing

**Table 4** Comparison of energy consumption by activities

| Main construction activities | P1 | P2 |
|---|---|---|
| Demolition | 1,529,458.20 kJ/item | 17,246,324.54 kJ/item |
| Topsoil removal | 410.81 kJ/m$^2$ | 399.01 kJ/m$^2$ |
| Excavation | 3,132.02 kJ/m$^3$ | 3,037.62 kJ/m$^3$ |
| Backfilling | 2,174.42 kJ/m$^3$ | 2,173.67 kJ/m$^3$ |
| Concreting | 40,106.31 kJ/m$^3$ | 44,368.53 kJ/m$^3$ |

structure, whereas the P2 project involves the demolition of plaque. Energy consumed for excavation and topsoil removal of P1 is slightly higher than P2 because of two reasons. First, the P1 project deals with the excavation of strip, raft, and footings, whereas the P2 project deals with the excavation in footing areas. Secondly, the P1 project used an excavator and backhoe loader, whereas the P2 project only used a backhoe loader for excavation. Energy consumed for backfilling activity in both projects P1 and P2 is almost the same. Turning to concreting activity, the P2 project consumes more energy compared to P1 because the P2 project mainly used a concrete mixture that runs with diesel for the preparation of concrete, whereas the P1 project mainly used ready-mix concrete.

## *4.2 Energy-Saving Measures*

The energy-saving measures obtained from the literature findings confirmed to what extent those energy-saving measures are used in each project. The project managers' views were collected on 1–5 Likert scale, where 1—represents very low, 2—low, 3—neutral, 4—high, and 5—very high (Fig. 3).

Figure 2 illustrates the extent of energy-saving measures adopted in the selected projects. Projects P1 and P2 have efficient site layouts to carry out the works and they are concerned about reducing machine idle time as most of the equipment is hired for execution of work. Furthermore, consideration of these two energy-saving measures should be given to save energy. However, both projects have not given

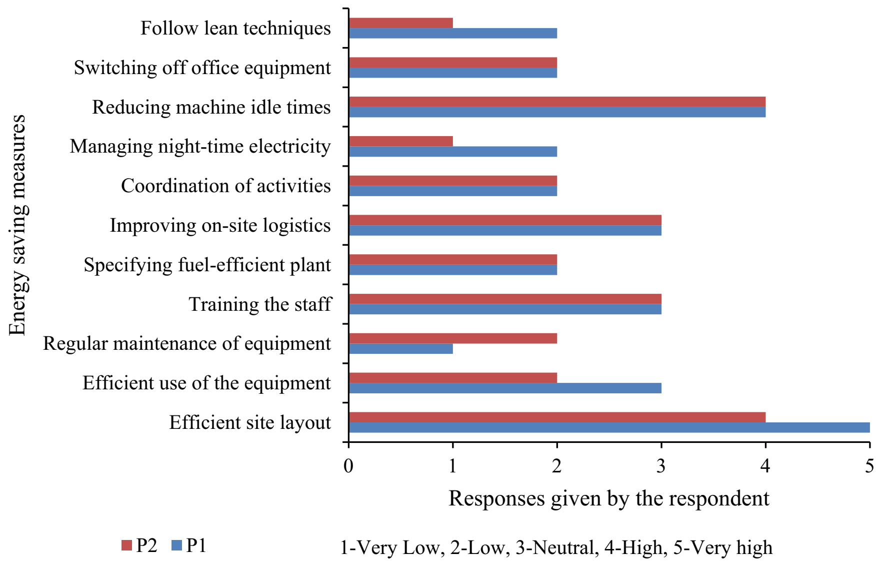


**Fig. 3** Level of use of energy-saving measures

much consideration to energy-saving measures such as coordination of activities, regular maintenance of the equipment, efficient use of the equipment, switching off office equipment, and training of staff. Proper consideration of the coordination of activities that use common equipment can save energy consumption. Further, training the operating labor to a certain extent can save energy by finishing the work quickly. Moreover, office equipment such as HVAC, fans, and lights should be switched off when they are left on unnecessarily. Consideration in managing nighttime electricity can save energy as concreting works are executed mostly at nighttime. Further, both Projects P1 and P2 do not follow the lean techniques. Therefore, adopting lean techniques that focus on the reduction of fuel consumption can improve the overall efficiency of the equipment. Therefore, energy can be optimized by focusing on and improving the above-mentioned energy-saving measures.

## 5 Conclusions

Demolition, topsoil removal, excavation, backfilling, and concreting activities are considered the key construction activities in this study. Based on the total energy consumption, concreting activity consumes a high level of energy in these projects. However, as the project involves the demolition of buildings and trees, it turned out to be an energy-intensive activity. Based on the unit quantity analysis, the energy consumed for topsoil removal, excavation, backfilling, and concreting activities was 405 $kJ/m^2$, 3100, 2174, and 42,000 $kJ/m^3$, respectively. Therefore, concreting activity can be considered as a highly energy-consuming activity over other activities even though ready mixed concrete is used in the projects.

Energy-saving measures such as efficient site management practices, specifying fuel-efficient plants, accommodation and improving on-site logistics and coordination of activities, and using energy-efficient equipment are identified as the alternative methods for optimizing energy. Improving those energy-saving measures at the optimum level can save energy. Further, adopting a lean technique that focuses on the reduction of fuel consumption can improve the efficiency of the equipment.

The findings of this study are expected to be valuable guidance to all construction industry practitioners in identifying the energy consumption pattern of the key construction trades. Thereby can suggest the appropriate solutions for the minimization of excessive energy consumption. This will result in the reduction of project construction costs as well as greenhouse gas emissions.

Though there are many merits in this study, there are certain limitations. For example, this research study has utilized only two ongoing construction projects for the case study within the Jaffna district due to time constraints and entry restrictions in the organizations. Further, this study was limited to assessing the energy consumption of key construction activities. Therefore, it is recommended similar study which can be carried out for a large number of projects to generalize the findings.

## Appendix 1

Comparison of energy consumed for activity—Project P1.

| Main construction activity | Sub activity | Equipment | Energy type |
|---|---|---|---|
| Demolition | Clearing site | Tractor with trailer | Diesel |
| | Demolition of plaque | Backhoe loader | Diesel |
| Topsoil removal | Topsoil removal | Excavator PC 120/240 | Diesel |
| Excavation and disposal | Excavation | Excavator PC 120/240 | Diesel |
| | | Backhoe loader | Diesel |
| | Disposal | Tractor with trailer | Diesel |
| | | Tipper (3 cubes) | Diesel |
| | | Tipper (1 cube) | Diesel |
| | Rock excavation | Driller | Electricity |
| | | Breaker | Electricity |
| | Dewatering | Submersible pump | Electricity |
| Backfilling | Filling | Tractor with trailer | Diesel |
| | | Tipper (3 cubes) | Diesel |
| | | Tipper (1 cube) | Diesel |
| | Compaction | Vibrating plate rammer | Petrol |
| | | Baby roller (1 ton) | Diesel |
| | | Wacker | Petrol |
| | | Vibrating roller (4 Ton) | Diesel |
| | | Vibrating roller (10 Ton) | Diesel |
| Concreting | Reinforcement cutting | Bar cutter | Electricity |
| | Reinforcement bending | Bar bending machine | Electricity |
| | Formwork | Power saw | Electricity |
| | | Driller | Electricity |
| | Cleaning before concreting | Air compressor | Diesel |
| | | Blower | Electricity |
| | Soil compacting before floor concrete | Wacker | Petrol |
| | Mixing concreting | Concrete mixer (2 Bags) | Diesel |
| | | Concrete mixer (1 Bags) | Diesel |
| | Vibrating concreting | Poker vibrator | Petrol |
| | Cutting extra concreting | Grinder | Electricity |
| | Curing | Water jet | Electricity |
| Rubble work | Manual works tools are used | | |

(continued)

(continued)

| Main construction activity | Sub activity | Equipment | Energy type |
|---|---|---|---|
| Brickwork | Manual works tools are used | | |
| Plastering | Manual work- tools are used | | |
| Timber door and window | | Driller | Electricity |
| Common purpose | | Generator | Diesel |
| | | Water bowser | Petrol |

Comparison of energy consumed for activity—Project P2.

| Main construction activity | Sub activity | Equipment | Energy Type |
|---|---|---|---|
| Demolition | Clearing site | Tractor with trailer | Diesel |
| | Removal of trees | Cutter | Petrol |
| | Demolition of structure | Backhoe loader | Diesel |
| Topsoil removal | Topsoil removal | Backhoe loader | Diesel |
| | | Backhoe loader | Diesel |
| | Disposal | Tractor with trailer | Diesel |
| | | Tipper (1 cube) | Diesel |
| | Rock excavation | Driller | Electricity |
| | | Breaker | Electricity |
| | Dewatering | Submersible pump | Electricity |
| Backfilling | Filling | Tractor with trailer | Diesel |
| | | Tipper (1 cube) | Diesel |
| | Compaction | Rammer | Petrol |
| | | Baby roller (1 ton) | Diesel |
| | | Wacker | Petrol |
| | | Vibrating roller (4 Ton) | Diesel |
| Concreting | Reinforcement cutting | Bar cutter | Electricity |
| | Reinforcement bending | Bar bending machine | Electricity |
| | Formwork | Power saw | Electricity |
| | | Driller | Electricity |
| | Cleaning before concreting | Blower | Electricity |
| | Soil compacting before floor concrete | Rammer | Petrol |
| | Mixing concreting | Concrete mixer (2 Bags) | Diesel |
| | | Concrete mixer (1 Bags) | Diesel |
| | Vibrating concreting | Poker vibrator | Petrol |

(continued)

(continued)

| Main construction activity | Sub activity | Equipment | Energy Type |
|---|---|---|---|
| | Cutting extra concreting | Grinder | Electricity |
| | Curing | Manual—horse pipe | |
| Block work | Manual works—tools are used | | |
| Brickwork | Manual works—tools are used | | |
| Plastering | Manual works—tools are used | | |
| Plumbing | Manual works—tools are used | | |
| HVAC work | Manual works—tools are used | | |
| Electrical work | | Driller | Electricity |
| | | Grinder | Electricity |
| Al door and window | | Driller | Electricity |
| | | Grinder | Electricity |
| Tile finishes | Manual work—tools are used | | |

## References


1. Abas N, Kalair A, Khan N (2015) Review of fossil fuels and future energy technologies. Futures 69:31–49. https://doi.org/10.1016/j.futures.2015.03.003
2. Arnold AG (2008) Development of a method for recording energy costs and uses during the construction process. Texas A&M University
3. Asif M, Muneer T (2007) Energy supply, its demand, and security issues for developed and emerging economies. Renew Sustain Energy Rev 11:1388–1413. https://doi.org/10.1016/j.rser.2005.12.004
4. Brocklesby MW, Davison JB (2000) The environmental impacts of concrete design, procurement, and on-site use in structures. Constr Build Mater 14(4):179–188. https://doi.org/10.1016/S0950-0618(00)00010-6
5. Chini AR, Shrivastava S (2014) A framework to explore energy-saving measures during the construction phase. Springer, New York
6. Cole RJ, Rousseau D (1992) Environmental auditing for building construction: energy and air pollution indices for building materials. Build Environ 27(1):23–30. https://doi.org/10.1016/0360-1323(96)00017-0
7. Davies PJ, Emmitt S, Firth SK (2015) Delivering improved initial embodied energy efficiency during construction. Sustain Cit Soc 14:267–279. https://doi.org/10.1080/09613218.2013.769745
8. Devi L, Palaniappan S (2014) A case study on life cycle energy use of residential building in Southern India. Energy Build 80:247–259. https://doi.org/10.1016/j.jclepro.2017.06.208

9. Enshassi A, Ayash A, Mohamed S (2018) Key barriers to the implementation of energy management strategies. Int J Build Pathol Adapt 36(1):15–40. https://doi.org/10.1108/IJBPA-09-2017-0043
10. Esmaeilifar R, Samari M, Mirzaei NF, MohdShafiei MW (2015) How is electricity consumption on construction sites in Malaysia related to. Adv Environ Biol 9(5):160–163
11. Garcia JO, Gago EJ, Bayo JA, Montes GM (2007) The use of solar energy in the buildings construction sector in Spain. Renew Sustain Energy Rev 11:2166–2178. https://doi.org/10.3390/en14133889
12. Gottsche J, Kelly M, Taggart M (2016) Assessing the impact of energy management initiatives on energy usage during the construction phase of an educational building project in Ireland. Constr Manag Econ 34(1):46–60. https://doi.org/10.1080/01446193.2016.1162317
13. Heravi G, Nafisi T, Mousavi R (2016) Evaluation of energy consumption during production and construction of concrete and steel frames of residential buildings. Energy Build 130:244–252. https://doi.org/10.1016/j.enbuild.2016.08.067
14. Hong T, Ji C, Jang M, Park H (2014) Assessment model for energy consumption and greenhouse gas emissions during building construction. J Manag Eng 30(2):226–235
15. Liu X, Li N, Liu F, Mu H, Li L, Liu X (2021) Optimal design on fossil-to-renewable energy transition of regional integrated energy systems under $CO_2$ emission abatement control: a case study in Dalian, China. Energies 14:1–25. https://doi.org/10.3390/en14102879
16. Mahbub R (2012) Readiness of a developing nation in implementing automation and robotics technologies in construction: a case study of Malaysia. J Civil Eng Architect 6(7):858–866
17. Muhwezi L, Kiberu F, Kyakula M, Batambuze AO (2012) An assessment of the impact of construction activities on the environment in uganda: a case study of iganga municipality. J Constr Eng Project Manag 2(4):20–24
18. Novy M, Novakova J (2021) Electricity consumption in construction projects in the Czech Republic. IOP Conf Ser Earth Environ Sci 656:12006. https://doi.org/10.1088/1755-1315/656/1/012006
19. Nowotarski P, Pasławski J, Dallasega P (2021) Multi-criteria assessment of lean management tools selection in construction. Arch Civil Eng 67(1):711–726
20. Peters V, Manley D (2012) An examination of fuel consumption trends in construction projects. Energy Policy 50:496–506. https://doi.org/10.1016/j.enpol.2012.07.048
21. Pullen SF (2015) Energy is used in the construction and operation of houses. Architect Sci Rev 43:87–94. https://doi.org/10.1080/00038628.2000.9697439
22. Ries R, Velayutham S, Chang Y (2010) Life cycle assessment modeling of heavy construction activities. Constr Res Congress 62:1467–1475. https://doi.org/10.1061/41109(373)147
23. Rowings JE, Asce AM, Walker RO (1984) Construction energy use. J Constr Eng Manag 110(4):1445
24. Seo M-S, Kim T, Hong G, Kim H (2016) On-site measurements of $CO_2$ emissions during the construction phase of a building complex. Energies 9:1–13. https://doi.org/10.3390/en9080599
25. Sharrard AL, Matthews H, Roth M (2007) Environmental implications of construction site energy use and electricity generation. J Constr Eng Manag 133(11):846–854
26. Tabrizikahou A, Nowotarski P (2021) Mitigating the energy consumption and the carbon emission in the building structures by optimization of the construction processes. Energies 14:3287. https://doi.org/10.3390/en14113287
27. Talukhaba AA, Phungula B, Manchidi MB (2013) Managing the efficient use of energy on construction sites and cost reduction. SB13, p 252
28. Trani M, Bossi B, Gangolells M, Casals M (2016) Predicting fuel energy consumption during earthworks. J Clean Product 112:3798–3809. https://doi.org/10.1016/j.jclepro.2015.08.027
29. Xue X et al (2015) Measuring energy consumption efficiency of the construction industry: the case of China. J Clean Product 107:509–515. https://doi.org/10.1016/j.jclepro.2014.04.082
30. Yüksek I, Karadayi TT (2017) Energy-efficient building design in the context of building life cycle. Energy Effic Build 54:93–123. https://doi.org/10.5772/66670
31. Zhang Y, Yan D, Hu S, Guo S (2019) Modelling of energy consumption and carbon emission from the building. Energy Policy 134:949. https://doi.org/10.1016/j.enpol.2019.110949

# Embracing Circular Economy in Australian Universities: Learning from Global Perspectives Using State-of-the-Art Review

**Olabode Emmanuel Ogunmakinde**

## 1 Background of the Study: Imperatives of Circular Economy in Universities

Sustainable practices and circular economy (CE) principles have increasingly become essential to combating pressing environmental challenges. Ramakrishna et al. [34] provide an insightful look into the emergent symbiosis between Industry 4.0 and CE, emphasising the transformative role of academic institutions in propelling this shift. As breeding grounds for innovation and intellectual capital, universities are strategically positioned to pioneer these developments. Nunes et al. [24] rightly point out that while universities' overt curriculum contributes significantly to developing CE literate graduates, there is also a hidden curriculum where universities demonstrate their commitment to CE principles. Such commitment is demonstrated in how they manage their campuses, deliver services, and interact with their local communities.

This paper seeks to explore this hidden curriculum and, more broadly, the role of universities in championing the adoption of CE principles. Notably, integrating CE strategies into campus management has proven to be a viable approach towards sustainable campuses. For example, Mendoza et al. [20] developed a methodological framework for implementing CE thinking in higher education institutions, which aims to guide universities in developing strategies for sustainable campus management. Fortes et al. [12], Kamarudin et al. [18] and Ramakrishna et al. [33] also present an innovative approach towards smart campus environments through a

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multi-disciplinary mix of architecture, greening, and ICT which are related to CE implementation.

Taking a cue from these studies, this investigation seeks to delve deeper into the application of CE principles in Australian universities by drawing insights from regional. This study aims to understand how Australian universities can adopt these strategies to foster sustainability while delivering excellent academic services.

## 2 Methods, Materials, and Data Sources

In investigating integrating CE principles and strategies from universities in other countries for Australian universities, a State-of-the-Art Review (SOTA) was particularly efficacious. This approach facilitates a comprehensive synthesis and critical evaluation of the most current and relevant studies, enabling an overview of current knowledge, significant findings, and research gaps in this field. Compared to a traditional literature review, the SOTA review is a more intensive process that includes cutting-edge research, ensuring the inclusion of the most recent and relevant findings [30, 39]. However, this comprehensive approach does not preclude the necessity for a judicious selection of sources. It is essential to apply discerning judgement to identify and incorporate studies that exhibit methodological rigour, high impact, and relevance to the topic [16]. Furthermore, the SOTA review's distinctive focus on the latest research helps to delineate the trajectory of the evolving discourse surrounding CE in higher education institutions [2]. Moreover, compared to systematic reviews, the SOTA review is less restrictive, allowing for the incorporation of diverse studies to gain a more comprehensive perspective. SOTA provides an opportunity to embrace the breadth of the academic landscape, creating an ideal foundation for identifying lessons from global perspectives and informing future CE strategies for Australian universities. In the SOTA search, using the keywords highlighted in the section below, the countries studied were based on relevant outputs and were not pre-determined before the study.

### *2.1 Data Sources*

The primary data sources for this State-of-the-Art Review (SOTA) were peer-reviewed academic articles, books, and reports from reputable organisations such as governmental agencies or non-governmental organisations working in sustainability and education. The keywords applied in the search were: "*Circular Economy*", "*Sustainability*", "*Higher Education Institutions*", "*Universities*", "*Australia*", "*Waste Management*", "*Resource Optimisation*", "*Circular Procurement*", "*Energy Efficiency*", "*Global Perspectives*", "*Best Practices*", "*Stakeholder Engagement*", "*Policy Frameworks*", "*Institutional Engagement*", and "*Circular economy in*

*Universities*". Databases and search engines such as Scopus, Google Scholar, Elsevier, University open-access portals, and government websites were explored to conduct the SOTA. The application of SOTA in this study will be geographical region and country specifics. This is to provide a global narrative of CE in universities across developed and developing nations for applications in Australian Universities. However, the first section of the SOTA sought to define CE principles and strategies from the generic perspective of universities. The outcome of the SOTA review delivered present CE gaps and transferrable knowledge for Australian University campuses.

## 3 State-of-the-Art (SOTA) Review and Analysis

### *3.1 The United Kingdom*

With the intensifying global focus on sustainability, circular economy (CE) strategies are progressively embedded in university operations. There has been a growing adoption of CE approaches on UK university campuses to augment the environmental sustainability of campus operations [20]. This has been enabled by implementing sustainable campus management frameworks encapsulating CE thinking. In addition, there is an emerging trend towards enhancing student skills through promoting new CE enterprises on campus [24]. This approach drives sustainability and presents sustainable commerce as a tangible business opportunity for students. With the evolution of digital transformation, the 'smart campus' concept is also gaining traction, synergising with CE strategies [1, 27]. Notably, the smart campus concept encompasses digital solutions to manage solid waste and further the circular economy [31]. This integration of digitalisation with CE thinking represents a promising avenue for the future of sustainable campus management.

### *3.2 Germany*

German universities progressively embrace circular economy (CE) strategies, underscored by practical and educational initiatives. Weber and Stuchtey [41] articulate the broader landscape of Germany's transition towards a CE. Within this context, universities are taking actionable steps, such as the sustainability innovation lab's project for 'Greening the University Canteen', connecting regional stakeholders and students to promote integrated regional development [40]. In academia, integrating CE concepts in curricula and research is gaining momentum [14]. Furthermore, Bugallo-Rodriguez and Vega-Marcote [5] report the importance of teacher training in CE to foster sustainable attitudes and behaviours in campus life.

### 3.3 The USA

American universities have demonstrated a palpable commitment to incorporating circular economy (CE) strategies within their operational and pedagogical systems. Gallo et al. [13] underscored that successful waste prevention and reduction initiative had been implemented, fostering a model that could inspire other universities and communities. The role of education is paramount, with universities serving not only as a hub for teaching CE concepts but also for training future educators in sustainability [5]. Such an approach empowers students to become change agents, instigating sustainable practices within the campus environment [24]. Concurrently, Serrano-Bedia and Perez-Perez [37] assert that higher education institutions play a significant role in the global transition towards a circular economy, showcasing the influence of universities as critical stakeholders in implementing and promoting CE initiatives.

### 3.4 South Africa

South African universities steadily integrate circular economy (CE) strategies into their operations and pedagogies. A study at a rural tertiary institution highlighted the importance of Knowledge, Attitude, and Perception (KAP) to successful solid waste management, reflecting a crucial step towards embracing CE practices [29]. The use of simulation and serious games has emerged as a potent tool for conveying CE and sustainable energy concepts [9], while the development of a dynamic capabilities' framework has enabled the implementation of 4IR-enabled CE practices in technology universities [38]. Moreover, South African universities are also transitioning into smart campuses [4, 27], which can serve as microcosms for smart city development, enabling a broader implementation of CE strategies.

### 3.5 China

Chinese universities are increasingly adopting circular economy (CE) strategies. Most CE research is affiliated with Chinese institutions [21]. The development of CE-related specialities has further underscored this trend [32]. Moreover, a broader implementation of CE initiatives on Chinese campuses has been noted by Serrano-Bedia and Perez-Perez [37]. Thus, Chinese institutions have a growing commitment towards sustainability and resource efficiency. Therefore, these universities not only form part of the CE intellectual community but also act as practical embodiments of its principles.

### 3.6 Brazil

The integration of circular economy strategies within Brazilian universities entails several key approaches. Firstly, developing specific academic programmes and curricula focusing on circular economy principles is paramount [19]. This not only instils the concept of sustainability within the educational structure but also encourages innovative thought processes that align with the goals of a circular economy. Universities are establishing practical initiatives on campus that emulate the principles of a circular economy. These include waste management strategies that emphasise reduction, reuse, and recycling and implementing energy-efficient practices [36]. These initiatives are tangible examples of the circular economy in action, providing students with practical experience and a clearer understanding of its principles.

Universities are forming partnerships with local businesses and communities, fostering a collaborative approach towards sustainable practices [8]. This extends the reach of the circular economy beyond the university campus and facilitates the integration of these practices within the broader community.

### 3.7 Overview of Strategic Principles of CE for Universities

CE has emerged as an innovative paradigm shift away from the traditional linear '*take-make-dispose*' model towards a system of optimised resource use, waste minimisation, and regeneration [6, 25, 27, 28]. Under the umbrella of sustainability, CE presents a viable route towards achieving Sustainable Development Goals (SDGs), particularly in Higher Education Institutions (HEIs) [7, 26]. Murray et al. [23] opined that CE, at its core, is about designing out waste, keeping products and materials in use, and regenerating natural systems. Through this principle, the idea of waste is reconfigured into a concept of resource, thereby transforming the conventional consumption model. HEIs play a crucial role in propagating CE principles by modelling them within their campuses and integrating them into curricula [34].

For instance, the University of Leuven offers a "*Science and Sustainability*" course to teach students CE principles [5]. Similarly, the University of Manchester has been exploring the potential for embedding CE practices within its operational strategies [20]. Learning from the Brazil-Colombia network of HEIs, [19] reported the effectiveness of implementing CE strategies on university campuses. However, it is worth noting that each institution will have its unique challenges and opportunities, and therefore, the applicability of CE strategies needs to be considered in context. Looking towards the future, CE can be considered a strategic tool for HEIs in their quest for sustainability. By inculcating these principles into the fabric of the institutions, universities can drive meaningful change within their premises and extend this influence on the wider community, fostering a resilient, sustainable future [3].

# 4 SOTA Review Findings

Table 1 presents an overview of how various universities across regions embrace the circular economy (CE) principles. This section discusses the key CE implementable strategies and principles for university campuses.

## 4.1 *Waste Prevention and Resource Optimisation Strategies*

Waste prevention and resource optimisation strategies refer to measures to reduce waste generation and maximise resource utilisation in a circular economy context.

**Table 1** SOTA review findings for university CE strategies in selected countries

| Key output | Region | Country | University CE strategies | References |
|---|---|---|---|---|
| Waste prevention and resource optimisation strategies | Africa | South Africa | Promoting sustainable practices on campus | [38] |
| | Europe | The UK | Implementing waste management systems | [9, 10] |
| | North America | The USA | Sustainable resource management | [11] |
| Circular infrastructure | Asia | China | Implementing sustainable management systems | [32] |
| | Europe | The UK | Implementing waste management systems | [9, 10] |
| Smarter campuses | Africa | South Africa | Integration of 4IR technology | [38] |
| | Asia | China | Promoting new circular economy enterprises on campus | [21] |
| | South America | Brazil | Implementing on-campus initiatives | [36] |
| | North America | The USA | Introducing circular economy practices in campus operations | [11] |
| Local partnerships | South America | Brazil | Fostering partnerships with local businesses and communities | [19] |
| CE teaching and development | Asia | China | Strengthening scholarly cooperation | [21] |
| | South America | Brazil | Developing circular economy-focused curricula | [19] |
| | Europe | The UK | Utilising simulation games for education, promoting research and collaboration | [9] |
| | North America | The USA | Encouraging student entrepreneurship in the circular economy | [11] |

These strategies are instrumental in supporting environmental sustainability and demonstrating commitment towards responsible resource use. Under the 'Waste Prevention and Resource Optimisation Strategies', South African universities are spearheading sustainability initiatives [38], while the UK and the USA are focusing on waste management and sustainable resource management, respectively [9–11]. In the UK, waste management systems are key to waste prevention and resource optimisation.

This could encompass waste audits to identify areas for improvement, implementing comprehensive recycling programmes, and raising awareness about waste minimisation among students and staff [9, 10]. Meanwhile, in the USA, the focus is on sustainable resource management. This could be reflected in procurement policies favouring environmentally friendly suppliers, using renewable energy sources for campus operations, and adopting water-saving measures like rainwater harvesting and efficient irrigation systems [11]. Waste prevention and resource optimisation strategies encapsulate a wide range of practices aimed at minimising waste and maximising resource efficiency, thereby playing a critical role in the transition towards a more circular and sustainable economy on university campuses.

### *4.2 Circular Infrastructure*

The 'Circular Infrastructure' category showcases China's initiatives in creating sustainable management systems [32], with the UK also contributing significantly to the waste management sector [9, 10]. Circular infrastructure refers to the physical and organisational structures, facilities, and services needed to operate a circular economy within the university environment. This includes waste management systems, sustainable resource usage, and integration of renewable energy sources.

In the context of Chinese university campuses, creating sustainable management systems represents a key part of their circular infrastructure [32]. These systems could involve, for instance, the implementation of advanced recycling and composting facilities, energy-efficient buildings, and water conservation systems. Additionally, they might encompass organisational structures that promote collaboration between departments, fostering a campus-wide commitment to sustainability. Circular infrastructure refers to physical facilities and organisational strategies that support implementing and operating a circular economy within a university campus.

### *4.3 Smarter Campuses*

Smarter campuses outline how technological advancements are integrated within South Africa and China campuses to promote new CE enterprises [21, 38]. The US and Brazil contribute equally to this sector through their on-campus initiatives and CE practices [11, 36]. The term 'Smarter Campuses' refers to a strategic approach that leverages the power of technology and innovative practices to transform university campuses into more sustainable, efficient, and digitally advanced spaces, in line with the circular economy (CE) principles. This approach often incorporates advancements in technology and digital systems, infrastructural development, and improved management systems to optimise resource use, waste reduction, and overall campus sustainability.

In the South African and Chinese contexts, smarter campuses involve the integration of Fourth Industrial Revolution (4IR) technologies such as artificial intelligence, big data, and the Internet of Things. These technologies aid in streamlining campus operations, enhancing resource efficiency, and promoting new CE enterprises [21, 38]. Awuzie et al. [4] and Omotayo et al. [27] agreed that smarter campus designs are multifaceted strategies encompassing many initiatives and practices to advance CE principles within the university setting. For effective implementation of CE on university campuses, the smart campus approach has been proven to be the prime approach.

### *4.4 Local Partnerships*

Regarding local partnerships, Brazilian institutions stand out by establishing strong ties with local communities and businesses [19]. In the context of circular economy strategies, local partnerships refer to the collaborations and alliances between universities and local stakeholders, which include businesses, government bodies, non-profit organisations, and communities. These partnerships aim to create an enabling environment for circular economy initiatives, fostering sustainable development on a regional scale.

These partnerships can take various forms and involve a range of activities. Joint research initiatives allow universities to collaborate with local stakeholders to develop innovative solutions and strategies for circularity. Knowledge-sharing forums provide a platform for exchanging ideas, experiences, and best practices related to the circular economy. Student internships with local businesses offer valuable learning opportunities for students to gain hands-on experience in implementing circular economy principles within real-world contexts. Additionally, community engagement programmes enable universities to involve local communities in circular economy initiatives, raising awareness and fostering active participation.

Brazilian universities are notably proactive, forming robust connections with local entities to push forward circular economy agendas. Maruyama et al. [19] highlighted that these partnerships can take various forms, such as joint research initiatives, knowledge-sharing forums, student internships with local businesses, and community engagement programmes. By forging strong local partnerships, universities can leverage local stakeholders' expertise, resources, and networks, promoting knowledge transfer, driving innovation, and creating a shared commitment towards circularity. These partnerships contribute to developing a collaborative ecosystem where all stakeholders work together to achieve sustainability goals and address local challenges comprehensively and inclusively.

## 4.5 CE Teaching and Development Practices

CE teaching and development underline the importance of scholarly cooperation in China, curriculum development in Brazil, and innovation in teaching and research in the UK and the USA [9, 11, 19, 21]. CE teaching and research practices refer to educational and scholarly approaches incorporating and promoting the circular economy (CE) principles within academia. These practices embody disseminating CE concepts and principles through academic curricula and advancing CE theory and practice through scholarly research. In the context of the table above, CE teaching and development encapsulate a variety of strategies employed in different countries.

For instance, in China, a particular emphasis is placed on scholarly cooperation, which denotes collaborations between researchers, departments, and institutions to foster a greater understanding of the CE [21]. CE teaching and development are innovative teaching and research methods in the UK and the USA. This could include experiential learning through simulation games, promoting student entrepreneurship, or pioneering research into new CE approaches [9, 11]. CE teaching and development is an overarching strategy for fostering CE adoption and advancement within the academic sphere, albeit executed differently depending on local context and capabilities. The concept of CE teaching and research practices pertains to the educational and scholarly approaches that integrate and promote CE principles within academic institutions. These practices encompass disseminating CE concepts and principles through academic curricula and advancing CE theory and practice through scholarly research. The significance of CE teaching and development practices is underscored by their incorporation into various strategies implemented in different countries.

For example, in China, scholarly cooperation plays a central role, emphasising collaborations between researchers, departments, and institutions to enhance the understanding of CE principles [21]. This collaborative approach fosters a deeper exploration and dissemination of CE knowledge within academic circles. On the other hand, in the UK and the USA, CE teaching and development take on innovative forms. These may include experiential learning through simulation games, initiatives promoting student entrepreneurship in the CE realm, or cutting-edge research exploring novel approaches to CE [9, 11]. These countries prioritise incorporating innovative teaching methods and research practices to advance CE education and contribute to developing novel CE strategies. CE teaching and research practices serve as overarching strategies to foster the adoption and advancement of CE within the academic sphere. However, the specific implementation and emphasis may vary depending on the local context and the academic institutions' capabilities. By integrating CE principles into teaching and research, universities can nurture the next generation of sustainability leaders and drive transformative change towards a circular economy.

## 5 Contribution to Knowledge: Proposed CE Framework for Australian Universities

In line with universities' role as leaders in knowledge creation and dissemination, universities also have a unique opportunity to spearhead the implementation of the circular economy concept. However, as Mendoza et al. [20] outlined, building a robust business case is a critical initial step to mobilising resources and institutional support. Therefore, Australian universities must comprehensively review their existing sustainability practices, identifying areas of strength and opportunities for enhancement by applying CE principles and strategies such as those highlighted in Fig. 1. Furthermore, as Mindt and Rieckmann [22] suggested that embedding sustainability-driven entrepreneurship in the curriculum can effectively engage students and foster a culture of sustainability within universities. Additionally, creating 'living laboratory' experiences on campus that exemplify CE practices could serve as a potent tool for enhancing student learning and promoting the adoption of sustainable behaviours [15]. Universities, including Australia, significantly drive the transition towards a circular economy. Their influence extends beyond the confines of their campuses, impacting the broader community and contributing towards global sustainability goals. As CE practices encompass numerous aspects of organisational operations, universities must adopt these practices strategically and systematically. Mendoza et al. [20] demonstrated the importance of strategic planning in implementing CE initiatives in universities, highlighting that it requires a concerted effort to bring about institutional change. As indicated by their work, a successful CE strategy necessitates understanding the institution's current practices, identifying areas for improvement, and formulating a plan of action. This plan should set specific, measurable, achievable goals and outline the necessary steps.

Drawing upon the findings of Mendoza et al. [20], the nascent stages of a university's transition towards a circular economy (CE) must involve a thorough exploration of its existing sustainability protocols, thereby pinpointing their strengths as well as the gaps which can be bridged by incorporating the tenets of CE. This multifaceted exercise engenders a solid business case that underpins resource mobilisation and accrues institutional support. Further deepening their commitment to sustainability, universities can leverage the transformative potential of education. Concurring with Mindt and Rieckmann [22], there must be advocacy for integrating sustainability-driven entrepreneurship within academic curricula, bolstering student engagement, and fostering a campus culture steeped in sustainability.

Supplementing these measures, Gomez and Derr [15] contend that tangible on-campus manifestations of CE practices, colloquially termed *'living laboratories'*, can be a powerful mechanism to enhance student learning while simultaneously cultivating sustainable behaviours. Universities worldwide, including Australia, are pivotal in facilitating the transition towards a CE, extending their influence beyond their immediate surroundings to significantly impact broader societal paradigms and global sustainability goals. Mendoza et al. [20] advocated for the comprehensive


**Fig. 1** Proposed circular economy strategies for Australian universities

approach to CE calls for strategic and systemic adoption within universities. It necessitates a painstaking assessment of the institution's existing practices, identifying improvement areas, and formulating an action plan.

The transformative capacity of circular practices in constructing sustainable urban environments offers valuable guidance for Australian universities' campus planning and development. Education that integrates CE principles, as proposed by Peters [30], can catalyse a culture of sustainability on campus. Universities, through education, hold the power to equip tomorrow's leaders with the skills and knowledge needed to steer the transition to a CE. Establishing green policies that promote and facilitate sustainable practices is crucial, incorporating elements such as waste management, energy efficiency, and circular procurement. By benchmarking against best practice examples from varied contexts, Australian universities can identify strategies most apt for their unique circumstances, thereby building a compelling case for adopting a circular economy.

In the context of Australian universities, CE strategic planning can be guided by the best practices observed in universities within this study. Integrating CE principles in Australian university teaching, as illustrated by Peters [30], can play a pivotal role in fostering a culture of sustainability on campus. Through education, universities can equip future leaders with the knowledge and skills required to drive the transition to a circular economy. Furthermore, Junior et al. [17] emphasised the importance of governance in promoting sustainable development in higher education institutions. It is essential to have green policies that encourage and facilitate the adoption of sustainable practices, including those related to waste management, energy efficiency, and circular procurement. By drawing on best practice examples from different contexts, Australian universities can identify strategies most suitable for their specific circumstances and build a robust case for implementing a circular economy within their institutions.

## 6 Conclusion and Future Directions

Global transition towards CE principles is evidenced within higher educational institutions. These campuses have begun integrating diverse CE strategies, from waste prevention and resource optimisation to circular infrastructure, smarter campuses, local partnerships, and incorporating CE teachings into their curricula. Universities' varied global approaches underline CE principles' adaptability and wide applicability. Focusing on Australian universities, adopting CE practices could foster environmental sustainability, boost student engagement with pressing global issues, and strengthen relationships with local communities and businesses. Furthermore, embedding such principles within their curricula could equip future leaders with the necessary skills to navigate the world's sustainability challenges. Higher education institutions worldwide increasingly reflect the global transition towards circular economy principles. Their campuses have started integrating diverse strategies underpinning this concept, including waste prevention, resource optimisation, circular infrastructure, smart campuses, local partnerships, and the integration of such principles into their curricula. This divergence in approach across global universities signifies these principles' adaptability and broad applicability, irrespective of geographic or institutional contexts. For Australian universities in particular, adopting these practices offers a promising path towards achieving environmental sustainability. This shift can catalyse increased student engagement with salient global issues, fostering a transformative educational experience. Moreover, it strengthens relationships with local communities and businesses, thus aligning educational objectives with broader societal and economic goals. Furthermore, incorporating these principles into the curricular discourse is instrumental in equipping the leaders of tomorrow with the requisite competencies for navigating a world grappling with sustainability challenges. As these principles increasingly become integral to academic programmes, students can harness the knowledge and skills they need to effect meaningful change in their future professional roles, contributing to a more sustainable future.

Future research could delve into case-specific challenges and successes of implementing CE strategies in Australian universities. Additionally, comparative studies exploring the effectiveness of different CE strategies across various universities will provide useful insights to further advance the development and implementation of

CE principles in Australian higher education. Researchers could uncover best practices, problems, and opportunities by thoroughly investigating and comparing the effects of varied CE principles across multiple institutions, thus assisting the continuous development of CE in the university context. To complement the findings of this study, future researchers will need to conduct additional comparative studies in several crucial areas. The impact of CE curriculum on Australian student experiences, behaviours, and values is one of these areas and the potential research question could be, "How do students perceive the relevance and importance of CE principles to their future careers and daily lives"? Another research might look at the governance models and administrative structures in place at Australian universities to supervise campus-wide CE efforts. The research question can be, "How can universities measure and track their progress towards CE goals and benchmark their performance against peer institutions"? Similarly, the synergistic potential of CE initiatives and sustainability programmes on Australian campuses is an intriguing area for future research. The research may provide an answer to the question: "In what ways are CE models complementary to existing sustainability frameworks and agendas at Australian universities"? Another important area to examine is a broad comparative analysis of CE strategies, operations, and outcomes across Australian universities. The potential research question can be, "How do international benchmarks and practices inform CE agendas at Australian higher education institutions"?

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## References

1. Adedokun O, Egbelakin T, Omotayo T (2023) Random forest and path diagram taxonomies of risks influencing higher education construction projects. Int J Constr Manag 1:1–9. https://doi.org/10.1080/15623599.2023.2211406
2. Agrawal R, Wankhede VA, Kumar A, Rangnekar S (2022) Nexus of circular economy and sustainable business performance in the era of digitalization. Int J Product Perform Manag 71(3):748–774. https://doi.org/10.1108/IJPPM-12-2020-06766
3. Alvarez-Risco A, Rosen MA, Del-Aguila-Arcentales S (2022) Towards a circular economy. Springer, London

4. Awuzie B, Ngowi AB, Omotayo T, Obi L, Akotia J (2021) Facilitating successful smart campus transitions: a systems thinking-SWOT analysis approach. Appl Sci 11(5):2044. https://doi.org/10.3390/app11052044
5. Bugallo-Rodríguez A, Vega-Marcote P (2020) Circular economy, sustainability and teacher training in a higher education institution. Int J Sustain Higher Educ 21(5):934–950. https://doi.org/10.1108/IJSHE-02-2020-0049
6. Charter M (ed) (2018) Designing for the circular economy. Routledge, New York
7. Chen TL, Kim H, Pan SY, Tseng PC, Lin YP, Chiang PC (2020) Implementation of green chemistry principles in circular economy system towards sustainable development goals: challenges and perspectives. Sci Total Environ 716:136998. https://doi.org/10.1016/j.scitotenv.2020.136998
8. De Mattos CA, De Albuquerque TLM (2018) Enabling factors and strategies for the transition toward a circular economy (CE). Sustainability 10(12):4628. https://doi.org/10.3390/su10124628
9. De la Torre R, Onggo BS, Corlu CG, Nogal M, Juan AA (2021) The role of simulation and serious games in teaching concepts on circular economy and sustainable energy. Energies 14(4):1071. https://doi.org/10.3390/en14041138
10. Ferronato N, Gorritty Portillo MA, Guisbert Lizarazu EG, Torretta V (2020) Application of a life cycle assessment for assessing municipal solid waste management systems in Bolivia in an international cooperative framework. Waste Manag Res 38(1_suppl):98–116
11. Fleischmann K (2019) Design-led innovation and circular economy practices in regional Queensland. Local Econ 34(4):382–402. https://doi.org/10.1177/0269094219854679
12. Fortes S, Hidalgo-Triana N, Sánchez-la-Chica JM, García-Ceballos ML, Cantizani-Estepa J, Pérez-Latorre AV et al (2021) Smart tree: an architectural, greening and ICT multidisciplinary approach to smart campus environments. Sensors 21(21):7202
13. Gallo M, Marotta V, Del Borghi A, Strazza C (2017) University campus waste prevention and reduction: a circular-economy approach. Univ Campus Towards Sustain 173:61088
14. Geisendorf S, Pietrulla F (2018) The circular economy and circular economic concepts—a literature analysis and redefinition. Thunderbird Int Bus Rev 60(5):771–782
15. Gomez T, Derr V (2021) Landscapes as living laboratories for sustainable campus planning and stewardship: a scoping review of approaches and practices. Landscape Urban Plann 216:104259. https://doi.org/10.1016/j.landurbplan.2021.104259
16. Heshmati A (2017) A review of the circular economy and its implementation. Int J Green Econ 11(3–4):210–224. https://doi.org/10.1504/IJGE.2017.089856
17. Junior BA, Majid MA, Romli A, Anwar S (2020) Green campus governance for promoting sustainable development in institutions of higher learning-evidence from a theoretical analysis. World Rev Sci Technol Sustain Develop 16(2):141–168
18. Kamarudin N, Nizam NZ, Win CK (2023) Green supply chain management integrate for environmental sustainability in university smart campus. In: Handbook of research on designing sustainable supply chains to achieve a circular economy. IGI Global, pp 377–394
19. Maruyama Ú, Sanchez PM, Trigo AGM, Motta WH (2019) Circular Economy in higher education ınstitutions: lessons learned from Brazıl-Colombıa network. Brazil J Oper Product Manag 16(1):88–95
20. Mendoza JMF, Gallego-Schmid A, Azapagic A (2019) Building a business case for implementation of a circular economy in higher education institutions. J Clean Product 234:1022–1035. https://doi.org/10.1016/j.jclepro.2019.02.045
21. Merli R, Preziosi M, Acampora A (2018) How do scholars approach the circular economy? A systematic literature review. J Clean Product 178:703–722. https://doi.org/10.1016/j.jclepro.2017.12.112
22. Mindt L, Rieckmann M (2017) Developing competencies for sustainability-driven entrepreneurship in higher education: a literature review of teaching and learning methods. Teoría de la educación: revista interuniversitaria
23. Murray A, Skene K, Haynes K (2017) The circular economy: an interdisciplinary exploration of the concept and application in a global context. J Bus Ethics 140:369–380

24. Nunes BT, Pollard SJ, Burgess PJ, Ellis G, Bruyere S (2018) University contributions to the circular economy: professing the hidden curriculum. Sustainability 10(8):2936. https://doi.org/10.3390/su10082719
25. Ogunmakinde OE (2019) Developing a circular-economy-based construction waste minimisation framework for Nigeria. University of Newcastle, Newcastle
26. Ogunmakinde OE, Egbelakin T, Sher W (2022) Contributions of the circular economy to the UN sustainable development goals through sustainable construction. Resour Conser Recycl 178:106023. https://doi.org/10.1016/j.resconrec.2021.106023
27. Omotayo T, Moghayedi A, Awuzie B, Ajayi S, Oyeyipo O (2021) A systems thinking model for transitioning smart campuses to cities. Front Built Environ 7:755424. https://doi.org/10.3389/fbuil.2021.755424
28. Osobajo OA, Oke A, Omotayo T, Obi LI (2022) A systematic review of circular economy research in the construction industry. Smart Sustain Built Environ 11(1):39–64. https://doi.org/10.1108/SASBE-04-2020-0034
29. Owojori OM, Mulaudzi R, Edokpayi JN (2022) Attitude, and perception (KAP) to solid waste management: a survey towards a more circular economy from a rural-based tertiary institution in South Africa. Sustainability 14(4):1883. https://doi.org/10.3390/su14031310
30. Peters O (2001) Learning and teaching in distance education: pedagogical analyses and interpretations in an international perspective. Routledge, New York
31. Polin K, Yigitcanlar T, Limb M, Washington T (2023) The making of smart campus: a review and conceptual framework. Buildings 13(4):891
32. Qu D (2023) Formation of management system of university's educational and scientific assets in the context of transition to the model of circular economy in China. https://repo.snau.edu.ua:8080/xmlui/handle/123456789/10485
33. Qu D, Shevchenko T, Yan X (2020) University curriculum education activities towards circular economy implementation. Int J Sci Technol Res 9(5):200–206
34. Ramakrishna S, Ngowi A, Jager HD, Awuzie BO (2020) Emerging industrial revolution: symbiosis of industry 4.0 and circular economy: the role of universities. Sci Technol Soc 25(3):505–525
35. Rieckmann M (2017) Education for sustainable development goals: learning objectives. UNESCO publishing
36. Salas DA, Criollo P, Ramirez AD (2021) The role of higher education institutions in the implementation of circular economy in Latin America. Sustainability 13(17):9805. https://doi.org/10.3390/su13179805
37. Serrano-Bedia AM, Perez-Perez M (2022) Transition towards a circular economy: a review of the role of higher education as a key supporting stakeholder in Web of Science. Sustain Product Consump 29:205–218. https://doi.org/10.1016/j.spc.2022.02.001
38. Sinxadi L, Ngowi AB, Ramakrishna S, Awuzie B (2021) Toward a dynamic capabilities framework for engendering 4IR-enabled circular economy in a university of technology. Front Sustain 2:28. https://doi.org/10.3389/frsus.2021.718723
39. Tan CNL, Md-Noor S (2013) Knowledge management enablers, knowledge sharing and research collaboration: a study of knowledge management at research universities in Malaysia. Asian J Technol Innov 21(2):251–276. https://doi.org/10.1080/19761597.2013.866314
40. Weber SM, Heidelmann M (2019) Towards regional circular economies. 'greening the university canteen' by sustainability innovation labs. In: Leal Filho W, Azul A, Brandli L, Özuyar P, Wall T (eds) Decent work and economic growth: encyclopedia of the UN sustainable development goals. Springer, New York, pp 1–16
41. Weber T, Stuchtey M (2019) Pathways towards a German circular economy. Lessons from European Strategies. Acatech—National Academy of Science and Engineering

# Circular Economy Strategies for Enhancing the Sustainable Performance of Building Sector: A Systematic Review

**M. Gowsiga, Thanuja Ramachandra, P. Sridarran, N. Thurairajah, and Niluka Domingo**

## 1 Introduction

The building sector contributes significantly to the worldwide economy, generating about 12% of the global gross domestic product whilst using around 35% of the world's resources, 40% of its energy, and 12% of its potable water. This sector is also a significant producer of waste, with one-third of it going to landfills, and also it accounts for about 40% of the world's carbon emissions [5, 12]. Carbon emissions related to the building sector reached 31 billion metric tonnes in 2021, and embodied energy is another issue that can reach 60% during a building's lifecycle [5, 30]. For example, it is a highly material- and emission-intensive sector, consuming between 1.2 and 1.8 Mt of materials annually in Europe and producing about 50% of greenhouse gas emissions in the UK [1, 42], and also in the European Union, around a billion tonnes of construction demolition waste (CDW) produced each year [22]. In addition, the Organisation for Economic Cooperation and Development [OECD] [44] indicated that the extraction and processing of key metals and the production of concrete will result in a 21% rise in total emissions by 2060. Subsequently, [51] also

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indicated that the current linear pattern of material usage will result in the scarcity of certain essential materials (e.g. steel and copper) in the building sector.

To address all of the aforementioned issues, the application of the circular economy (CE) concept is deemed essential in various building lifecycle stages to manage the building and its components from cradle to cradle [4]. The concept of CE is a collection of principles that combines a wide range of practices with the shared goal of reducing waste generation and resource consumption by preserving the value of resources for as long as possible, improving material and energy efficiency, utilising renewable energy sources, and using environmentally friendly, toxic-free, and low-impact materials [32]. It can be described as a living economic system as value is created through usage (and reuse) rather than destroyed via consumption [18]. In the long term, the CE is more effective and sustainable than the conventional system and it commits to reducing carbon emissions whilst improving resource and energy efficiency [43, 58]. This pushes the boundaries of environmental sustainability by highlighting the concept of transforming products in a way that ecological systems and economic growth can be connected in a practical way [42]. According to [55], the building sector has the greatest potential to support the concepts of CE, as it ensures that waste sent to landfills is reduced by maintaining the values derived from materials in the economy for a long time. For instance, the Ellen MacArthur Foundation [20] predicted that adopting CE in Europe's building sector may save £300 billion worth of primary resources by 2030. This circular way of promoting the cycling of waste during the building's lifecycle can improve resource efficiency, reduce energy consumption, reduce waste, increase the number of new materials used, and reduce carbon emissions [10, 12, 39]. Accordingly, the CE concept should be used for building materials to keep them sustainable and lower their embodied energy and carbon [4].

On the other hand, most of the previous strategies that were recommended in different studies to reduce the embodied impacts in the building sector are based on the few principles of CE, including reduce, reuse, and recycle. For example, extending the lifespan of buildings, using less material or material with lower energy intensity, reducing waste, reusing, and recycling [8], material minimisation, material reuse, and recycling [3], reducing, reusing, and recovering building materials; extending material life; and refurbishing existing buildings rather than creating new ones [46]. According to Brutting et al. [13], reuse implies higher embodied emissions savings than recycling construction products when they reach their end of life. To prioritise those minimising embodied emissions measures, it is necessary to first accurately quantify the situation and then choose the best CE solutions [27]. When only looking at direct energy and carbon savings during the use of building materials, the benefits of CE solutions are likely to be understated. Thus, it is essential to analyse the effects of CE solutions from a cradle-to-grave lifecycle perspective, considering the embodied emissions of the materials.

Moreover, the use of CE in the building sector is still in its infancy, but it has started receiving more attention from both theoretical and practical perspectives [41]. Although there is a growing amount of literature on how CE principles can be applied to the building sector [33], detailed studies on CE strategies for the building sector are limited in scope as the previous studies narrowed their focus to certain aspects. For instance, Ghisellini et al. [23] determined whether the adoption of CE is environmentally sustainable by focusing on selected CE principles, including reducing, reusing, and recycling for construction and demolition waste. Wijewansha et al. [59] have focused on the application of the 6R principles of CE, particularly during the pre-construction stage of a construction project. In addition, [1] highlighted that there has been limited research on the application of circular economy principles in the built environment within a whole systems' context. In addition, Adams et al. [1] noticed that the primary applications of CE have been minimisation and recycling of construction waste. Further, Akanbi et al. [2] identified that some studies on CE in buildings believed buildings to be worth, whilst other studies on CE in buildings viewed buildings as material banks for material extraction during operation and at the end of life. Osobajo et al. [45] disclosed that numerous studies on CE in the building sector have concentrated on resource consumption and waste management. Moreover, recycling, waste management, resource efficiency, reuse, and remanufacturing were found to be the most relevant terms for CE generally by Alhawari et al. [6].

The review of the literature reveals that only a few studies have been conducted in the global context on the application of principles of CE in the building sector. However, evidence suggests that no research has focused on the CE strategies for the whole R-framework (R-imperatives) of CE, particularly for all the lifecycle stages. To this end, this study aims to investigate the current state of knowledge regarding the use of CE strategies within the building sector. The remaining sections of the paper are structured as follows: The study methodology is discussed in Sect. 2. The literature findings, analysis, and summarised CE strategies for enhancing the sustainable performance of the building sector are presented in Sect. 3. Finally, the conclusions of the study are presented in Sect. 4.

## 2 Research Methodology

The systematic review technique was used to carry out the literature search in this study. A systematic literature review is "research that bears on a particular question, using organised, transparent, and replicable procedures at each step in the process" [35], pp. 1–2. This research was a continuation of the previous study of the authors [25], a systematic literature review on CE principles for the building sector, which was carried out using Preferred Reporting Items for Systematic Reviews (PRISMA). For the literature search, the Web of Science, Scopus, and Science Direct databases was chosen as they contain academic papers with high rankings and indexes. In addition, Google Scholar was also looked at to see if any other papers might have been around and answered this research question, which is "What are the strategies of CE for enhancing the sustainable performance of building sector?". Circular economy, building sector, and strategies are the basic search terms used in this study. The Boolean operator "AND" was used to combine each keyword mentioned, wild cards such as question marks (?) and asterisk marks (*) were introduced to several terms

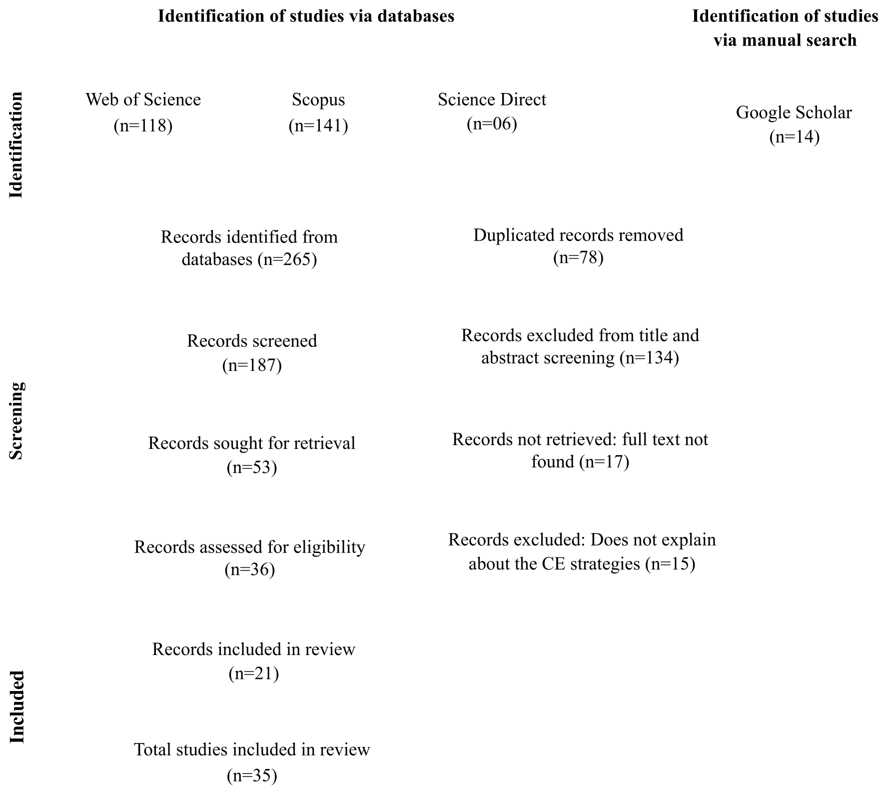


**Fig. 1** PRISMA flow diagram

to maximise the search results, and quotation marks (“”) were used to get the exact term in this study. Figure 1 illustrates the PRISMA flow diagram of the study.

To strengthen the literature selection, the number of eligibility and exclusion criteria was specified. Only peer-reviewed articles on the strategies of CE and the building sector that were published in English between 2010 and 2022 were selected. The TITLE-ABS-KEY was used as the search field.

Figure 1 illustrates the PRISMA flow diagram of the study. The total of 265 records resulted in 187 after the removal of 78 duplicate records. From that, 53 records were chosen after the title, abstract, and keyword screening processes. Then, only 36 records were eligible for the full paper review due to the absence of 17 full articles. Fifteen out of 36 were found to be irrelevant to the research question of the study during the preliminary assessments. Finally, a total of 35 records, including the remaining 21 records and 14 records from Google Scholar, are eligible for in-depth analysis.

In the next section, the search results were further analysed and their contents were synthesised to extract the CE strategies for the building sector.

## 3 Results and Discussion

The results of this research are presented in two parts: (1) a descriptive analysis of the selected articles and (2) CE strategies applicable to the building sector.

### *3.1 Descriptive Analysis*

The selected articles were scrutinised to identify the CE domains and R-imperatives of the building sector covered in the previous scholarly works. Only 11 out of 35 studies discuss the CE domains, whether R-framework, ReSOLVE model, or CE loops. In terms of CE domains, most of the studies (seven out of 11) have considered the CE principles in R-frameworks, whilst only two articles covered each CE loop and the CE ReSOLVE model. Figure 2 presents the number of articles that discussed the different CE domains. This indicates that R-frameworks have received significant attention in terms of CE principles applicable to the building sector.

Subsequently, the R-imperatives of the building sector that were the focus of those seven studies were compared with the 17 R-imperatives identified as the CE principles of the building sector by the authors [25]. Two of seven studies that consider R-imperatives focus on 10R-frameworks by Potting et al. [47] and Reike et al. [50]. Another two studies each focus on 6R and 3R, another is about reuse and recycling, another is only about reuse, and one is about resolve. Although reuse was considered in all seven articles, 14 out of 17 R-imperatives are less than half of the studies on reuse (less than or equal to three). Further, five of the 17 R-imperatives are not considered in any of the studies including retain, return, retrofit, reverse, and recondition. It shows the necessity of studies that discuss the CE strategies of the building sector concerning each R-imperative of the building sector. Figure 3 presents the R-imperatives of the building sector referred to in articles.

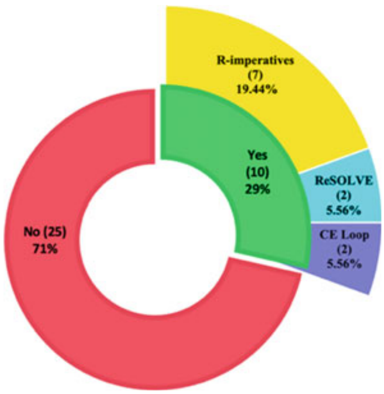


**Fig. 2** Distribution of articles with CE domains

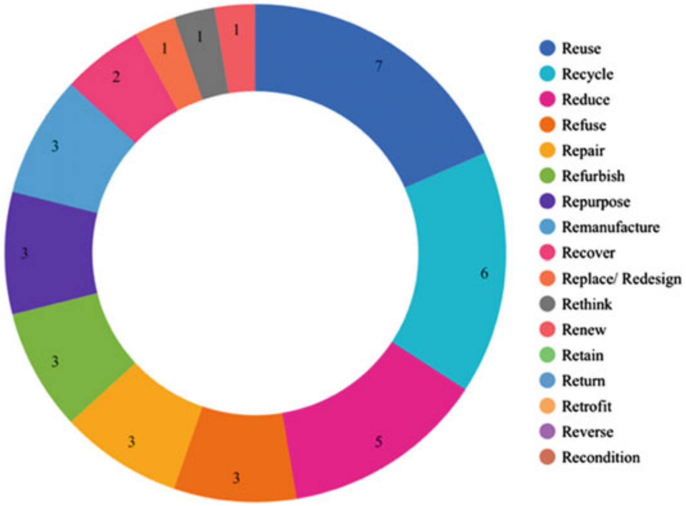


**Fig. 3** R-imperatives of the building sector referred to in articles

Following the above descriptive analysis, Fig. 4 displays the distribution of building lifecycle stages considered in the selected articles. Thirteen out of 35 articles have not focused specifically on a particular lifecycle stage of building, whilst 22 articles have focused on at least one of the building lifecycle stages. Six of these 22 studies focused on almost all the stages of the building lifecycle, whilst two articles focused on the design, construction, and end-of-life stages, and five articles focused on both the design and construction stages. However, other articles focused only on one of the lifecycle stages: four articles about construction, two about design and use, and one on the end-of-life stage.

Figure 5 displays the distribution of the focus of the articles in terms of materials, waste, energy, or carbon emissions. As seen from Fig. 5, generally, studies have considered materials and waste to discuss CE implementation in the building sector.

**Fig. 4** Building lifecycle stages referred to in articles

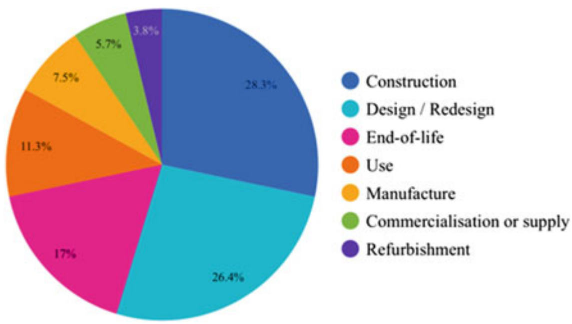


**Fig. 5** Scope of the area covered in articles

Energy is also considered adequate, as 27 out of 35 studies mention it. However, carbon emissions are only mentioned in about one-third of the selected papers.

## 3.2 *Strategies of Circular Economy for Building Sector*

CE is defined as an economic system that aims to facilitate sustainable development by substituting the end-of-life concept, using various R-imperatives (or resource loops) at all three levels (micro, meso, and macro) of the built environment, and employing effective strategies for the use of resources through the whole life cycle of the system" [24]. Further, the authors explained that CE principles in the building sector are required to achieve the objective of CE, which is substituting the end-of-life concept, and CE strategies are the tool to achieve the CE principles. Accordingly, the strategies for the building sector in 86 CE that make the CE principles practically possible were summarized with their descriptions in Tables 1 and 2, indicating which of the 17 R-imperatives (CE principles) and phases of the building material life cycle each strategy applies to.

In addition, materials and waste are taken into account in all of the studies that were chosen for this study, as shown in Fig. 5. This remained true when the CE strategies were analysed. According to Fig. 5, less than one-third of studies are concerned with carbon emissions, and even fewer studies involve carbon emissions in the discussion of CE strategies. Gallego-Schmid et al. [22] discussed the potential carbon benefits of combining design for disassembly with material optimisation to reuse building materials. For example, reusing concrete-based floor slabs, core walls, roof slabs, columns, and beams twice or three times throughout a building's life can reduce material-related carbon emissions by 25–60% compared to using original materials. Further, material substitution may be a better way to reduce carbon

**Table 1** Strategies of circular economy for building sector

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S1 | Adaptability and flexibility | The ability to be changed or evolve to fit changed circumstances | [2, 4, 8, 15, 19, 21–23, 26, 31–32] |
| S2 | Allow for dematerialisation | Substitution of a product by a non-material alternative with the same utility for users | [3, 17, 24] |
| S3 | Analyse the potential of materials | Evaluate the potential of materials for reuse and recycling | [12] |
| S4 | Application of modern techniques and technologies | Use the latest technologies and techniques to reduce raw resource consumption | [4, 5, 7, 8, 15–16, 21, 28–29, 33, 35] |
| S5 | Application of smart maintenance | Using digital tools to make maintenance more efficient | [17] |
| S6 | Building layer concept | Differentiates the various elements that constitute a building and their different lifespans | [5] |
| S7 | Certain instructions for material circularity | Comprehensive guidelines for material reuse, recycling, and reclamation | [2, 3, 12, 21, 26, 28] |
| S8 | Collaboration of stakeholders | Involvement of stakeholders in exchanging information and communication among them | [2, 15, 26] |
| S9 | Development of material passport | Database with a series of data describing the characteristics of the building's elements | [11, 12, 19, 21, 26] |
| S10 | Design for adaptability/ flexibility | A design that accommodates evolving demands and maximises value throughout | [2, 5, 8, 11, 12, 14, 23, 31] |
| S11 | Design for attachment and trust | Design that creates products that will be loved, liked, or trusted longer | [14] |
| S12 | Design for a biological cycle | Design products for the biological cycle not for the technical cycle | [14] |
| S13 | Design for compatibility | Design that makes it easy to connect any firmware version with any hardware | [14] |
| S14 | Design for re-/ deconstruction | Design that allows neat disassemble of components and materials | [2, 7, 10, 11, 15, 18, 19, 21, 28, 30] |
| S15 | Design for disassembly | Design that facilitates to be reversible, and dismantled connections and elements | [3, 5, 7, 10–19, 23, 29, 31, 32] |
| S16 | Design for durability | Design that enables a product to endure physical damage for a long time | [14, 17, 28, 32] |
| S17 | Design for ease of maintenance and repair | Design that reduces the difficulties and costs associated with maintaining product | [14, 17, 31, 32] |
| S18 | Design for interchangeability | Design that allows components to be chosen randomly for assembly and then fitted together within the required tolerances | [17] |

(continued)

**Table 1** (continued)

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S19 | Design for longevity | Design that takes into consideration the psychological (emotional bond) and physical (quality, durable workmanship, good fit) aspects that influence a product's life | [17] |
| S20 | Design for manufacture and assembly | Design the components of the product to be produced with minimal effort, and make the final product's assembly as simple as possible | [30–32] |
| S21 | Design for modularity | Design that ensures the minimum waste is generated during construction processes by emphasising the modularity of components | [2, 3, 8, 9, 12, 17, 22, 28, 32] |
| S22 | Design for multi-functional use | Stimulates the search for multiple functions and a maximum combination of functions that can best be served by the design | [17, 29] |
| S23 | Design optimisation | Design to achieve weight reduction through shape and size modifications and optimal use of materials to meet the design requirements | [13] |
| S24 | Design for prefabrication | Design that allows assemblies that are manufactured under factory conditions and assembled onsite | [23] |
| S25 | Design for reassembly | Design that facilitates the dismantled connections and elements to assemble again | [14, 17] |
| S26 | Design for recyclability | Design the products or elements that can be recyclable over multiple use cycles | [19, 23, 28, 31] |
| S27 | Design for reliability | Design that ensures the performance of a specified function within a given environment for the expected lifecycle of a product | [14, 17, 28, 32] |
| S28 | Design for reuse | Design the products or elements that can be reused over multiple use cycles | [17, 19] |
| S29 | Design for standardisation | Design to enforce a level of consistency or uniformity to certain practices or operations within the selected environment | [2, 3, 8, 14, 17, 19, 28, 32] |
| S30 | Design for sustainability | It is a holistic design approach to the activities that emphasise the well-being of people and the environment as the outcome | [2] |
| S31 | Design for technological cycle | Design of material and energy resources to achieve the highest levels of efficiency with the technical and/or technological usage and transformation | [14] |
| S32 | Design for upgradability | Design products that are capable of being adapted to future enhancements of product performance and functions | [14, 17, 32] |
| S33 | Design out waste | Design that facilitates the zero waste | [2, 3, 5, 8, 10, 28] |

(continued)

**Table 1** (continued)

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S34 | Easy for repair, maintenance, and upgrade | Materials or products that are simple to maintain, repair, and update | [2, 8, 24, 27] |
| S35 | Effective schedule to monitor material usage | Prepare and follow an appropriate schedule to track the material flow | [11] |
| S36 | Efficient management of resources and waste | Lowering the expenses and resources needed and waste produced | [3, 10, 16, 22, 26, 35] |
| S37 | Encourage material separability | Simplify the connections of material for easy separability | [17, 21] |
| S38 | Enhancement of regulations | Enact and follow better regulations (e.g. Pay-As-You-Throw) | [9, 25] |
| S39 | Enhance supervision and management | Strengthen the management and supervision of material consumption and waste handling | [6, 9] |
| S40 | Facilitate material recovery/ reprocessing | Ensure material recycling or remanufacturing back into the same product | [2, 7, 9, 15, 21, 27, 32] |
| S41 | Generate predictive data analytics | Make predictions about future events using historical data mixed with statistical modelling, data mining, and machine-learning approaches | [35] |
| S42 | Handling waste at the source | Use proper technique for onsite sorting, and waste collection procedure | [2, 10] |
| S43 | Increase the durability of material/product | Strengthen the quality of material/product to increase the life span | [2, 3, 13, 16, 19, 28, 32] |
| S44 | Introduction of economic incentive/ reward scheme | Establishing a financial incentive or reward scheme (e.g. construction waste disposal charging scheme or stepwise incentive system) | [6, 10, 17, 25] |
| S45 | Maintaining the detailed specification of materials | Management and access to information including component details, metrics, technical drawings, pictures, etc | [2, 3, 7, 11, 21, 25, 26] |
| S46 | Material flow analysis | Evaluate the status of material along the material flow | [7, 12, 21, 22, 35] |
| S47 | Material substitution | Replacement of materials with sustainable alternatives for the current ones | [13, 16, 22, 27, 32] |
| S48 | Minimal maintenance | Reduce the need for maintenance as much as possible | [2, 8, 32] |
| S49 | Minimise composite materials | Use fewer materials that combine more than two materials with different physical and chemical properties | [21] |

(continued)

**Table 1** (continued)

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S50 | Minimise hazardous and toxic materials | Use less hazardous and toxic materials as much as possible | [2, 3, 19, 21, 28, 32] |
| S51 | Optimise the use of resources | Optimise/minimise the use of material and energy | [2, 13, 21, 25, 27, 32] |
| S52 | PDCA cycle-based management | Manage the material follow effectively using a plan to check and act on cycle | [10, 21, 25, 29, 33] |
| S53 | Preventive maintenance actions | Minimise recuperative maintenance with preventive maintenance | [3, 12, 19, 21, 29] |
| S54 | Procure used / repairable material/ component | Choose and reuse existing materials or repairable material/ component | [2, 8, 22, 27, 28, 29, 31, 32] |
| S55 | Procurement transformation | Change the procurement process (e.g. Green Procurement) | [2, 9] |
| S56 | Product service system (PSS) | Offer the product as a service including hired/ shared/refunded-deposit products/ return for service under contract or dispose | [7, 11, 24] |
| S57 | Proper material storage | Use better material storage techniques (e.g. just in time) | [32] |
| S58 | Raising awareness and offering training | Increase the level of awareness and provide training to improve the practices | [9, 11, 19, 25, 26, 29] |
| S59 | Reduce the number or types of components | Simplification of the products | [2, 17, 21] |
| S60 | Reduce the product usage and utilise it more carefully and thoroughly | Lessen the usage of purchased products and use them with more care and longer | [17, 29] |
| S61 | Renewable energy and material sources | Using renewable energy sources or material sources (solar, biomass) | [3, 11, 16, 25, 26–29, 32] |
| S62 | Reuse and recycling of building materials | Reuse and recycle the materials | [3, 8, 22, 27] |
| S63 | Selective demolition or deconstruction | Selective dismantlement of building materials/ components to increase their lifespan | [2, 7, 10, 12, 13, 15, 19, 21, 27, 26] |
| S64 | Sharing of product/ component | Share the product/component | [3, 8, 17, 20, 24, 28, 29, 32] |
| S65 | Take back scheme/ reverse logistics | Return the products from end users back to either the retailer or manufacturer | [2, 3, 8, 28] |
| S66 | Tender specification with circular options | Detailed tender specifications with circular alternatives | [34] |
| S67 | Use of bio-based or biodegradable materials | Use materials that are to be safely returned to the biosphere | [15, 23, 24, 27, 29, 31, 32] |

(continued)

**Table 1** (continued)

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S68 | Use of durable material/ components | Use materials and components with high quality and long-life span | [22, 27, 28, 32] |
| S69 | Use eco-design OR smart design | Use environmentally friendly and smart designs | [2, 8, 19, 25, 33] |
| S70 | Use eco-labelled materials | Use authorised environmentally friendly materials | [28, 32] |
| S71 | Use of disassembled materials/ components | Use materials/components that can be dismantled easily | [17, 27, 26, 32] |
| S72 | Use of hybrid system solutions | Use of materials or parts that are bio-based, technical, and/or reused | [15] |
| S73 | Use less or emission-intensive transportation | Reduce, or emission-intensive transportation as much as possible | [1, 13, 35] |
| S74 | Use of lightweight materials and components | Use the material/component with lightweight | [17, 21, 28, 29] |
| S75 | Use of local material | Use locally available material | [13, 25, 26, 29, 31, 32] |
| S76 | Use of low-carbon materials and technologies | Use materials/technology that have low-carbon emission | [16, 26, 29] |
| S77 | Use of modular elements or components | Construct with standardised units or dimensions for flexibility and variety in use | [5, 13, 21, 22, 25, 26, 29, 32] |
| S78 | Use prefabricated materials/ components/ elements | Use materials, components, or elements that are manufactured off-site | [2, 5, 7–10, 12, 19, 21, 23, 24, 26, 29, 30, 32, 35] |
| S79 | Use of reclaimed or remanufactured elements | Use elements or components that were remanufactured or reclaimed | [5, 28] |
| S80 | Use of recycled materials | Use materials that can be recycled | [1, 2, 13, 15, 22, 27–29] |
| S81 | Use of recyclable materials | Use materials that can be recycled | [3, 19, 27–29, 32] |
| S82 | Use reusable materials | Use materials that can be reused | [2, 3, 7, 12–14, 15, 21, 27–29, 31–32] |
| S83 | User behaviour and ownership | Change of use of materials, by giving it ownership to the manufacturers to reuse the materials after the end of life of the first building | [11, 12, 17] |

(continued)

**Table 1** (continued)

| No | CE strategies | Description | Sources |
|---|---|---|---|
| S84 | Virtualise information using the latest technology | Use the latest technology (e.g. BIM, digital twin) to virtualise the information | [4, 7, 8, 10, 12, 21, 26, 29] |
| S85 | Waste minimisation | Set of processes and practices intended to reduce the amount of waste produced | [2, 3, 8, 12, 17, 22] |
| S86 | Zero-waste strategy | Keeping waste out of landfills and encouraging to produce and consume less waste | [7, 15, 17] |

[1]—Nasir et al. [42], [2]—Adams et al. [1], [3]—Cayzer et al. [14], [4]—Swift et al. [57], [5]—Mangialardo and Micelli [36], [6]—Huang et al. [29], [7]—Akanbi et al. [2], [8]—Chang and Hsieh [15], [9]—Esa et al. [21], [10]—Ruiz et al. [53], [11]—Anastasiades et al. [7], [12]—Benachio et al. [11], [13]—Gallego-Schmid et al. [22], [14]—Jansen et al. [31], [15]—Kanters [33], [16]—Mercader-Moyano and Esquivias [38], [17]—Morseletto [40], [18]—Sanchez et al. [54], [19]—Akhimien et al. [4], [20]—Antonini et al. [9], [21]—Bertino et al. [12], [22]—Cimen [16], [23]—Dams et al. [18], [24]—Kosanovic et al. [34], [25]—Marika et al. [37], [26]—Rahla et al. [48]; [27]—Rahla et al. [49]; [28]—Wijewansha et al. [59], [29]—Torgautov et al. [58], [30]—Al-Obaidy et al. [5]; [31]—Dabaieh et al. [17]; [32]—Eberhardt et al. [19], [33]—Huang et al. [28], [34]—Ruiter et al. [52], [35]—Spisakova et al. [56]

emissions compared to reusing some materials. Although 27 out of the 35 studies in Fig. 5 take energy into account, far less attention is given to energy when talking about CE strategies. The amount of energy utilised throughout the building process and also in the production of construction materials is crucial [38]. Another study by [59] acknowledges renewable energy as a CE's principal source of energy, lowering its dependence on fossil fuels for energy production. Further authors mentioned that construction requires a significant amount of energy, as does the process of obtaining and producing building materials.

Table 2 clearly shows that CE strategies provide significantly greater attention to reduce, reuse, and recycle with more than 20 strategies, which is confirmed in Fig. 3 and which implies the necessity to pay attention to the other 14 R-imperatives. Retain, return, retrofit, reverse, and recondition were not available in Fig. 3, whilst according to Table 2, refuse, renew, and reverse got the least attention in the CE strategies. The categorisations are based on direct mentioned by various authors and authors' best judgement after careful reading. The direct mentions are shown in black colour and authors' interpretations are shown in red colour.

Further, the majority (more than half) of the strategies used in the material lifecycle are related to the design phase and the manufacturing phase, but according to Fig. 4, although the design phase got the second largest percentage (26.4%), manufacture got the least attention with just 7.5%. In the case of construction, which got the highest attention in Fig. 4, it got fifth place within these six material lifecycle stages with one-third of total CE strategies. According to Fig. 4, the use and maintenance stages are followed by the end-of-life stage, yet in Table 2, the order is reversed.

Furthermore, when looking into these CE strategies, the CE strategies are interconnected with one another, irrespective of the stage at which they are applied. In

**Table 2** The CE strategies (in Table 1) with CE principles and stages of building material life cycle

| CE strategies | R-imperatives | Lifecycle stages | | | | | | CE strategies | R-imperatives | Lifecycle stages | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | | | A | B | C | D | E | F |
| S1 | R6, R14 | Y | Y | Y | | Y | Y | S44 | *G* | Y | Y | Y | Y | Y | Y |
| S2 | R5, *R17* | Y | Y | | | | | S45 | *G*, R6, R7, R14 | Y | Y | Y | Y | Y | Y |
| S3 | *G* | Y | | | | | Y | S46 | *G* | Y | Y | Y | Y | Y | Y |
| S4 | *G* | Y | Y | Y | Y | Y | Y | S47 | R5, R6, R14, R15, R16, R17 | Y | Y | | Y | Y | |
| S5 | *G, R6, R8* | | | | | Y | | S48 | *R6, R8* | | | | | Y | |
| S6 | *R6, R7*, R14, R17 | Y | Y | | Y | Y | Y | S49 | *R6* | Y | Y | Y | | Y | |
| S7 | *G* | Y | Y | | Y | | | S50 | *R6* | | Y | Y | Y | Y | |
| S8 | *G* | Y | Y | Y | Y | Y | Y | S51 | *G* | Y | Y | Y | Y | Y | Y |
| S9 | R7, *R9, R11*, R12, *R13*, R14, *R15, R16* | Y | Y | Y | Y | Y | Y | S52 | *G* | Y | Y | Y | Y | Y | Y |
| S10 | R7, R8, R9, R10, R11, R12, R13 | Y | | | | Y | | S53 | *R2, R6, R8* | | | | | Y | |
| S11 | R7, R8, R9, R10, R11, R12, R13 | Y | | | | | | S54 | R7, R8 | | Y | | | | |
| S12 | R14, R15, R16, R17 | Y | | Y | | | | S55 | *G* | | Y | | | | |
| S13 | R7, R8, R9, R10, R11, R12, R13 | Y | | Y | | | | S56 | *R6*, R10, *R11*, R12, *R13, R14* | | Y | | | | Y |
| S14 | *R7, R14, R15, R16* | Y | | Y | | | Y | S57 | *G* | | Y | Y | Y | Y | Y |
| S15 | R7, R13 R14, R15, R16, R17 | Y | | | | | Y | S58 | *G* | | | | Y | Y | Y |

(continued)

**Table 2** (continued)

| CE strategies | R-imperatives | Lifecycle stages | | | | | | CE strategies | R-imperatives | Lifecycle stages | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | | | A | B | C | D | E | F |
| S16 | R6, R7, R8, R9, R10, R11, R12, R13 | Y | | | | | | S59 | *R6* | *Y* | Y | | | | |
| S17 | R6, R7, R8, R9, R10, R11, R12, R13 | Y | | | | *Y* | | S60 | *G* | | *Y* | | *Y* | *Y* | |
| S18 | R8, R9, R12, R13 | Y | | | | | | S61 | R3, R15 | | Y | *Y* | *Y* | Y | |
| S19 | *R1, R2, R6* | Y | *Y* | | | | | S62 | R7, R14 | | | | | | Y |
| S20 | *R11, R12, R13* | Y | *Y* | | | | | S63 | R7, *R12, R13*, R14, *R15, R16* | Y | Y | Y | | | Y |
| S21 | R6 | Y | | | Y | | | S64 | *R1, R2, R6*, R7 | | Y | | *Y* | *Y* | |
| S22 | *R1, R2, R6* | Y | | | | | | S65 | *R4*, R7 | | Y | | | | Y |
| S23 | R5, R6 | Y | | | | | | S66 | *G* | | *Y* | | | | |
| S24 | R6 | Y | | | *Y* | | | S67 | R16 | Y | | Y | | *Y* | |
| S25 | R14, R15, R16, R17 | Y | | | | | *Y* | S68 | R6, R7 | | Y | Y | | *Y* | |
| S26 | R14 | Y | | | | | | S69 | *G* | Y | | | | | |
| S27 | R6, R7, R8, R9, R10, R11, R12, R13, R14 | Y | | | | | | S70 | *G* | | *Y* | *Y* | | *Y* | |
| S28 | R7 | Y | | | | | | S71 | *R1, R2*, R6, R7 | | *Y* | *Y* | | | |
| S29 | R6, R7, R8, R9, R10, R11, R12, R13, R14 | Y | *Y* | | | | | S72 | *G* | Y | | Y | | *Y* | |
| S30 | *G* | Y | | | | | | S73 | R14, R15, R16, R17 | | Y | Y | *Y* | *Y* | *Y* |
| S31 | R14, R15, R16, R17 | Y | | *Y* | | | | S74 | R6 | *Y* | *Y* | *Y* | | *Y* | |

(continued)

**Table 2** (continued)

| CE strategies | R-imperatives | Lifecycle stages | | | | | | CE strategies | R-imperatives | Lifecycle stages | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | | | A | B | C | D | E | F |
| S32 | R7, R8, R9, R10, R11, R12, R13 | Y | | | | *Y* | | S75 | R6 | Y | Y | Y | | *Y* | |
| S33 | *R2*, R6 | Y | | | | | | S76 | R14, R15, R16, R17 | Y | Y | Y | | *Y* | |
| S34 | *R8, R9, R10, R11* | | | Y | | Y | Y | S77 | R6 | | | *Y* | *Y* | *Y* | |
| S35 | *G*, R7, R14 | *Y* | *Y* | | *Y* | *Y* | | S78 | R6 | | Y | Y | Y | Y | |
| S36 | *G* | *Y* | *Y* | *Y* | *Y* | *Y* | *Y* | S79 | R7, R12 | | Y | Y | | | *Y* |
| S37 | R12, R13, R14, R15, R16 | | *Y* | | *Y* | *Y* | *Y* | S80 | R14 | | Y | Y | Y | Y | |
| S38 | *G* | *Y* | *Y* | *Y* | *Y* | *Y* | *Y* | S81 | R14 | | Y | Y | Y | Y | |
| S39 | *G* | *Y* | *Y* | *Y* | *Y* | *Y* | *Y* | S82 | R7 | | Y | Y | Y | *Y* | Y |
| S40 | R15 | | | Y | | | *Y* | S83 | *G* | | Y | | | | |
| S41 | *G* | *Y* | *Y* | | | | *Y* | S84 | R17 | *Y* | *Y* | *Y* | *Y* | *Y* | *Y* |
| S42 | *G* | | *Y* | | Y | *Y* | | S85 | R6 | | *Y* | *Y* | Y | *Y* | *Y* |
| S43 | R1, R2, R6, *R7* | Y | Y | | | | | S86 | *G* | *Y* | *Y* | *Y* | *Y* | *Y* | *Y* |

[A]—design/redesign; [B]—manufacture; [C]—material selection and procurement; [D]—construction; [E]—use and maintenance; [F]—end of life and recover; [R1]—retain; [R2]—refuse; [R3]—renew; [R4]—reverse; [R5]—rethink; [R6]—reduce; [R7]—reuse; [R8]—repair; [R9]—retrofit; [R10]—refurbish; [R11]—recondition; [R12]—remanufacture; [R13]—repurpose; [R14]—recycle; [R15]—recover; [R16]—return; [R17]—replace; [G]—general strategies; [Y]—available; Roman—available in existing studies; Italic—authors' contribution terms of design principles, design for adaptability (DfA) and design for disassembly (DfD) are well-established ideas in both the manufacturing and building sectors [18]. The way a product is designed becomes crucial to close material loops, and these two strategies for design overlap with one another [7]. Further authors stated that DfA and DfD make it easier for products to be repaired, reconditioned, and refurbished to keep them in use for as long as possible. This will result in a longer lifetime for the product, which will result in less consumption. Gallego-Schmid et al. [22] highlighted that the DfD is a critical approach to facilitating material reuse, including the creation of methods to estimate possible reductions in carbon emissions. Accordingly, DfA is used during the design phase to keep focus on the use and end-of-life stages, for instance, it enables the building to be enlarged horizontally or vertically and DfD ensures that the various materials can be readily separated for recycling [18]. Therefore, DfA can support the "easy for repair, maintenance and upgrade" strategy of the use stage, and DfD is associated with the "material recovery and reprocessing" strategy of the end-of-life stage. Similarly, Kanters [33] concluded that design for deconstruction (DfDe) enhances the flexibility of buildings. In DfDe, each building is viewed as a storehouse for resources that, at the end of their useful lives, should find their way back rather than being disposed of. A deconstruction plan is required to enable the deconstruction activities to be successful, which could be related to the strategy of "appropriately managing change using the PDCA cycle" or "development of a material passport" [12]. Further, Gallego-Schmid et al. [22] say that deconstruction activities must be carried out by skilled deconstruction experts, which could be raised by the strategy "Raising the level of awareness and providing training".

It is crucial to recognise that in addition to the relatively easy product design, the success of the CE also heavily depends on the less easily controllable user's behaviour [7]. Most consumers are ignorant of the adverse effects of their purchase patterns and refuse to accept responsibility for changing them. This uncertainty necessitates re-evaluating the CE's ownership idea, and it is offered to the end user as a service. Furthermore, this provides the manufacturer with an incentive to engage in more intelligent product design, such as DfA and DfD, and to produce higher-quality products. On the other hand, the "introduction of economic incentive or awarding schemes" can be used to change the behaviour such as disposal charging schemes that encourage waste producers to prioritise CE principles over disposal, as they can reduce disposal costs [53]. Further Morseletto [40] mentioned that multiple tactics can be used to promote desirable behaviours, such as implementing durability standards, extending warranty periods, ensuring producers' accountability, or promoting zero-waste products whenever feasible. Accordingly, specific targets can also be used in conjunction with legislative (e.g. laws, regulations) and semi-legislative (e.g. standards' guidance, recommendations) or market-based (e.g. taxes, liabilities) and non-market-based instruments (e.g. reporting, voluntary approaches). Materials can be divided into two categories: technical (intended to be reused at the end of the product life cycle) and bio-based (generally non-toxic, to be safely released back into the biosphere or placed through a cascade of successive uses) [59]. Sustainably managed bio-based materials can offer a renewable supply chain and reduce carbon emissions through the natural processes of bio-material sequestering carbon, thus locking carbon into constructed buildings [18]. Here, the CE strategies of "minimise hazardous and toxic materials," "use of bio-based or biodegradable materials," and "design for a biological cycle" are interrelated.

The CE strategy and application of modern techniques and technologies are cited in twelve articles, but each of them discusses the same as well as different techniques or technologies. For instance, in the case of technologies, Adams et al. [1] discussed off-site technologies, whereas Torgautov et al. [58] discussed eco-friendly technologies, Mangialardo and Micelli [36] and Spisakova et al. [56] studied modern construction techniques, and Bertino et al. [12] discussed digital twins. Then talk about technologies: many studies discussed building information modelling (BIM), Spisakova et al. [56] discussed the Internet of Things (IoT), geographic information systems (GIS), and radio frequency identification (RFID). In addition to these techniques and technologies, innovative methods must be applied throughout the whole building life cycle to make CE practically feasible. Further, CE supports these kinds of innovative strategies, and much more innovation in this field is needed. Although this strategy relates directly to the latest technology, a few other strategies also indirectly relate to it. This implies the necessity of adopting the latest technology to achieve CE in the building sector. For example, using easily accessible RFID and BIM data can improve building adaptability, flexibility, and reuse of building materials or components through the ability to store useful data, including the site's location (country and building), owner of the component or assembly, type of component, the material used in construction, historical information about the component, dates of installation and removal, design standard, manufacturer, and its maintenance history [12]. Similar to this, there are already planning and execution strategies intended to take building deconstruction into account. For instance, BIM is a method for optimising the planning, construction, and management of buildings that includes all information relating to their lifecycles and connects all the actors in the building process along the different stages of the supply chain [12]. The authors further stated that this consequently enables figuring out the building's potential for deconstruction from the beginning of the design process, preventing demolition after the end of the lifecycle. In addition, Akanbi et al. [2] and Spisakova et al. [ 56] highlighted BIM as an information and communication tool for effective waste management in the building sector.

## 4 Conclusions

In this study, the current state of knowledge regarding the use of CE strategies within the building sector was investigated. This study was a continuation of the previous study of the authors [25], titled a systematic literature review on CE principles for the building sector, and a condensed list of 17 CE principles (R-imperatives) was derived with a logical link between the three popular domains of CE principles, including CE loops, the ReSOLVE model, and the R-framework (R-imperatives). A critical review carried out on 35 peer-reviewed scholarly articles retrieved through the systematic review using the PRISMA tool indicated that few of the studies (11 out of 35) represented the CE domain, and seven of these 11 studies discussed R-imperatives, which indicates that R-imperatives have received more attention in CE strategies applicable to the building sector. Within those seven, reuse was considered in all seven articles, whilst 14 (of 17) R-imperatives were focused on less than or equal to three. Further, five of the 17 R-imperatives, including retain, return, retrofit, revere, and recondition, were not considered in any of the studies. It shows the necessity of studies that discuss the CE strategies of the building sector concerning each R-imperative of the building sector. In addition, although almost all the studies describe the same building material's lifecycle stages, there are some differences in the way they are interpreted. To avoid confusion, this study adopts the stages that materials pass through in a typical material lifecycle: design or redesign, manufacture, material selection and procurement, construction, use and maintenance, end of life, and recovery. Moreover, the review provided a list of 86 CE strategies applicable to the building sector. Of the 86 strategies, most of the study contexts (over 12 out of 23) have identified few R-imperatives, including reduce, reuse, recycle, and reuse, whereas strategies towards retention and refuse are largely missing, although they are considered critical for the transition towards a CE. Furthermore, the CE strategies are interconnected with one another, irrespective of the stage at which they are applied. Most of the strategies focused on end of life and design, and to a lesser extent, the use stage. Technology plays a major role in CE strategies, both directly and indirectly, which underscores the necessity of technology for CE implementation. All selected studies considered materials and waste for CE strategy formation, while carbon and energy received much lesser focus on this. Thus, it is recommended to focus on carbon reduction and energy consumption to formulate CE strategies, and attention should also be given to other stages of the material flow except for design, material selection and procurement, manufacturing, and all other R-imperatives in the building sector. A detailed understanding of strategies provides useful insights for the stakeholders in the building sector to promote the transition towards CE in the building sector.

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## References


1. Adams KT, Osmani M, Thorpe T, Thornback J (2017) Circular economy in construction: current awareness, challenges, and enablers. Institution of Civil Engineers-Waste and Resource Management
2. Akanbi LA, Oyedele LO, Omoteso K, Bilal M, Akinade OO, Ajayi AO, Delgado JMD, Owolabi HA (2019) Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. J Clean Product 223:386–396. https://doi.org/10.1016/j.jclepro.2019.03.172
3. Akbarnezhad A, Xiao J (2017) Estimation and minimization of embodied carbon of buildings: a review. Buildings 7(5):271
4. Akhimien NG, Latif E, Hou SS (2021) Application of circular economy principles in buildings: a systematic review. J Build Eng 38:102041. https://doi.org/10.1016/j.jobe.2020.102041
5. Al-Obaidy M, Courard L, Attia S (2020) A parametric approach to optimizing building construction systems and carbon footprint: a case study inspired by circularity principles. Sustainability 14:3370. https://doi.org/10.3390/su14063370
6. Alhawari O, Awan U, Bhutta M, Ali Ulku M (2021) Insights from circular economy literature: a review of extant definitions and unravelling paths to future research. Sustainability 13(859):1–22
7. Anastasiades K, Blom J, Buyle M, Audenaert A (2020) Translating the circular economy to bridge construction: lessons learnt from a critical literature review. Renew Sustain Energy Rev 117:109522
8. Anderson N, Wedawatta G, Rathnayake I, Domingo N, Azizi Z (2022) Embodied energy consumption in the residential sector: a case study of affordable housing. Sustainability 14(9):5051
9. Antonini E, Boeri A, Giglio F (2021) Classification criteria and markers for biomimetic building envelope within circular economy principles: a critical review. Architect Eng Des Manag 18:387–409
10. Askar R, Braganca L, Gervasio H (2022) Design for adaptability (DfA)—frameworks and assessment models for enhanced circularity in buildings. Appl Syst Innov 5:24
11. Benachio GLF, Freitas MDCD, Tavares SF (2020) Circular economy in the construction industry: a systematic literature review. J Clean Product 260:121046
12. Bertino G, Kisser J, Zeilinger J, Langergraber G, Fischer T, Osterreicher D (2021) Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials. Appl Sci 11:939. https://doi.org/10.3390/app11030939
13. Brutting J, De Wolf C, Fivet C (2019) The reuse of load-bearing components. In: IOP conference series: earth and environmental science
14. Cayzer S, Griffiths P, Beghetto V (2017) Design of indicators for measuring product performance in the circular economy. Int J Sustain Eng 10(4–5):289–298
15. Chang YT, Hsieh SH (2019) A preliminary case study on circular economy in Taiwan's construction. In: IOP conference series: earth and environmental science
16. Cimen O (2021) Construction and built environment in circular economy: a comprehensive literature review. J Clean Product 305:127180
17. Dabaieh M, Maguid D, El-Mahdy D (2020) Circularity in the new gravity—re-thinking vernacular architecture and circularity. Sustainability 14:328. https://doi.org/10.3390/su14010328
18. Dams B, Maskell D, Shea A, Allen S, Driesser M, Kretschmann T, Walker P, Emmitt S (2021) A circular construction evaluation framework to promote designing for disassembly and adaptability. J Clean Product 316:128122
19. Eberhardt LCM, Birkved M, Birgisdottir H (2022) Building design and construction strategies for a circular economy. Architect Eng Des Manag 18(2):93–113. https://doi.org/10.1080/17452007.2020.1781588
20. Ellen MacArthur Foundation (2015) Circularity indicators an approach to measuring circularity. https://ellenmacarthurfoundation.org/search

21. Esa MR, Halog A, Zulkepli J, Rigamonti L, Shaari SM (2019) A circularity-based planning approach for construction and demolition (C&D) waste management: a case study of Malaysia. In: MATEC web of conferences
22. Gallego-Schmid A, Chen HM, Sharmina M, Mendoza JMF (2020) Links between circular economy and climate change mitigation in the built environment. J Clean Product 260:121115
23. Ghisellini P, Ripa M, Ulgiati S (2018) Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector: a literature review. J Clean Product 178:618–643
24. Gowsiga M, Ramachandra T, Sridarran P, Thurairajah N (2022) A critical review on definitions of circular economy in the built environment. In: Proceedings of the 13th international conference on sustainable built environment
25. Gowsiga M, Ramachandra T, Sridarran P, Thurairajah N (2023) Principles of circular economy for building sector: a systematic review. In: Proceedings of the 11th world construction symposium
26. Grover R (2020) Towards zero carbon buildings: reducing the embodied carbon footprint of a construction
27. Hertwich EG, Ali S, Ciacci L, Fishman T, Heeren N, Masanet E, Asghari FN, Olivetti E, Pauliuk S, Tu Q, Wolfram P (2019) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Environ Res Lett 14(4):043004
28. Huang H, Wang H, Hu YJ, Li C, Wang X (2022) The development trends of existing building energy conservation and emission reduction: a comprehensive review. Energy Rep 8:13170–13188
29. Huang B, Wang X, Kua H, Geng Y, Bleischwitz R, Ren J (2018) Construction and demolition waste management in China through the 3R principle. Resour Conser Recycl 129:36–44
30. Huberman N, Pearlmutter D (2008) A life-cycle energy analysis of building materials in the Negev desert. Energy Build 40(5):837–848
31. Jansen BW, van Stijn A, Gruis V, van Bortel G (2020) A circular economy life cycle costing model (CE-LCC) for building components. Resour Conser Recycl 161:104857. https://doi.org/10.1016/j.resconrec.2020.104857
32. Joensuu T, Edelman H, Saari A (2020) Circular economy practices in the built environment. J Clean Product 12:276
33. Kanters J (2020) Circular building design: An analysis of barriers and drivers for a circular building sector. Buildings 10(4):77
34. Kosanovic S, Miletic M, Markovic L (2021) Energy refurbishment of family houses in Serbia in line with the principles of circular economy. Sustainability 13:5463. https://doi.org/10.3390/su1310546
35. Littell J, Corcoran J, Pillai V (2008) Systematic reviews and meta-analysis. Oxford University Press, Oxford
36. Mangialardo A, Micelli E (2018) Rethinking the construction industry under the circular economy: principles and case studies. In: Smart and sustainable planning for cities and regions: results of SSPCR 2017 2, pp 333–344
37. Marika G, Beatrice M, Francesca A (2021) Adaptive reuse and sustainability protocols in Italy: relationship with circular economy. Sustainability 13:8077. https://doi.org/10.3390/su13148077
38. Mercader-Moyano P, Esquivias PM (2020) Decarbonization and circular economy in the sustainable development and renovation of buildings and neighbourhoods. Sustainability 12(19):7914
39. Minunno R, O'Grady T, Morrison G, Gruner R, Colling M (2018) Strategies for applying the circular economy to prefabricated buildings. Buildings 8(9):125
40. Morseletto P (2020) Targets for a circular economy. Resour Conser Recycl 45:153. https://doi.org/10.1016/j.resconrec.2019.104553
41. Murano MR, Tavares SF, Braganca L (2020) Towards circular and more sustainable buildings: a systematic literature review on the circular economy in the built environment. J Cleaner Prod 260

42. Nasir MHA, Genovese A, Acquaye AA, Koh SCL, Yamoah F (2017) Comparing linear and circular supply chains: a case study from the construction industry. Int J Product Econ 183:443–457
43. Nikolaou I, Jones N, Stefanakis A (2021) Circular economy and sustainability: the past, the present and the future directions. Circul Econ Sustain 1(1):1–20
44. Organisation for Economic Cooperation and Development [OECD] (2014) Measuring and managing results in development co-operation A review of challenges and practices among DAC members and observers. OECD Development Co-operation Directorate
45. Osobajo O, Oke A, Omotayo T, Obi L (2020) A systematic review of circular economy research in the construction industry. Smart Sustain Built Environ 11:39–64
46. Pomponi F, Moncaster A (2018) Scrutinising embodied carbon in buildings: the next performance gap made manifest. Renew Sustain Energy Rev 81:2431–2442
47. Potting J, Hekkert M, Worrell E, Hanemaaijer A (2017) Policy report: circular economy: measuring innovation in the product chain. PBL Netherlands Environmental Assessment Agency
48. Rahla KM, Mateus R, Braganca L (2021) Implementing circular economy strategies in buildings—from theory to practice. Appl Syst Innov 4:26. https://doi.org/10.3390/asi4020026
49. Rahla KM, Mateus R, Braganca L (2021) Selection criteria for building materials and components in line with the circular economy principles in the built environment: a review of current trends. Infrastructures 6:49. https://doi.org/10.3390/infrastructures6040049
50. Reike D, Vermeulen WJ, Witjes S (2018) The circular economy: new or refurbished as CE 3.0? Resour Conserv Recycl 135:246–264
51. Rios F, Grau D (2020) Circular economy in the built environment: designing, deconstructing, and leasing reusable products. Encycl Renew Sustain Mater 5:338–343
52. Ruiter H, De Feijter F, Wagensveld K (2022) Management control and business model innovation in the context of a circular economy in the Dutch construction industry. Sustainability 14:366. https://doi.org/10.3390/su14010366
53. Ruiz LAL, Ramon XR, Domingo SG (2019) The circular economy in the construction and demolition waste sector: a review and an integrative model approach. J Clean Product 248:119238. https://doi.org/10.1016/j.jclepro.2019.119238
54. Sanchez B, Rausch C, Haas C, Saari R (2020) A selective disassembly multi-objective optimization approach for adaptive reuse of building components. Resour Conser Recycl 154:104605
55. Smol M, Kulczycka J, Avdiushchenko A (2016) Circular economy indicators in relation to eco-innovation in European regions. Clean Technol Environ Policy 19:669–678
56. Spisakova M, Mandicak T, Mesaros P, Spak M (2022) Waste management in a sustainable circular economy as a part of design of construction. Appl Sci 12:4553. https://doi.org/10.3390/app12094553
57. Swift J, Ness D, Kim K, Gelder J, Jenkins A, Xing K (2017) Towards adaptable and reusable building elements: harnessing the versatility of the construction database through RFID and BIM. In: UIA Seoul world architects congress, Seoul, pp 3–10
58. Torgautov B, Zhanabayev A, Tleuken A, Turkyilmaz A, Mustafa M, Karaca F (2021) Circular economy: challenges and opportunities in the construction sector of Kazakhstan. Buildings 11:501. https://doi.org/10.3390/buildings11110501
59. Wijewansha AS, Tennakoon GA, Waidyasekara KGAS, Ekanayake BJ (2021) Implementation of circular economy principles during pre-construction stage: the case of Sri Lanka. Built Environ Project Asset Manag 4:750–766

# Factors Influencing Circular Economy Adoption in the South African Construction Sector

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## 1 Introduction

Circular economy (CE) has been propagated by the European Union (EU), and governments of nations, which includes those of Japan, China, the UK, Canada, France, Sweden, Finland, and the Netherlands, together with numerous enterprises across the globe. Based on an assessment conducted by the European Commission, the manufacturing sector of the EU might make an annual gain of up to 600 billion euros from economic reforms associated with CE [14, 17]. Estimations provided by the Finland Independence Celebration Fund (FICF, SITRA) and Mckinsey [19] show that CE will benefit the national economy of Finland annually by 2.5 billion euros. CIRAIG [8] opined that in 2008, China became the first country globally to enact a law governing CE. As a strategy for growth is consistent with sustainability and economic advancement, CE is advised [39]. The concept of CE can be summed up as an economic model that focuses on maximizing the efficiency of resources through value retention, the reduction of waste, the reduction of primary resources, and closed-loop production for items, component parts, and materials while maintaining socioeconomic and environmental protection. A CE might result in sustainable development while separating economic expansion from the detrimental effects of depletion of resources and environmental damage [3, 22].

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The traditional and current "extract-produce-use-dump" paradigm for energy and material flow of the contemporary economic system is not sustainable. An alternate, cyclical flow model for the economy is provided by CE [14]. Since the beginning of industrialization, the idea of material cycles has existed. Desrochers [11] posited that the idea has also been used in practice, asserting that it reduces detrimental environmental consequences and opens up new opportunities for business right from the start of industrialization. However, the whole development has been controlled by the linear consumption flow paradigm, significantly hurting the environment. Unlike conventional recycling, the realistic regulations and business-focused CE strategy lay emphasizes on product, material, and component reuse, refurbishment, remanufacturing, repair, upgrading, and cascading, as well as the use of wind, solar, biomass, and waste-derived energy, all through the value chain of products and life cycle [14]. Hence, several studies have attempted to look up the concept by conducting literature reviews that expand knowledge on CE in an attempt to promote the paradigm shift. For example, the reuse, reduce, and recycle (3Rs) taxonomy, value creation along the supply chain [38], and circular business models [5, 27] are a few research that has covered these topics. Much study has recently focused on clarifying the CE as a paradigm, its relationship to sustainable development, and the many ideas that characterize it [21, 25]. Despite using various approaches, each of these investigations has the same objective.

Without a doubt, the environmental strategy of whoever adopts CE will benefit from its implementation [29], and it will also likely result in an excellent economic strategy [46]. Thus, some sectors are already adopting and implementing its principles. According to Eberhardt et al. [13], methods for CE are being created and implemented more in the construction sector now, although the process has been inconsistent and lacks a widely accepted or set direction. It is important to note that as economic development increases, the world has started to pay more attention to sustainability and the environment. The construction sector attracts much attention since it uses many resources and energy and has a significant environmental impact. The construction sector, as opined by Majdalani et al. [28], is critical because it supplies the infrastructure and services that affluent nations require to continue economic growth. This growth comes at a cost since it depletes natural resources, harming the environment and all living beings. The status of the environment is one of the most often contested topics at local, national, and international levels [2]. According to Du Plessis [12], the construction sector has a particularly harmful environmental impact in developing nations such as South Africa. This is owing to emerging countries' low degree of industrialization and continuous construction activities.

The construction industry uses a large quantity of non-renewable natural resources. Thus, the end-of-life phase of construction projects is considered the least sustainable, considering how much waste the demolition process produces [9]. Furthermore, the environment is a significant source of construction materials such as aggregates, sand, and wood. According to research, building construction consumes 25% world's virgin timber, and 40% of raw stones, gravel, and sand each year [2, 40]. In addition, it consumes 16% of water and 40% of the energy used in a year.

The enormous increase in energy consumption, as well as the use of finite fossil fuel resources for the purpose of construction, has had an impact on $CO_2$ emissions. Sterner [41] revealed that the construction industry is the principal cause of environmental damage owing to its high energy demand for home heating and electricity. Most of this energy is produced from non-renewable resources such as coal and petroleum-based goods. Hence, the industry is responsible for widespread deforestation, particularly in developing countries. Timber, for example, is mainly extracted from natural forests for construction and to create the energy required to manufacture building components. According to Kibert [24], around 0.8 ha of rainforest are destroyed each second due to deforestation worldwide. As a result, around 1.8 billion tons of $CO_2$ are emitted yearly. Additionally, cutting down trees and their roots can cause avalanches and landslides. Other indirect effects include desertification, siltation of waterways, loss of biodiversity, and soil erosion. Large-scale deforestation alters rainfall patterns by changing the energy and temperature of the earth's surface and the rate at which surface water is absorbed. Furthermore, construction activities that result in the formation of structures like houses, roads, and dams [2, 36] irreversibly modify critical farmland and forests. Other activities that contribute to land loss include quarrying and mining for building raw materials, as well as the disposal of waste created during construction.

Hence, CE is promoted in the construction industry as a low-cost practice of converting resources into materials that may be utilized in other processes and products [37]. It will address aspects like recycling resources, streamlining the supply chain and the quantity of materials required, enhancing the planning and design phase, and implementing new eco-friendly technology. So, it has a significant chance of lowering carbon emissions and overall waste from the construction sector. Bao et al. [4] opined that saving the value of buildings and their parts while minimizing construction and demolition waste (C&DW) is the primary goal of CE. This includes the whole life cycle of the building construction process, commencing with building design, manufacture of building materials and components, building usage, and demolition after use. According to Business in the Community (BITC) [7], the following are a few prevalent CE uses in construction projects: reduced use of materials made from carbon, use of fuel ash and crushed slag as cement substitutes, the use of lighter materials, reuse of numerous smaller structures to create one larger structure, usage of wooden components and façade from previous structures, use of the modular construction approach using steel from older structures, the installation of solar panels, the use of readily available biomaterials in the area, and the use of PVC that has been completely recycled and recyclable from electric cable covers, pipes, and hose, development on polluted soil. Considering the above-mentioned prevalent CE use in construction projects and the fact that there is no study that has identified the factors or rationale behind the use or adoption of CE in the South African (SA) construction industry, this study seeks to evaluate the factors influencing the adoption of CE in the country's construction sector. To achieve this aim, extant literature is reviewed to understand the factors influencing the adoption of CE in the construction sector and then benchmarking the influencing factors in the

SA construction sector. Based on the study's findings, the influencing factors to CE adoption in the SA construction sector will be proposed.

## 2 Method

The research adopted a post-positivist stance, rooted in quantitative research methodology, to investigate the factors influencing the adoption of Circular Economy (CE) practices in the South African construction sector. Employing a questionnaire survey as the primary data collection method, the study comprised two distinct segments. The first segment of the questionnaire focused on gathering background data from the participants, who were qualified construction professionals—engineers, architects, quantity surveyors, and construction managers—with a minimum of five years of industry experience. The study specifically targeted professionals operating within the Gauteng Province, South Africa. Due to practical constraints, a convenience sampling method was employed. A total of 145 questionnaires were distributed to the construction professionals, and 97 completed responses were deemed suitable for analysis. The second segment of the questionnaire aimed to address the identified factors influencing the adoption of Circular Economy practices within the South African construction context. Participants were requested to assess the significance of these factors using a five-point Likert scale, ranging from 1 (not significant) to 5 (strongly significant). To ensure the reliability of the questionnaire, a Cronbach's alpha test was conducted, yielding a robust alpha value of 0.826. This result, surpassing the conventional cutoff point of 0.6, attests to the high reliability of the questionnaire according to established standards [42]. In the subsequent data analysis, standard deviation, percentages, mean item scores, one-sample t-test, and Kruskal–Wallis tests were employed, following the methodology adopted by Otasowie and Oke [33]. These statistical tools were instrumental in elucidating patterns and trends within the collected data, providing a comprehensive understanding of the factors influencing the adoption of circular economy practices in the South African construction sector. The study's meticulous approach to data analysis, coupled with the validation of questionnaire reliability, enhances the credibility and robustness of the research findings. This research contributes valuable insights into the dynamics of circular economy adoption within the construction industry, particularly in the South African context.

## 3 Results

The survey conducted in South Africa's Gauteng Province involved the participation of construction professionals. The survey revealed a diverse representation of the profession, with quantity surveyors leading the way at 28% involvement, followed by engineers (22%), architects (20%), construction managers (18%), and project managers for construction (12%). In terms of educational background, a significant majority of respondents (65.2%) held bachelor's degrees. The subsequent levels of education varied, with 6.9% holding certificates, 14.5% having master's degrees, and 13.4% possessing doctoral degrees. This distribution indicates a well-educated sample, providing a solid foundation for comprehending the survey questions. The respondents collectively demonstrated substantial industry experience, with an average working history of 8.4 years. This extended period in the field suggests a seasoned group of professionals, adding credibility to their responses. The findings underscore that the study's target respondents, namely construction professionals, were not only adequately represented but also possessed the necessary educational background and professional expertise to provide informed answers to the survey questions [34]. The depth of professional experience among the respondents further enhances the reliability and depth of insights derived from the survey results.

The investigation employed a one-sample t-test to assess the perceived importance of specific factors among respondents. A comprehensive analysis of respondent views was conducted by tabulating the mean rank for each factor. The significance level, set at the customary 95% threshold following [35], deemed a factor significant if it achieved a mean rating of 3.5 or higher on the five-point Likert scale. Tables 1 and 2 outline the factors identified as influential in the adoption of circular economy (CE) within the South African construction sector. In Table 2, the observed data mean is accompanied by the standard deviation. In instances where multiple factors shared the same mean, priority ranking was assigned based on the factor with the lowest standard deviation, following the methodology suggested by [18]. The results of the one-sample t-test are presented in Table 1, offering insights into the significance of each factor. This approach provides a robust understanding of the factors shaping perceptions and influencing the adoption of CE in the South African construction industry.

Analyzing the *p*-values (significance—two-tailed) for each factor as outlined in Table 1, it is evident that respondents collectively expressed a consensus on the significant impact of certain listed factors on the adoption of CE in the South African construction sector. Simultaneously, some factors did not attain statistical significance. For each factor, the evaluation involved two distinct outcomes: one aligned with the null hypothesis (H0: $U = U_0$), indicating no significance, and the other corresponding to the alternative hypothesis (Ha: $U > U_0$), signifying significance. Here, the population mean ($U_0$) was predefined at 3.5. To delve further into the statistical outcomes, the p-values corresponding to a one-tailed test are elucidated in Table 2. This presentation followed a multiplication by half of the original *p*-value from Table 1.

The results show that potential business opportunity is the highest-ranked and the most significant influencing factor to CE adoption in the SA construction sector (MIS = 4.85, SD = 0.43). This was followed by production of waste (MIS = 4.74, SD = 0.32); exploitation of resources (MIS = 4.57, SD = 0.31); production of greenhouse gases (MIS = 4.45, SD = 0.33); contribution to pollution (MIS = 4.33, SD = 0.34); and climate change (MIS = 4.32, SD = 0.52). Others such as loss of edaphic soil (MIS

**Table 1** One-sample test for factors influencing circular economy adoption

| | | | | | 95% confidence interval of the diff | |
|---|---|---|---|---|---|---|
| Factors | T | Df | Sig. (two-tailed) | Mean diff | Lower | Upper |
| Contribution to pollution | 6.963 | 96 | 0.000 | 0.778 | 0.743 | 0.815 |
| Climate change | 5.723 | 96 | 0.001 | 0.719 | 0.821 | 0.943 |
| Deforestation | 4.165 | 96 | 0.154 | 0.589 | 0.772 | 0.847 |
| Habitat destruction | 4.207 | 96 | 0.163 | 0.612 | 0.726 | 0.916 |
| Potential business opportunity | 12.193 | 96 | 0.000 | 0.713 | 0.715 | 0.871 |
| Reduce the availability of arable land | 4.501 | 96 | 0.157 | 0.654 | 0.816 | 0.956 |
| Loss of marine life | 4.291 | 96 | 0.169 | 0.732 | 0.745 | 0.837 |
| Loss of edaphic soil | 5.134 | 96 | 0.161 | 0.721 | 0.634 | 0.848 |
| Removal of vegetation | 4.370 | 96 | 0.146 | 0.662 | 0.751 | 0.817 |
| Desertification | 4.432 | 96 | 0.166 | 0.619 | 0.823 | 0.941 |
| Production of greenhouse gases | 7.511 | 96 | 0.000 | 0.784 | 0.748 | 0.862 |
| Exploitation of resources | 9.112 | 96 | 0.000 | 0.723 | 0.853 | 0.973 |
| Interference with the ecosystem | 4.081 | 96 | 0.153 | 0.788 | 0.647 | 0.783 |
| Soil erosion | 4.631 | 96 | 0.172 | 0.629 | 0.768 | 0.824 |
| Production of waste | 9.591 | 96 | 0.002 | 0.668 | 0.766 | 0.841 |

DF = Degree of freedom

= 3.32, SD = 1.17); soil erosion (MIS = 3.31, SD = 1.19); reduce the availability of arable land (MIS = 3.30, SD = 1.22); desertification (MIS = 3.17, SD = 1.21); removal of vegetation (MIS = 3.05, SD = 1.43); and loss of marine life (MIS = 2.96, SD = 1.25) ranked low and not considered significant factors influencing CE adoption in SA construction sector.

Furthermore, an analysis was performed to assess the variation in responses across diverse construction professions using the Kruskal–Wallis test. The obtained p-values for all factors surpass the significance threshold of 0.05. This suggests that concerning the factors influencing the adoption of circular economy practices in the South African construction sector, there is no statistically significant difference among participants' responses. The detailed results are outlined in Table 3.

**Table 2** T-test summary showing factors influencing circular economy adoption

| Factors | $t$ | Sig. (one-tailed) | $\bar{x}$ | $\sigma x$ | $R$ |
|---|---|---|---|---|---|
| Potential business opportunity | 12.193 | 0.000 | 4.85 | 0.427 | 1 |
| Production of waste | 9.591 | 0.000 | 4.74 | 0.318 | 2 |
| Exploitation of resources | 9.112 | 0.000 | 4.57 | 0.307 | 3 |
| Production of greenhouse gases | 7.511 | 0.000 | 4.45 | 0.330 | 4 |
| Contribution to pollution | 6.963 | 0.000 | 4.33 | 0.341 | 5 |
| Climate change | 5.723 | 0.000 | 4.32 | 0.523 | 6 |
| Loss of edaphic soil | 5.134 | 0.008 | 3.32 | 1.166 | 7 |
| Soil erosion | 4.631 | 0.009 | 3.31 | 1.189 | 8 |
| Reduce the availability of arable land | 4.501 | 0.008 | 3.30 | 1.216 | 9 |
| Desertification | 4.432 | 0.008 | 3.17 | 1.212 | 10 |
| Removal of vegetation | 4.370 | 0.007 | 3.05 | 1.427 | 11 |
| Loss of marine life | 4.291 | 0.009 | 2.96 | 1.253 | 12 |
| Habitat destruction | 4.207 | 0.008 | 2.81 | 1.276 | 13 |
| Deforestation | 4.165 | 0.008 | 2.71 | 1.162 | 14 |
| Interference with the ecosystem | 4.081 | 0.008 | 2.69 | 1.130 | 15 |

$\sigma x$ = Standard deviation; $\bar{x}$ = Mean item score; $R$ = Rank

**Table 3** Test for Kruskal–Wallis showing *p*-values for factors influencing circular economy adoption

| Factors | *P*-values |
|---|---|
| Potential business opportunity | 0.060 |
| Production of waste | 0.082 |
| Exploitation of resources | 0.051 |
| Production of greenhouse gases | 0.072 |
| Contribution to pollution | 0.070 |
| Climate change | 0.061 |
| Loss of edaphic soil | 0.083 |
| Soil erosion | 0.049 |
| Reduce the availability of arable land | 0.063 |
| Desertification | 0.087 |
| Removal of vegetation | 0.058 |
| Loss of marine life | 0.086 |
| Habitat destruction | 0.047 |
| Deforestation | 0.073 |
| Interference with the ecosystem | 0.092 |

## 4 Discussion

From the study's results, the most significant factor influencing the adoption of CE in the SA construction sector is the business potential or opportunity provided by the concept. This was further confirmed by the Kruskal–Wallis test conducted. This study corroborates the position of EMF [15] that the ultimate goal of CE is to produce many forms of value to improve the resource effectiveness and efficiency of an economy in response to the mounting demand for natural resources. CE provides business opportunities by modifying how economic value and the understanding of items are addressed, It seeks to increase resource effectiveness and efficiency (by shortening or lengthening energy and resource loops) and ultimately close energy and resource flows [6, 10]. For instance, closing the loop in the supply chain for goods and resources results in cost savings, resource resilience, alternative revenue streams, and creative new products while also perhaps lowering consumption [16, 30, 32, 44]. By creating CE's "closed loop" in the construction sector, entrepreneurial circular economic activity within the sector may enhance economic development while maintaining environmental sustainability.

Furthermore, entrepreneurship depends on seeing possibilities and creating businesses [45]. According to the knowledge-based perspective, new information could provide the most significant competitive advantage [1]. Entrepreneurs' decisions are heavily influenced by differences in knowledge, their information emphasis, and their attitude toward that information [23]. In addition, market failures give birth to entrepreneurial possibilities, and environmental deterioration is one such market failure. Market failures brought about by a lack of information can lead to opportunities. CE opportunities, which include remanufacturing, reuse, or recycling, have not been fully utilized by conventional entrepreneurs in the construction sector or any other sector [16]. If it is profitable, construction entrepreneurs will be eager to practice sustainability. CE opportunities can reduce the volatility of global prices, promote innovation, boost employment, and strengthen the local economy. Hence, for greater entrepreneurship, more employment, better environmental circumstances, less construction waste dumped in landfills, enhanced economic sustainability, and decreased raw material needs, governments must promote the adoption of CE in the SA construction sector.

Also, the results of the study show that the production of waste is a significant factor influencing the adoption of CE in the SA construction sector. This was further confirmed by the Kruskal–Wallis test conducted. This result corroborates the findings of Torgautov et al. [43] and Bao et al. [4] that one of the significant reasons for CE adoption in construction is minimizing construction and demolition waste. Construction and demolition waste (CDW) is a collection of extra materials left behind after renovating, demolition, or erecting new buildings and other structures [26]. Since there is a lack of concern for CDW reduction in the early stages of a project, waste created by CD occurs across the life cycle of buildings, even during the planning and design phases. Due to this massive amount of CDW production and the world's rapid economic growth, there are significant adverse environmental effects. Thus, construction professionals are under increased pressure to promote CDW management techniques based on the 3Rs principle: reduce, recycle, and reuse. In this context, the construction sector is now being influenced by this pressure to consider the adoption of CE, which can help CDW management practices reach their potential economic and environmental advantages. In the CE paradigm, construction materials that have outlived their usefulness would be reused and their components and pieces would be dismantled and used as material banks for future construction, maintaining materials, and components in a closed loop.

Furthermore, the exploitation of resources is a significant factor influencing the adoption of CE in the SA construction sector as revealed by the study. This result corroborates the findings of Charef et al. [9]. It has been discovered that massive amounts of virgin materials are used by the construction sector. For instance, 8% of the global carbon dioxide emissions are produced by the cement sector alone [31]. There is a direct correlation between the rising global population and the rising demand for virgin materials required for manufacturing. Natural resources are heavily used due to the existing linear economy paradigm. The move to a more efficient CE model in the construction industry, which strives to address sustainability challenges on a higher level, comprises two important elements: improved recycling and the creation of material loops. For these reasons, major construction firms in Europe and other parts of the world are currently attempting to incorporate CE thinking into their business strategies, and while some of them have reported on cutting-edge and experimental initiatives, the widespread and thorough translation of such reasoning into construction operations is still at the embryonic stage.

Production of greenhouse gases, contribution to pollution, and climate change are other significant factors influencing the adoption of CE in the SA construction sector, as revealed by the study. Numerous environmental hazards, including noise, air pollution, liquid and solid waste, water pollution, hazardous gases, and dust, are produced by the building sector. According to the European Institute of Architects, the global emissions of greenhouse gases (GHGs) from the construction sector account for 42% of all GHG emissions and 50% of air pollution [20]. Meanwhile, it is expected that with the growing rate of urbanization, GHG emissions from the building sector will continue to rise. These GHG emissions bring about climate change. As a result, building GHG emissions have been the subject of several research to manage the construction industry's GHG emissions as demand to find ways to lower these emissions grows. Such research has led to the discovery that the shift to a CE has the potential to lower GHG emissions. For instance, the design for disassembly, repairability, modularity, adaptability, and biodegradability aids the processes of reuse, remanufacturing, refurbishing, or regeneration and so contributes to waste minimization. By eliminating the manufacture and use of new materials and end-of-life processes like incineration or landfilling, the usage of recycling materials in the system can lower GHG emissions. Utilizing renewable resources in the construction sector would help cut GHG emissions. Therefore, the CE initiatives may have a substantial influence on the sustainable development goals, the global effort to battle climate change, and the reduction of GHG emissions. Hence, the SA construction sector is slowly adopting its principles.

However, other factors such as deforestation, soil erosion, desertification, and loss of marine life, although they can occur due to construction activities, are not considered by the study's respondents as significant factors influencing the adoption of CE in the SA construction sector. Construction activities that result in the formation of structures like houses, roads, and dams irreversibly modify critical farmland and forests. Other activities that contribute to land loss include quarrying and mining for building raw materials, as well as the disposal of waste created during and after construction.

## 5 Conclusion

This study examines the factors influencing CE adoption in the SA construction sector in a bid to understand the rationale behind the adoption of CE within the sector. This is to bring to the fore the issues and impact of the construction sector on the environment amidst the adoption of CE. The factors were discovered after a survey of the available literature, which was then presented to construction professionals. The study's results show that the most important factor influencing CE adoption in the construction sector is the potential business opportunity. Production of waste, exploitation of resources, production of greenhouse gases, contribution to pollution, and climate change are the other significant influencing factors, whereas factors such as soil erosion, desertification, loss of marine life, deforestation, and interference with the ecosystem are not considered significant. Based on the study's findings, it is obvious the ultimate goal of CE is to produce many forms of value to improve the resource effectiveness and efficiency of an economy in response to the mounting demand for natural resources. CE provides business opportunities by modifying how economic value and the understanding of items are addressed. CE opportunities have not been fully utilized by conventional entrepreneurs either in the construction sector or any other sector. If it is profitable, construction entrepreneurs will be eager to practice sustainability. Hence, for greater entrepreneurship, more employment, better environmental circumstances, less construction waste dumped in landfills, enhanced economic sustainability, and decreased raw material needs, governments must promote the adoption of CE in the SA construction sector through policies. Finally, the current study evaluates the factors influencing CE adoption in the SA construction sector. The findings could inform construction actors and stakeholders on these factors and encourage them to take significant steps toward putting the necessary policies in place to adopt a fully circular economy concept to help solve environmental issues.

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## References

1. Albort-Morant G, Leal-Millán A, Cepeda-Carrion G, Henseler J (2018) Developing green innovation performance by fostering of organizational knowledge and coopetitive relations. Rev Manage Sci 12(2):499–517
2. Ametepey SO, Ansah SK (2014) Impacts of construction activities on the environment: the case of Ghana. J Constr Proj Manage Innov 4(sup-1):934–948
3. Babbitt CW, Gaustad G, Fisher A, Chen WQ, Liu G (2018) Closing the loop on circular economy research: from theory to practice and back again. Resour Conserv Recycl 135:1–2
4. Bao Z, Lu W, Chi B, Yuan H, Hao J (2019) Procurement innovation for a circular economy of construction and demolition waste: lessons learnt from Suzhou, China. Waste Manage 99:12–21
5. Bocken NM, Short SW, Rana P, Evans S (2014) A literature and practice review to develop sustainable business model archetypes. J Clean Prod 65:42–56
6. Bocken NM, De Pauw I, Bakker C, Van Der Grinten B (2016) Product design and business model strategies for a circular economy. J Ind Prod Eng 33(5):308–320
7. Business in the Community (BITC) (2020) Advancing circular construction: case studies from the building and infrastructure sectors. BITC, London, UK
8. CIRAIG (International Reference Centre for the Life Cycle of Products, Processes and Services) (2015) Circular economy: a critical literature review of concepts. Polytechnique Montréal, Canada
9. Charef R, Morel JC, Rakhshan K (2021) Barriers to implementing the circular economy in the construction industry: A critical review. Sustainability 13(23):12989
10. den Hollander M, Bakker C (2016) Mind the gap exploiter: circular business models for product lifetime extension. In: Electronics goes green 2016+: inventing shades of green. Fraunhofer IZM Berlin, pp 1–8
11. Desrochers P (2004) Industrial symbiosis: the case for market coordination. J Clean Prod 12(8–10):1099–1110
12. Du Plessis C (2002) Agenda 21 for sustainable construction in developing countries. CSIR Rep BOU E 204:2–5
13. Eberhardt LCM, Birkved M, Birgisdottir H (2022) Building design and construction strategies for a circular economy. Archit Eng Des Manage 18(2):93–113
14. Ellen MacArthur Foundation (2013) Towards the circular economy, economic and business rationale for an accelerated transition. Ellen MacArthur Foundation, Cowes, UK, pp 21–34
15. Ellen MacArthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Ellen MacArthur Foundation
16. Ellen MacArthur Foundation (2018) The circular economy concept-regenerative economy. https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept. Accessed 3rd Mar 2023
17. European Commission (2014) Towards a circular economy: a zero waste programme for Europe Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels (EN)
18. Field A (2005) Discovering statistics, using SPSS for windows. Sage Publications, London
19. Finland's Independence Celebration Fund (FICF, Sitra) and Mckinsey (2014) Kiertotalouden Mahdollisuudet Suomelle (the possibilities of circular economy for Finland). SITRA, Helsinki, Finland

20. Ge Z, Gao Z, Sun R, Zheng L (2012) Mix design of concrete with recycled clay-brick-powder using the orthogonal design method. Constr Build Mater 31:289–293
21. Geissdoerfer M, Savaget P, Bocken NM, Hultink EJ (2017) The circular economy–a new sustainability paradigm? J Clean Prod 143:757–768
22. Hofmann F (2019) Circular business models: business approach as driver or obstructer of sustainability transitions? J Clean Prod 224:361–374
23. Jin L, Madison K, Kraiczy ND, Kellermanns FW, Crook TR, Xi J (2017) Entrepreneurial team composition characteristics and new venture performance: a meta–analysis. Entrep Theory Pract 41(5):743–771
24. Kibert CJ (2016) Sustainable construction: green building design and delivery. Wiley & Sons
25. Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy: an analysis of 114 definitions. Resour Conserv Recycl 127:221–232
26. Kofoworola OF, Gheewala SH (2009) Estimation of construction waste generation and management in Thailand. Waste Manage 29(2):731–738
27. Lewandowski M (2016) Designing the business models for circular economy—Towards the conceptual framework. Sustainability 8(1):43
28. Majdalani Z, Ajam M, Mezher T (2006) Sustainability in the construction industry: a Lebanese case study. Constr Innov 6(1):33–46
29. McKinsey & Company, Inc. (2017) Mapping the benefits of a circular economy. McKinsey Q 2:12–17
30. Millette S, Williams E, Hull CE (2019) Materials flow analysis in support of circular economy development: plastics in Trinidad and Tobago. Resour Conserv Recycl 150:104436
31. Miller SA, John VM, Pacca SA, Horvath A (2018) Carbon dioxide reduction potential in the global cement industry by 2050. Cem Concr Res 114:115–124
32. Mulrow JS, Derrible S, Ashton WS, Chopra SS (2017) Industrial symbiosis at the facility scale. J Ind Ecol 21(3):559–571
33. Otasowie OK, Oke AE (2022a) Drivers of mentoring practices in construction related firms: Nigerian quantity surveying firms' perspective. Eng Constr Archit Manage, vol ahead-of-print No. ahead-of-print. https://doi.org/10.1108/ECAM-09-2020-0679
34. Otasowie K, Oke A (2022b) An assessment of exhibited drivers of mentoring in construction professional firms: a case of Nigerian quantity surveying firms. J Constr Develop Countries 27(2):63–86. https://doi.org/10.21315/jcdc-10-20-0225
35. Otasowie OK, Oke AE (2020) Mentoring practices in construction professional firms in Nigeria. In: Aigbavboa C, Thwala W (eds) The construction industry in the fourth industrial revolution. CIDB 2019. Springer, Cham. https://doi.org/10.1007/978-3-030-26528-1_13
36. Pearce P (2012) The ulysses factor: evaluating visitors in tourist settings. Springer Science & Business Media
37. Preston F (2012) A global redesign? Shaping the circular economy. Retrieved from https://www.academia.edu/download/32547802/A_global_redesign_-_shaping_the_circular_economy.pdf
38. Schenkel M, Caniëls MC, Krikke H, van der Laan E (2015) Understanding value creation in closed loop supply chains–Past findings and future directions. J Manuf Syst 37:729–745
39. Schulze G (2016) Growth within: a circular economy vision for a competitive Europe. Ellen MacArthur Foundation and the McKinsey Center for Business and Environment, pp 1–22
40. Son H, Kim C, Chong WK, Chou JS (2011) Implementing sustainable development in the construction industry: constructors' perspectives in the US and Korea. Sustain Dev 19(5):337–347
41. Sterner E (2002) 'Green procurement' of buildings: a study of Swedish clients' considerations. Constr Manag Econ 20(1):21–30
42. Tavakol M, Dennick R (2011) Making sense of Cronbach's Alpha. Int J Med Educ 2:53–55
43. Torgautov B, Zhanabayev A, Tleuken A, Turkyilmaz A, Mustafa M, Karaca F (2021) Circular economy: challenges and opportunities in the construction sector of Kazakhstan. Buildings 11(11):501
44. Tunn VS, Bocken NM, van den Hende EA, Schoormans JP (2019) Business models for sustainable consumption in the circular economy: an expert study. J Clean Prod 212:324–333

45. Vogel P (2017) From venture idea to venture opportunity. Entrep Theory Pract 41(6):943–971
46. Yuan Z, Bi J, Moriguichi Y (2006) The circular economy: a new development strategy in China. J Ind Ecol 10(1–2):4–8

# Perceived Benefits of Circular Economy Adoption in the South African Construction Sector

**Kenneth Otasowie, Clinton Aigbavboa, Ayodeji Oke, and Peter Adekunle**

## 1 Introduction

There is no denying that the construction sector is a crucial part of every economy since it is essential to a country's social and economic growth. While [21] said that 30% of the world's population relies on the sector for survival, the United Nations Economic Commission [41] claimed that the construction sector contributes over 6% of the global Gross Domestic Product (GDP). However, the sector has had a substantial negative influence on the environment [5]. Since the Industrial Revolution, when mankind saw fast exploitation of natural resources for economic expansion, construction activities have been known to harm the environment. Nevertheless, Erlandsson and Levin [12] claim that this knowledge of environmental degradation has only recently spread worldwide. In fact, the sector has been described as the biggest user and exploiter of Earth's resources. Its extensive reliance on the environment's ability to provide resources is the reason behind this. Furthermore, according to Shen et al. [36], the primary causes of environmental contamination and deterioration are construction activities. This impact starts as soon as a project is conceived and lasts throughout its life, including building and operation. Depletion of resources and waste creation were two environmental effects of a building that Enshassi et al. observed. This was supported by the European Union Commission (EU), which asserted that 35% of the waste produced in the EU comes from the building sector,

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which accounts for nearly 50% of all materials extracted. This is particularly true in developing nations like South Africa, where the manufacturing of building materials results in the emission of 18 metric tonnes of carbon dioxide yearly, or 23% of the nation's total greenhouse gas emissions [37].

This trend has been linked to the industry's adoption of the linear economy model, which only adheres to the take-make-dispose maxim. In the linear economy model, raw materials are obtained for processing, which results in a completed good that is then used by the consumer before becoming waste. In the light of the volume of waste produced by the demolition process, the end-of-life phase of a construction project is the least sustainable [8]. Despite other industries, like manufacturing, switching to a sustainable method, the linear model still predominates in the building sector. According to Marsh et al. [24], a sustainable strategy is one that attempts to reduce resource depletion and environmental damage to develop an ecologically friendly building sector. Though not the only sector to use this linear strategy, the construction sector's very considerable adverse effects on the environment need the quick adoption of an alternate strategy to preserve the environment. A strategy built on the idea of zero waste, where it is possible to recycle old materials back into the production process to reduce waste creation and resource consumption.

According to Warodell and Lindholm [43], the need for an alternative approach that could lead to environmentally sustainable development has resulted in the introduction of the circular economy (CE) model, where the focus is to conserve resources and ensure that the design is done in such a way that waste is eliminated. This approach is contrary to the linear model in that materials flow in a closed manner in the economy. Ghisellini et al. [14] opined that the environmental impact of the construction industry can be reduced by applying the CE approach. This was further corroborated by van Stijn and Gruis [38] that to achieve a resource-effective society within the built environment, there must be a transition from the linear economy approach that has negatively impacted the environment to a CE. According to Omotayo et al. [31], there has been a belief within the construction sector that suggests that the adoption of CE can ensure the sustainability of the sector. However, considering how buildings are disposed of at the end of life, it seems that very unlikely materials can be reused in the construction sector. Also, Hossain et al. [18] claimed that there have been concerns in some quarters regarding the barriers associated with adopting the CE approach in the construction sector. Charef and Lu [8] posited that this might result from a lack of familiarity with the CE concept within the built environment. The study further attributed the concerns and barriers to different causes, such as the nature of buildings and the process of fabrication, with each client desiring a bespoke building, the different stakeholders involved in the construction and management of buildings from the inception to demolition, and the usually long timescale of building life cycles which most times is between 30 and 60 years. On the other hand, Oluleye et al. [30] attributed the lack of adoption to the non-availability of complete circular economy business models that organizations could mimic in implementing the necessary changes.

According to Oluleye et al. [30], the adoption of CE principles in construction will encompass resource management and waste management to extend the productive life of the resource. Agrawal et al. [1] posited that the outcome of adopting CE principles will see a reduction in environmental degradation through reduced demand for new materials, the durability of products, the substitution of raw materials during manufacturing, and the expansion of the secondary sector. Furthermore, Upadhyay et al. [42] opined that the ultimate aim of CE in building construction is to ensure the use of a modern manufacturing system in the industry that provides economic growth without the degradation of the environment which often occurs as a result of the need for virgin materials. However, many studies have considered the complexities in the construction industry based on how fragmented the industry is in the adoption of CE principles which are guided by the 3Rs of recycling, reuse, and recovery. Nevertheless, the adoption of CE in the construction sector will reduce the environmental impact of the sector [14]. Considering developing nations like South Africa (SA), where the manufacturing of building materials results in the emission of 18 metric tonnes of carbon dioxide yearly, or 23% of the nation's total greenhouse gas emissions, this study aims to examine the benefits CE adoption offers the country's construction sector. To realize this aim, a literature review is conducted to understand the benefits of adopting CE and then benchmarking the benefits in the SA construction sector. Based on the study's findings, the benefits of CE adoption in the construction sector in SA will be presented.

## 2 Method

This research adopted a post-positivist philosophical perspective and employed a quantitative research approach, utilizing a questionnaire survey to investigate the benefits of adopting a circular economy (CE) in the construction sector. The survey instrument was structured into two segments: the first segment aimed to gather background information from the participants, while the second segment focused on exploring the perceived benefits of circular economy adoption in construction. Respondents, comprising construction professionals, were tasked with rating the significance of identified circular economy benefits using a five-point Likert scale. The scale ranged from 5 (indicating "Strongly Significant") to 1 (denoting "Not Significant"). The study targeted qualified construction professionals, including engineers, architects, quantity surveyors, and construction managers, with a minimum of five years of professional experience. Convenient sampling was employed due to constraints in time and financial resources. Out of the 145 questionnaires distributed, 97 were received and deemed suitable for analysis. The gathered data underwent a comprehensive analysis, employing statistical methods such as standard deviation, percentages, mean item scores, one-sample t-test, and Kruskal–Wallis tests. These analytical tools were consistent with the approach used by Otasowie and Oke [33]. To ensure the reliability of the questionnaire, the researchers conducted a Cronbach's alpha test, yielding a robust alpha value of 0.840. This result surpassed the commonly accepted cutoff point of 0.6, affirming the questionnaire's high degree of reliability as established by Tavakol and Dennick [39]. In conclusion, the study employed research methodologies and statistical analyses to explore the perceived benefits of circular economy adoption in the construction sector. The use of a reliable questionnaire and a diverse sample of experienced construction professionals in the Gauteng Province, South Africa, enhanced the credibility and applicability of the findings.

## 3 Result

The survey conducted in Gauteng Province, South Africa, enlisted the participation of construction professionals. The predominant professional category amongst respondents was quantity surveyors, constituting 28% of the surveyed group. Engineers closely followed, comprising 22%, while architects and construction managers accounted for 20% and 18%, respectively. Project managers for construction represented 12% of the respondents. Education levels amongst the participants were diverse, with a majority (65.2%) holding bachelor's degrees. Following this, 14.5% possessed master's degrees, 13.4% had doctoral degrees, and 6.9% held certificate degrees. These varying educational backgrounds indicate a broad spectrum of expertise amongst the surveyed construction professionals. The average working experience of the respondents was 8.4 years, signifying a substantial period of engagement within the construction field. This extensive professional experience underscores the depth of knowledge and expertise within the surveyed group. The survey's demographic characteristics suggest a comprehensive representation of construction professionals, ensuring a diverse range of perspectives. The substantial educational qualifications further indicate that respondents were well-equipped to comprehend and respond effectively to the survey questions. As highlighted by Otasowie and Oke [34], the responses provided in the survey were grounded in a wealth of professional expertise, further bolstering the reliability and relevance of the study's findings.

To assess the perceived importance of specific benefits associated with the adoption of CE practices in the construction sector, a one-sample t-test was utilized. The objective was to determine whether respondents considered each benefit to be significant or not. For a comprehensive understanding of the respondents' views, mean ranks were calculated for each benefit. A significance level of 95%, following the customary threshold [32], was established. A benefit was considered significant if its mean rating on the Likert scale of five points was 3.5 or higher. The outcomes, indicating the identified benefits of CE adoption in the construction sector, have been presented in both Tables 1 and 2. In Table 2, the observed data mean is accompanied by the standard deviation, providing insights into the variability within the responses. In cases where two or more benefits shared the same mean, the benefit with the lowest standard deviation was accorded the highest priority ranking, aligning with the methodology suggested by Field [13]. Table 1, which follows, encapsulates the results of the one-sample t-test, offering valuable information on the statistical significance of each benefit. This analysis aims to contribute to a nuanced understanding of how respondents perceive the various benefits associated with CE adoption in the construction industry.

Upon examination of the *p*-values [sig. (two-tailed)] associated with each benefit in Table 1, it is evident that respondents overwhelmingly agreed on the significance of the listed benefits in driving the adoption of circular economy practices within the South African construction sector. For each benefit, the statistical analysis considered two distinct hypotheses: a null hypothesis (H0: $U = U_0$) suggesting no significance and an alternative hypothesis (Ha: $U > U_0$) implying significance, where the population mean ($U_0$) was established at 3.5. The obtained *p*-values supported the

**Table 1** One-sample test for benefits of circular economy adoption in construction

| | | | | | 95% confidence interval of the diff | |
|---|---|---|---|---|---|---|
| Benefits | *T* | Df | Sig. (two-tailed) | Mean diff | Lower | Upper |
| Energy cost reduction | 8.491 | 96 | 0.000 | 0.459 | 0.545 | 0.734 |
| Conservation of natural resources | 5.192 | 96 | 0.000 | 0.524 | 0.728 | 0.911 |
| Improved public health level | 4.311 | 96 | 0.000 | 0.716 | 0.451 | 0.692 |
| Foster collaboration | 4.932 | 96 | 0.000 | 0.417 | 0.817 | 0.931 |
| Mitigate resource depletion | 5.736 | 96 | 0.000 | 0.557 | 0.551 | 0.842 |
| Standardization on construction waste collection | 4.353 | 96 | 0.001 | 0.719 | 0.626 | 0.733 |
| Availability of environmentally friendly products | 4.429 | 96 | 0.001 | 0.389 | 0.685 | 0.811 |
| Revenues from the sale of construction wastes | 4.638 | 96 | 0.000 | 0.628 | 0.725 | 0.885 |
| Greenhouse gases reduction | 10.419 | 96 | 0.000 | 0.593 | 0.835 | 0.972 |
| Improved efficiency and productivity | 4.302 | 96 | 0.002 | 0.560 | 0.672 | 0.843 |
| Decrease waste generation | 6.824 | 96 | 0.000 | 0.716 | 0.741 | 0.872 |
| Improved awareness and environmental consciousness | 4.192 | 96 | 0.000 | 0.682 | 0.611 | 0.757 |
| Effective life cycle management | 4.245 | 96 | 0.000 | 0.659 | 0.730 | 0.825 |
| Better designs | 4.283 | 96 | 0.000 | 0.742 | 0.582 | 0.748 |
| Creation of job opportunities | 4.815 | 96 | 0.002 | 0.663 | 0.547 | 0.699 |

DF = Degree of freedom

**Table 2** T-test summary showing benefits of circular economy adoption in construction

| Benefits | $t$ | Sig. (one-tailed) | $\bar{x}$ | | $\Sigma x$ | $R$ |
|---|---|---|---|---|---|---|
| Greenhouse gases reduction | 10.419 | 0.000 | 4.69 | | 0.402 | 1 |
| Energy cost reduction | 8.491 | 0.000 | 4.66 | | 0.322 | 2 |
| Decrease waste generation | 6.824 | 0.000 | 4.59 | | 0.329 | 3 |
| Mitigate resource depletion | 5.736 | 0.000 | 4.59 | | 0.412 | 4 |
| Conservation of natural resources | 5.192 | 0.000 | 4.53 | | 0.355 | 5 |
| Foster collaboration | 4.932 | 0.000 | 4.52 | | 0.308 | 6 |
| Creation of job opportunities | 4.815 | 0.000 | 4.52 | | 0.370 | 7 |
| Revenues from the sale of construction wastes | 4.638 | 0.000 | 4.51 | | 0.316 | 8 |
| Availability of environmentally friendly products | 4.429 | 0.000 | 4.46 | | 0.323 | 9 |
| Standardization on construction waste collection | 4.353 | 0.000 | 4.43 | | 0.391 | 10 |
| Improved public health level | 4.311 | 0.000 | 4.40 | | 0.328 | 11 |
| Improved efficiency and productivity | 4.302 | 0.000 | 4.39 | | 0.303 | 12 |
| Better designs | 4.283 | 0.000 | 4.37 | | 0.341 | 13 |
| Effective lifecycle management | 4.245 | 0.000 | 4.34 | | 0.353 | 14 |
| Improved awareness and environmental consciousness | 4.192 | 0.000 | 4.28 | | 0.305 | 15 |

$\sigma x$ = Standard deviation; $\bar{x}$ = Mean item score; $R$ = Rank

rejection of the null hypothesis in favour of the alternative hypothesis, affirming the significance of the benefits. Notably, the chosen significance level was two-tailed, reflecting the possibility of significance in both directions. To further emphasize the observed significance, a subsequent one-tailed test was conducted. The significant *p*-values resulting from this one-tailed test are presented in Table 2. It is important to highlight that these values in Table 2 were derived by halving the p-values from Table 1. This adjustment aligns with the one-tailed testing approach, reinforcing the evidence that the listed benefits hold substantial significance in driving circular economy adoption within the South African construction sector.

The results show that greenhouse gas reduction is the highest-ranked and the most significant benefit of CE adoption in the SA construction sector (MIS = 4.69, SD = 0.40). This was followed by energy cost reduction (MIS = 4.66, SD = 0.32); decrease waste generation (MIS = 4.59, SD = 0.32); mitigate resource depletion (MIS = 4.59, SD = 0.41); conservation of natural resources (MIS = 4.53, SD = 0.36); foster collaboration (MIS = 4.52, SD = 0.31). Others include creation of job opportunities (MIS = 4.52, SD = 0.37); revenues from the sale of construction wastes (MIS = 4.51, SD = 0.32); availability of environmental friendly products (MIS = 4.46, SD = 0.32); standardization on construction waste collection (MIS = 4.43, SD = 0.39); improved public health level (MIS = 4.40, SD = 0.33); improved efficiency and productivity (MIS = 4.39, SD = 0.30); better designs (MIS = 4.37, SD = 0.34); effective life cycle management (MIS = 4.34, SD = 0.35); and improved awareness and environmental consciousness (MIS = 4.28, SD = 0.31).

Furthermore, an assessment of responses based on various construction occupations was conducted using a Kruskal–Wallis test. The findings indicate that there is no statistically significant difference amongst participants' responses regarding the benefits of adopting a circular economy in the South African construction sector. The detailed results are presented in Table 3.

**Table 3** Test for Kruskal–Wallis showing *p*-values for benefits of circular economy adoption in construction

| Benefits | *P*-values |
|---|---|
| Greenhouse gases' reduction | 0.080 |
| Energy cost reduction | 0.060 |
| Decrease waste generation | 0.052 |
| Mitigate resource depletion | 0.062 |
| Conservation of natural resources | 0.074 |
| Foster collaboration | 0.092 |
| Creation of job opportunities | 0.072 |
| Revenues from the sale of construction wastes | 0.061 |
| Availability of environmentally friendly products | 0.068 |
| Standardization on construction waste collection | 0.076 |
| Improved public health level | 0.087 |
| Improved efficiency and productivity | 0.081 |
| Better designs | 0.084 |
| Effective life cycle management | 0.066 |
| Improved awareness and environmental consciousness | 0.058 |

## 4 Discussion

From the results of the study, the most significant benefit of CE adoption in the SA construction sector is the greenhouse gases reduction. This was further confirmed by the Kruskal–Wallis test conducted. Minimizing greenhouse gas (GHG) emissions has emerged as an international priority due to the growing body of data linking greenhouse gases (GHGs) to climate change and global warming [44]. Since 2010, the amount of GHG emissions from the last stages of the disposal of construction and demolition waste (CDW), such as landfilling and incineration, has been less than 6.6%. However, due to further urbanization and industrialization, this is predicted to increase dramatically, for instance, CDW constitutes 46% of total waste in Europe, and in Japan and China, 20% and 30–40% of total solid waste, respectively [16, 19]. Also, developing countries like South Africa, where the manufacturing of building materials produces 18 metric tonnes of carbon dioxide yearly, or 23% of the nation's total greenhouse gas emissions [37]. Furthermore, as it is anticipated that by 2050, the worldwide CDW will rise significantly [29], immediate action is needed to limit CDW GHG emissions. Hence, this study corroborates [23], that reducing GHG is a significant benefit of adopting CE. This would guarantee that one of the most critical crises the world is currently facing—climate change caused by the release of a sizable amount of GHG, the depletion of non-renewable resources, and the rise in waste—will be resolved.

In addition, the study's results show that energy cost reduction is a significant benefit of CE adoption in the SA construction sector. This was further confirmed by the Kruskal–Wallis test conducted. Most nations that are mindful of environmental concerns and the conservation of natural resources have found that the recent rapid global economic expansion has become a significant burden. To achieve sustainable development, several nations and significant global corporations have concentrated on conserving energy [3]. This is because there is still more to be done to promote sustainable energy usage. The goal of the CE is to preserve resources for as long as feasible. This is done through various ecological activities, including cutting back on the usage of fossil fuels, recycling waste, lowering emissions, and more [22]. Due to its role as the primary engine of the world economy, renewable energy now accounts for most of the CE's activities. The aim is to reduce the use of fossil fuels, which is expected to significantly reduce energy costs. According to EMF [10] and Gower and Schroeder [15], circular economy techniques can significantly boost resource efficiency, creativity, productivity, and energy cost savings in several countries and sectors. Thus, this study corroborates EMF [10], Gower and Schroeder [15], and Kumar et al. [23] on the energy cost reduction potential of CE in the SA construction sector.

Another significant benefit of CE adoption in the SA construction sector, as revealed by the study, is the expected decrease in construction and demolition waste (CDW) generation. Approximately 40% of waste is produced by the construction industry [28]. As a result, it suggests that the sector is one of the biggest global waste producers [6]. This includes developing nations like South Africa. According to

Muzenda [27], construction and demolition waste comprise 21% of South Africa's total waste. Even though these wastes are produced due to building activity, over three billion tonnes of materials are utilized annually to make construction products around the globe. Hence, one of the steps required to lessen the amount of building and demolition waste dumped in landfills is the circular economy, because the amount of waste produced each year as building debris is disproportionately large. For this reason, the South African construction sector is anticipating that a shift towards the CE will reduce the waste generated during construction and at the end-of-life phase of buildings which often requires demolition.

Furthermore, mitigation of resource depletion is a significant benefit of CE adoption in the SA construction sector, as revealed by the study. Researchers and scientists are more aware of how the current pace of resource use is destroying the earth's supporting framework [4], a phenomenon that can be linked to the building sector. Its operations need enormous amounts of natural resources, such as water and various energy sources. Raw material extraction, processing, and transportation all have a tendency to deplete resources and destroy biological diversity. It is urgent to restructure the building business internationally, given the rapid pace at which resources on earth are depleting. In response, the CE has been advocated as a means of improving the economic, social, and environmental responsiveness of the building processes, activities, and practices. This study reveals and corroborates [23] that mitigating resource depletion is one crucial benefit expected from adopting CE in the SA construction sector.

Fostering collaboration is another significant benefit of adopting CE in the SA construction sector, as revealed by the study. Collaboration is essential to the implementation of CE along the whole construction value chain, which includes customer awareness and partnerships between buyers and suppliers. Environmental advantages of collaboration include less use of natural resources, decreased waste generation, and decreased emissions into the air, water, and land [9, 20, 35]. Due to the utilization of resources, talents, processes, and routines found in partner organizations, collaboration is seen as a catalyst for greater business performance. A few instances of organizational collaboration include having common knowledge of environmental planning, cooperating to decrease pollution and use resources wisely, and defining a shared environmental goal. Consequently, businesses must work together to achieve effective adoption of CE. The significance of collaboration in CE cannot be overemphasized, as it addresses difficulties with rising consumption, urbanization, and employment by developing a movement that inspires stakeholders beyond the enterprise to act circularly [2]. Successful collaboration might result in a shared competitive advantage that could lead to the production of value in developing nations like South Africa, which could benefit all partners.

The creation of job opportunities is yet another significant benefit of adopting CE in the SA construction sector, as revealed by the study. The ultimate goal of CE is to produce many forms of value to improve the resource effectiveness and efficiency of an economy in response to the mounting demand for natural resources [10]. Job opportunities are provided by CE by modifying how economic value and the understanding of items are addressed, and it seeks to increase resource effectiveness and efficiency (by shortening or lengthening energy and resource loops) and ultimately close energy and resource flows [7, 17]. For instance, closing the loop in the supply chain for goods and resources results in cost savings, resource resilience, alternative revenue streams, and creative new products while also perhaps lowering consumption [11, 25, 26, 40]. By creating CE's "closed loop" in the construction sector, job opportunities within the sector will be created, which may enhance economic development while maintaining environmental sustainability. CE job opportunities, which include remanufacturing, reuse, or recycling, have not been fully utilised by conventional entrepreneurs in the construction sector or any other sector [11]. CE job opportunities can reduce the volatility of global prices, promote innovation, boost employment, and strengthen the local economy. Hence, for greater entrepreneurship, more employment, better environmental circumstances, less construction waste dumped in landfills, enhanced economic sustainability, and decreased raw material needs, CE adoption must be promoted in the construction sector.

Other significant expected benefits of adopting CE in the SA construction sector, as revealed by the study, include better designs, improved public health level, improved efficiency and productivity, and standardization of construction waste collection, amongst others. By adopting CE in the SA construction sector, dangerous and unsafe products and materials are kept out of landfills and the seas, where they pose a significant threat to ecosystem life. Reusing waste products and resources also promotes better designs that improve efficiency and productivity, and standardization of construction waste collection.

## 5 Conclusion

This study examines the perceived benefits of CE adoption in the SA construction sector in a bid to understand the expected benefits if CE is adopted in the construction sector. The benefits were discovered after a survey of the available literature, which was then presented to construction professionals. The study's results show that the most critical benefit of circular economy adoption in the construction sector is greenhouse gas reduction. Energy cost reduction, decreased waste generation, mitigation of resource depletion, conservation of natural resources, fostering collaboration, and creation of job opportunities, amongst others, are the significant benefits. Based on the study's findings, it is evident that by adopting CE, dangerous and unsafe products and materials are kept out of landfills and the seas, where they pose a significant threat to ecosystem life. Reusing waste products and resources also promotes the creation of regional business networks that increase economic performance and provide new job possibilities. Despite its adverse effects on the environment and the general welfare of the populace, the building sector is essential to SA's economic growth. Therefore, it is crucial that many stakeholders are made aware of the available CE concepts to guarantee the sustainability of all of the projects that are executed across the nation. Finally, the current study evaluates the benefits of CE adoption in the SA construction sector. Therefore, it is suggested that the government establishes a framework for CE adoption nationwide and demonstrates its commitment to CE adoption by enacting legislation and providing incentives. To guarantee the application of rules, the government should promote collaboration with different professional bodies.

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## References

1. Agrawal R, Wankhede VA, Kumar A, Upadhyay A, Garza-Reyes JA (2022) Nexus of circular economy and sustainable business performance in the era of digitalization. Int J Product Perform Manag 71(3):748–774
2. Aidonis D, Folinas D (2017) Editorial: supply chain management. Int J Bus Sci Appl Manage 11(2):1–2
3. Almagtome A, Shaker A, Al-Fatlawi Q, Bekheet H (2019) The integration between financial sustainability and accountability in higher education institutions: an exploratory case study. Int J Innov Creat Change 8(2):202–221
4. Ametepey SO, Aigbavboa C (2014) Practitioners perspectives for the implementation of sustainable construction in Ghana. In: Proceedings of the DII-2014conference on infrastructure investments in Africa, pp 114–124
5. Baloi D (2003) Sustainable construction: challenges and opportunities. In: 19th Annual ARCOM conference, vol 1. University of Brighton, Association of Researchers in Construction Management, pp 289–297
6. Bilal M, Khan KIA, Thaheem MJ, Nasir AR (2020) Current state and barriers to the circular economy in the building sector: towards a mitigation framework. J Clean Prod 276:123250
7. Bocken NM, De Pauw I, Bakker C, Van Der Grinten B (2016) Product design and business model strategies for a circular economy. J Ind Prod Eng 33(5):308–320
8. Charef R, Lu W (2021) Factor dynamics to facilitate circular economy adoption in construction. J Clean Prod 319:128639
9. Chertow M, Lombardi D (2005) Quantifying economic and environmental benefits of co-located firms. Environ Sci Technol 39(17):6535–6541
10. Ellen MacArthur Foundation (2015) What is a circular economy?. Ellen MacArthur Foundation. Available at: www.ellenmacarthurfoundation.org/circular-economy. Accessed 6 May 2023
11. Ellen MacArthur Foundation (2018) The circular economy concept-regenerative economy. https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept, Accessed 3rd Mar 2023
12. Erlandsson M, Levin P (2005) Environmental assessment of rebuilding and possible performance improvements effect on a national scale. Build Environ 40(11):1459–1471
13. Field A (2005) Discovering statistics, using SPSS for windows. Sage Publications, London
14. Ghisellini P, Ripa M, Ulgiati S (2018) Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. J Clean Prod 178:618–643

15. Gower R, Schröder P (2016) Virtuous circle: how the circular economy can create jobs and save lives in low and middle-income countries. Institute of Development Studies and Tearfund, UK
16. Gálvez-Martos JL, Styles D, Schoenberger H, Zeschmar-Lahl B (2018) Construction and demolition waste best management practice in Europe. Resour Conserv Recycl 136:166–178
17. den Hollander M, Bakker C (2016) Mind the gap exploiter: circular business models for product lifetime extension. In: Electronics goes green 2016+: inventing shades of green. Fraunhofer IZM Berlin, pp 1–8
18. Hossain MU, Ng ST, Antwi-Afari P, Amor B (2020) Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction. Renew Sustain Energy Rev 130:109948
19. Huang B, Wang X, Kua H, Geng Y, Bleischwitz R, Ren J (2018) Construction and demolition waste management in China through the 3R principle. Resour Conserv Recycl 129:36–44
20. Jacobsen NB (2006) Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. J Ind Ecol 10(1–2):239–255
21. Jain G, Gupta V, Pandey M (2016) Case study of construction pollution impact on environment. Int J Emer Tech Eng Res (IJETER) 4(6)
22. Karstensen KH, Engelsen CJ, Saha PK (2020) Circular economy initiatives in Norway. In: Circular economy: global perspective. Springer, Singapore, pp 299–316
23. Kumar V, Sezersan I, Garza-Reyes JA, Gonzalez ED, Al-Shboul MDA (2019) Circular economy in the manufacturing sector: benefits, opportunities and barriers. Manag Decis 57(4):1067–1086
24. Marsh RJ, Brent AC, De Kock IH (2021) Understanding the barriers and drivers of sustainable construction adoption and implementation in South Africa: a quantitative study using the Theoretical Domains Framework and COM-B model. J South Afr Inst Civ Eng Joernaal van die Suid-Afrikaanse Instituut van Siviele Ingenieurswese 63(4):11–23
25. Millette S, Williams E, Hull CE (2019) Materials flow analysis in support of circular economy development: plastics in Trinidad and Tobago. Resour Conserv Recycl 150:104436
26. Mulrow JS, Derrible S, Ashton WS, Chopra SS (2017) Industrial symbiosis at the facility scale. J Ind Ecol 21(3):559–571
27. Muzenda E (2014) A discussion on waste generation and management trends in South Africa. Int J Chem Environ Biol Sci (IJCEBS) 2(2):2320–4087
28. Nasir MHA, Genovese A, Acquaye AA, Koh SCL, Yamoah F (2017) Comparing linear and circular supply chains: a case study from the construction industry. Int J Prod Econ 183(Part B):443–457
29. de Oliveira Andrade JJ, Possan E, Squiavon JZ, Ortolan TLP (2018) Evaluation of mechanical properties and carbonation of mortars produced with construction and demolition waste. Constr Build Mater 161:70–83
30. Oluleye BI, Chan DW, Saka AB, Olawumi TO (2022) Circular economy research on building construction and demolition waste: a global review of current trends and future research directions. J Clean Prod 131927
31. Omotayo T, Moghayedi A, Awuzie B, Ajayi S (2021) Infrastructure elements for smart campuses: a bibliometric analysis. Sustainability 13(14):7960
32. Otasowie OK, Oke AE (2020) Mentoring practices in construction professional firms in Nigeria. In: Aigbavboa C, Thwala W (eds) The construction industry in the fourth industrial revolution. CIDB 2019. Springer, Cham. https://doi.org/10.1007/978-3-030-26528-1_13
33. Otasowie OK, Oke AE (2022) Drivers of mentoring practices in construction related firms: Nigerian quantity surveying firms' perspective. Eng Constr Archit Manage, vol ahead-of-print No. ahead-of-print. https://doi.org/10.1108/ECAM-09-2020-0679
34. Otasowie K, Oke A (2022) An assessment of exhibited drivers of mentoring in construction professional firms: a case of Nigerian quantity surveying firms. J Constr Develop Countries 27(2):63–86. https://doi.org/10.21315/jcdc-10-20-0225
35. Schwarz EJ, Steininger KW (1997) Implementing nature's lesson: the industrial recycling network enhancing regional development. J Clean Prod 5(1–2):47–56

36. Shen LY, Lu WS, Yao H, Wu DH (2005) A computer-based scoring method for measuring the environmental performance of construction activities. Autom Constr 14(3):297–309
37. Simpeh EK, Smallwood JJ (2018) Analysis of the benefits of green building in South Africa. J Constr Proj Manage Innov 8(2):1829–1851
38. van Stijn A, Gruis V (2020) Towards a circular built environment: an integral design tool for circular building components. Smart Sustain Built Environ 9(4):635–653
39. Tavakol M, Dennick R (2011) Making sense of cronbach's alpha. Int J Med Educ 2:53–55
40. Tunn VS, Bocken NM, van den Hende EA, Schoormans JP (2019) Business models for sustainable consumption in the circular economy: an expert study. J Clean Prod 212:324–333
41. United Nations Economic Commission (UNEC) (2014) Share of construction in GDP. http://w3.unece.org/pxweb/quickstatistics/readtable.asp?qs_id=8&lang=1
42. Upadhyay A, Kumar A, Akter S (2021) An analysis of UK retailers' initiatives towards circular economy transition and policy-driven directions. In: Clean technologies and environmental policy, pp 1–9
43. Warodell E, Lindholm V (2016) Circular economy–the way to a more sustainable urban environment? A study of how conversion and a circular economic business model can benefit the aspects of sustainability
44. Yan H, Shen Q, Fan LC, Wang Y, Zhang L (2010) Greenhouse gas emissions in building construction: a case study of one Peking in Hong Kong. Build Environ 45(4):949–955. Kennedy P, McGown A (2002) Management of multi-method engineering design research: a case study. J Eng Technol Manage 19(2):131–140. https://doi.org/10.1016/S0923-4748(02)00006-1

# Evaluating How Energy Performance Certificates Could Influence the Supply of Net Zero Carbon Buildings

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## 1 Introduction

Net zero carbon buildings have been identified as a key tool to decarbonize the world economy [22]. The Intergovernmental Panel for Climate Change Sixth Assessment Report of 2022 has made clear that climate change is a direct result of human economic activity [7]. Consequently, there is a need to adopt sustainable economic practices to limit climate change. In response to the interconnected global challenge of reducing carbon emissions, the South African government has further committed to lowering the country's carbon emissions as part of its legal commitments to the Paris Agreement of 2015 [13]. Consequently, there is increasing legislative action to drive economic activity to reduce carbon emissions.

The South African built environment accounts for 15% of the country's carbon emissions and therefore has a key role to play in reducing carbon emissions [10]. Net zero carbon buildings offer a potential solution to carbon emission reduction of South Africa's built environment.

Supportive of the increased awareness of the need to decarbonize economies is the increased use of Environmental, Social, and Governance (ESG) metrics in the allocation of capital [16]. In the real estate sector, the provision of credible and transparent information on energy usage and carbon emissions is an important aspect of meeting the ESG conditions which are increasingly being incorporated into debt funding and investment criteria for real estate companies [5]. This creates the context in which the disclosure of reliable energy usage and carbon emissions is of equal importance to the upfront design and capital outlay considerations in the development of net zero carbon buildings.

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Complimentary to the use ESG factors by funders and investors in real estate investment decisions is the emergence of sustainable finance in recent years in response to the various climate change legislative frameworks which presents new opportunities to advance the supply of net zero carbon buildings as a tool for developing a lower carbon economy [10]. The recently published South African Green Finance Taxonomy 2022 has defined a green building as net zero carbon, limiting the energy usage intensity to a benchmark defined by South African building codes (Page 127, National Treasury [10]). In this sense, the provision of high assurance information through accurate measuring and regular certifying of energy usage, as the basis for credible data for carbon emission calculation, is an important integrating tool for the funding, construction, and ongoing management of a green building.

An Energy Performance Certificates is a government regulated energy usage certificate which provide high assurance information on the energy efficiency of a building [14]. The adoption of Energy Performance Certificates could help to accelerate the development of net zero carbon buildings as more stakeholders in the real estate value chain recognize the value of the certification in providing credible data on the energy usage of a building [19]. This study has three interrelated objectives being: (1) The barriers to the supply of green buildings and sustainable practices [17, 20]. (2) The simultaneous introduction of new legislation and the adoption of ESG factors by the financial sector in response to climate change [2, 10]. (3) Finally, the role of Energy Performance Certificates in supporting the value of real estate and meeting required legislative and ESG standards [23].

## 2 Literature Review

### 2.1 *Introduction to the Literature Review*

The review initially explores the concept and role of net zero carbon buildings and the barriers and drivers in the supply of net zero carbon buildings [17, 20]. The review then explores how the legislative environment has been updated, with a cross-sector focus on resource efficiency of the built environment which may be influencing the identified supply barriers to net zero carbon buildings.

Building on this theme, the review explores the role Energy Performance Certificates in (a) meeting regulatory and ESG standards and (b) supporting real estate value as a potential driver of supply of net zero carbon buildings [23]. Finally, the review will then explore how real estate value, which is a possibly driver for increasing the supply of net zero carbon buildings, is impacted upon by the emergence of Environmental Social and Governance (ESG) based investing and the related field of sustainable finance [19].

## 2.2 Findings from Literature Review

The key findings from the literature reviewed can be summarized as follows:

(1) The supply of net zero carbon buildings, and broader sustainable practices in the real estate sector, has been constrained due to combined effect of limited information, relatively weak legislative, including financing frameworks, and the perceived high capital and certification costs of developing resource efficient buildings [17, 20].
(2) There is evidence of the simultaneous development of more effective legislation for managing climate change in both the financial sector, national and local government development policies, and energy efficiency regulations [8, 27, 33]. Taken in combination, this creates a legislative context which requires that the design, development, operation and importantly, funding of a new building must provide more effective evidence of resource efficiency which proactively limits the effects of climate change, and other material environmental risks, through the lifecycle of a new building.
(3) The introduction of ESG and the related field of sustainable finance appears to be creating the conditions where the provision of verifiable information proving a building is green which can be audited is of equal importance to the design and capital requirements of developing green buildings [5, 16].
(4) The use of green building rating systems has become an effective way for real estate firms to meet the material risk disclosure requirements of ESG focused investment and sustainable finance products for firms with the human, operational, and financial resources to undertake the relative high design fees and registration costs to certify new buildings [17, 19].
(5) Energy Performance Certificates have been shown to create value in real estate markets [3, 23] and the tool could assist valuers in determining property value by way of improved operating income information [12, 19]. This tool appears well placed to be used as a way to share operational information to determine the climate related financial risks of an asset [16, 18].
(6) The combination of strengthened of financial standards for green buildings and development legislation governing development of new buildings and the introduction of a lowering costs' means of green building certification through use of a tool as an Energy Performance could create a supportive context for the increase in the supply of net zero carbon buildings.

# 3 Method

## *3.1 Research Approach*

The study follows an inductive approach by exploring the experiences from the sampled group of real estate developers to expand on knowledge and theory. This approach is necessary as the study will explore the experiences and interpretations of people about how a new legislative tool is being shaped by their ambitions to address climate change [18]. The resulting qualitative information is useful for interpreting whether this new tool in an evolving and supportive context could overcome the documented reasons for limited supply of net zero carbon buildings, which has been developed through the research into barriers of adoption of green buildings and sustainable property practices [17, 20].

## *3.2 Methodology*

The qualitative study explores the experiences of the real estate developers, of two concepts: net zero carbon buildings and Energy Performance Certificates. The findings are to be interpreted relative to existing knowledge regarding the barriers of implementing net zero carbon buildings, and the documented use and influence of Energy Performance Certificates [1]. The findings that emerged from the study are intended to advance the broader understanding of how real estate developers experience the barriers to the supply of green buildings such as net zero carbon buildings. Secondly, how the study group experience and understands the role that new legislative tools such as Energy Performance Certificates could play in developing new buildings.

The study places value on the knowledge to be gained from the review of these experiences which can be coded and assessed qualitatively against the existing understanding of the barriers to the supply of net zero carbon buildings. The qualitative study and supporting semi-structured interview approach used in a study of the barriers to adoption of sustainable practices in property have been instructive in developing this study [20].

## *3.3 Research Methods*

The study will undertake a quantitative study, generating findings to be reviewed against existing knowledge, through semi-structured in-depth interviews of ten real estate developers (study sample), to explore the experience of the study sample in supply of green buildings, such as net zero carbon buildings [15]. The responses to the semi-structure in-depth interviews were transcribed, grouped, and then coded to allow reflection against the study assumptions which seek to understand the influence and impact that a new legislative tool, Energy Performance Certificates, may have in enabling real estate developers to supply a net zero carbon buildings which have been shown to be necessary to address climate change, but to date have faced barrier in supply [8].

### *3.4 Population and Sampling Criteria*

The study focused on the respondents working in the four functional areas, detailed below, who are involved in the supply of buildings in South Africa and who have undertaken developments in the past five years. This is the period in which the existing barriers of supply have been documented and is recent enough to be aware of the increased strengthening of green building legislation and increase the marketing of sustainable finance.

**(A) Regulation** of buildings which includes local authorities who create policy and assess new building development applications, **(B) Financing** of building development projects which includes the creation of financial legislation, the financing of and investment in new buildings, **(C) Development** of building development projects, which includes the planning, design, and construction of new buildings, and **(D) Management** of completed buildings which includes companies which own and manage buildings and oversee the financial, operational and resource (utilities) performance of completed buildings.

### *3.5 Limitations*

This study explored the experiences of participants working in the functional areas of the real estate development sector which shape the decision-making process in developing new buildings. The sample size was limited to ten participants, in the four functional areas of real estate development which influences the decision-making process for new buildings. The findings represent the collective reported experiences of the participants in one jurisdiction and could be limited in their replicability to other geographies.

### *3.6 Selection of Participants*

The research has sought to investigate the barriers to, and potential drivers of adoption, for the development of net zero carbon buildings. These factors have been identified as legislative, financial, and the broad understanding and integration of green building approaches into new developments [17]. Consequently, the sourcing of participants has followed a purposive research approach using two variables. Firstly, role players and real estate development process and secondly participants, these participants stance in relation to identified factors influencing green building practices.

Firstly, the research has taken a supply chain approach to understand the real estate development process which has involved reviewing the different participants and the related decisions that participant influences, in the process of developing new buildings. The second variable which has determined the participant selection approach has then been intentional in sourcing participants that are both impacted by and influence the identified barriers to advancing further green building practices, such as net zero carbon building.

The demographic analysis has reviewed three areas:

1. The population sample and the total number of new buildings reviewed from 2018 to 2023.
2. The grouping of the buildings into four role player areas and impact on decision-making.
3. The existing green building practices undertaken by participants.

Prior to presenting the data in these three areas the justification for the (a) time period, (b) rationale for planned new buildings, and (c) selection of participants and are presented below.

(A) *Time period*

The time period considers new buildings from 2018 to 2023. This 5-year period takes into account the period of time affected by the Covid 19 pandemic which would potentially lower the level of development activities.

(B) *New Building in Planning*

The study has chosen to allow participants to report on all potential new building developments which were reviewed and planned. Some of these planned new buildings would have proceeded to construction and occupation.

The rationale for reporting on planned developments is that the decision-making process often reviews multiple projects and a low proportion. Further, the greater level of buildings improves the validity of the data which would be limited by the number of participants in the study.

(C) *Selection of Participants*

The participants selected for the research have been chosen due to their involvement in four functional areas in the decision-making process which leads to development of a new building:

*Policymakers*

Policymakers who shape the statutory legislation for new buildings, energy efficiency, and the broader non-statutory recommended best practice green building standards. In this grouping of participants, the experience of attempting to shape new developments through new statutory or voluntary green building standards is explored.

*Financial Institutions*

Funders are either participants who are working in banks providing loans to developers, or are staff who work in organizations which invest in new development projects seeking a defined financial return. In this grouping, the terms of funding, the responsiveness to green building practices, climate risk, and net zero corporate strategies are of particular importance to explore.

*Developer and/or Real Estate Investment Trust*

These participants take the direct managerial decisions for new development projects. This grouping primarily focusses on the staff working within the organizations, who take the lead role in managing new development projects raising the funder, managing the professional team and the construction of the development. This grouping may also include the external professional team who helps to support the management decisions of the development organization.

*Professional Consulting Team*

This grouping of participants who have worked as part of the professional teams which support the developer and may have also provided managerial input to the formulation. Due to the position of this grouping in needing to interpret or help to formulate policy, this grouping is of particular interest in how the role of green building practices, legislation, and voluntary standards is transmitted into a new development project.

## 4 Analysis of Data

This section analyzes the data sourced from conducting qualitative interviews with role players in the real estate sector that influence the decision-making process for new buildings. Section 5.1 presents the (1) population sample, (2) total number of buildings, and (3) existing green building practices reported by the participants. Section 6 then presents the data against the research objectives: (1) experience of status of barriers to green building practices and (2) experiences of the impact of ESG and sustainable finance. This data is intended to help provide insights into the ways in which Energy Performance Certificates may be able influence the supply of net zero carbon buildings.

**Table 1** Grouping of participants

| Role player | No of participants | Planned buildings | Portion (%) |
|---|---|---|---|
| Policymakers | 1 out of 10 | 6 | 1 |
| Funders | 3 out of 10 | 155 | 37 |
| Developers | 3 out of 10 | 19 | 5 |
| Professional teams | 3 out of 10 | 240 | 57 |

### 4.1 Population Sample

A total of ten interviews were conducted, which accounted for the planning of 420 new buildings over the past five years, from 2018 to 2023. Table 1 details the population sample and the total number of new buildings which were considered for planning over the past 5 years (2018–2023). The participants were purposively sourced from the four functional areas which inform the decision-making process for developing new buildings.

### 4.2 New Buildings and Decision-Making

Table 1 also indicates the amount of new planned buildings per grouping of participants. Financial institutions and professional consulting has the highest amount of planned new buildings under review, accounting for 94% of all buildings under review. For the purpose of this study, the greatest proportion of new buildings being reviewed by financial institutions and professional consulting teams would imply that the decision makers within these groupings are well placed to help shape and drive the planning of green building practices.

### 4.3 Reporting of Existing Green Building Practices

Before reviewing the respondents' experiences of the barriers to increasing the supply of net zero carbon buildings, the study explored what ***existing*** green building practices the participants already undertake. This was reviewed by asking the participants to categorise the new developments that they had been involved into four possible practice areas:

(1) *Planned energy efficiency: Net Zero Carbon*

The first category is new buildings that are planned with lower carbon emissions during the build and operational phases of the building and to be certified as Net Zero Carbon in terms of the standards set by Green Building Council of South Africa.

(2) *Planned energy/water efficiency: Green Star rating*

The second category is buildings that are proactively planned to achieve a Green Star rating from the Green Building Council of South Africa.

(3) *Planned energy/water efficiency: No certification*

The third category is buildings that are planned and managed with lower water and energy consumption in mind. However, no formal certification to provide verification and assurance of green claims has been made.

(4) *No planned energy/water efficiency*

The final category are buildings with no planning for reduction in water or energy usage.

Of the 420 new buildings which were planned, 298 buildings (equating to 71%) had pursued a formal certification with the Green Building Council of South Africa. While seven new buildings, which equates to 2% of the total, had been planned as net zero carbon buildings, pursuing a formal certification. Encouragingly, there were 92 buildings (equating to 22% of all buildings) which were planned with a level of focused water and energy efficiency in mind, while they were not formally certified. The fact that these buildings are being proactively planned with efficiency in mind is a positive finding.

The study found that green building practices are pervasive across all participants with only 17 out of the total building count that is being planned with proactive green building considerations in mind. This would seem to suggest that the legislative environment, which does require an increasing focus on improved energy efficiency through SANS 10400 Part XA, is having a positive effect in requiring efficiency in planning of new developments. The study shows that the majority of new buildings are being consciously planned with greater efficiency of water and energy management in mind. This information, showing that planning for efficiency, largely through metering of energy and water without certification, could provide an opportunity for the use of Energy Performance Certificates, which require the use of metering.

## 5 Discussion on Findings

The research instrument explored four interrelated themes (1) barriers to green building practices, such as the supply of net zero carbon buildings; (2) ESG as a driver of adoption of green building practices; (3) experiences with strengthening financial standards and incentives and government legislation for new building; and (4) role of Energy Performance Certificates in meeting the evolving ESG reporting and legislative environment. These areas are analyzed in two sections which follow (1) barriers to green buildings and (2) ESG as a driver.

## 5.1 Barriers to the Green Building Practices and Supply of Net Zero Carbon Buildings

While the need to decarbonize the built environment is evident, there are barriers to developing net zero carbon buildings which can primarily be grouped as a weak legislative environment and the perception of the higher capital costs, and related fees and surcharges for designing and certifying, more energy and water efficient buildings [7, 17]. It is noted that the perceptions of the higher and or additional costs of green building practices and related technologies were deliberately excluded as a barrier from the study.

This study has further grouped the barriers to green building practices into four areas: (1) limited demand for net zero carbon buildings and other green building practices and formally certified green buildings, (2) limited understanding of the technical inputs and environmental impact benefits of net zero carbon buildings, and other green building, (3) weak legislative framework governing the approval of new building approvals and certification of green buildings, which include local authority approvals, energy efficiency standards, and green building certification, and (4) limited capital available for net zero carbon buildings, and other types of green buildings, including loan and equity investment capital for new development projects.

The study found that financial institutions rank availability of capital for green buildings, such as net zero carbon buildings, as the lowest barrier, while the perception that there is weak legislation to enforce the requirement to lower the energy usage and carbon emissions of a building is considered the highest barrier.

## 5.2 Impact of ESG and Environment and Climate Disclosure as a Driver

This theme explored how the introduction of Environmental, Social, and Governance factors in corporate strategy is influencing the introduction of greening building practices and the supply of net zero carbon buildings. This was analyzed through the (1) qualitative questions posed to the participants and secondly (2) a desktop review of the environmental and climate risk reporting of two large commercial banks in South Africa.

### 5.2.1 Qualitative Responses

The qualitative responses were grouped into four possible categories:

(1) An Environmental, Social, and Governance strategy is being followed.
(2) Formalized climate risks, such as carbon emissions, is being identified and reported on.

(3) Carbon emissions are being reported.
(4) Energy usage is being reported on and used in management decisions.

The study found that the majority of participants are following an ESG strategy. Secondly, that half of all participants are reporting on climate risks such as the impact of energy usage and sources and carbon emissions. Thirdly, that one third of all participants are reporting on the carbon emissions generated from the business activities and the buildings it is involved in planning, financing, developing, and managing of buildings. Finally, that nine out of ten are reporting and making management decisions based on the energy usage of buildings.

This may suggest that energy usage information is a clear data point from which green building practices and alignment with ESG and climate risk reporting could be leveraged. The study found that:

- Financial institutions are a key stand out in the participant group with a clear focus on ESG, climate risk, carbon emissions, and energy usage reporting**.**
- While the cohort of developers/REITs interviewed in the research is not reporting on the other elements, all developers are reporting on energy usage and making management decisions using this data.
- As with developers, professional consulting teams are all reporting on energy use in the buildings in which they are participated in the planning.

#### 5.2.2 Review of Banks' Published Environmental and Climate Reporting

To further support the qualitative study, a review of the annual reports and associated environmental reporting, climate accounting, and risk disclosure (TCFD) reporting of the two large commercial banks in South Africa was undertaken. There is a drive to reporting on carbon missions in the banks' real estate operational portfolio, combined with the practice of reporting on new green finance products and the extent of 'financed emissions'. A key outcome from this review is that the need to improve the quality of annually metered energy consumption and the associated energy reporting is increasing. Energy Performance Certificates, due to their attributes of accuracy in measured energy usage, provision of base date for carbon emission calculation, and lower cost of certification, could be a tool to that influences the supply of net zero carbon buildings [3, 16, 18, 21].

### *5.3 Conclusion to Analysis*

The study undertook interviews with ten participants in the real estate development decision-making process for new buildings. The study consisted of 420 new buildings which were planned and considered for new development. Integrating these findings shows that Energy Performance Certificates, due to the provision of operational energy usage data, seems to provide a set of data which would allow funders, developers, and regulators the highest quality source of data to drive the development of new sustainable buildings. A concluding finding is that the drive of climate risk disclosure and carbon accounting relies on high assurance data of energy usage and the source of energy such as coal, gas, solar, or wind. This practice is growing among funders of real estate development projects. This resultant push on carbon accounting in financial institutions is driving the lowering of carbon footprints in their own building operations. It would appear that the increase in climate risk disclosure, more than the 'natural' adoption of green building practices by the real estate sector, will drive green building practices. In this sense, Energy Performance Certificates, due to the provision of high assurance information on the energy usage and in turn carbon footprint of buildings are well placed to support funders, developers, consultants, and regulators in the supply of net zero carbon buildings.

## 6 Discussion on Findings

This paper has explored how Energy Performance Certificates could be a simplified tool to help increase the supply of net zero carbon buildings. The paper has four broad findings:

The paper has found that while at design stage green building certification is proactively pursued, the practice of post-completion monitoring through Energy Performance Certificates is limited. The introduction of climate risk disclosure and climate accounting practices in support of TCFD reporting by major banks is on the increase. In particular, the reporting on both, total metered energy consumed and the associated carbon footprint of operations, compared to 'financed emissions'. The build to rent/affordable rental housing has a high level of post-completion energy usage monitoring and a low level of pre-development green certification. The asset class would appear to be 'implicitly' green through operations. The level of understanding of what a net zero carbon building is and how this category of green building essentially delivers value, is limited. This limitation in understanding restricts the effectiveness.

## 7 Conclusions

This research report has sought to understand how Energy Performance Certificates could influence the supply net zero carbon buildings. The conclusions against the objectives are discussed.

### 7.1 Barriers to Green Building Practices Are Reducing

While NZCB and GBCSA certification is not pursued beyond the first participant, all other participants planned their developments with energy and water efficiency in mind. However, the extent to which the efficiency targets were set is a function of the development asset class, client demands, and financial terms for the development. It would seem that the barriers to implementation are reducing. Finance and regulation did not rank as high as ‘understanding’ as a key barrier. And yet conversely, the participants are all pursuing efficiency. It would seem to suggest that the planning for lowering consumption and allowing lower end user cost of utilities is the ‘framing’ of ‘green’. The recent strengthening of the legislative environment including new green building policies at local government level, energy efficiency legislation, and the creation of new financial sector frameworks would appear to be creating a context in which these barriers could be less onerous [2, 14, 16].

Proving a building is net zero carbon post-completion, presents a cost and operational problem for developers and funders. Increasingly disclosing the energy usage, efficiency, and carbon footprint of properties is becoming mandatory or is being harnessed as competitive advantage [6]. The current use of green building rating tools through certificates with entities such as the Green Building Council of South Africa supports the disclosure of energy usage. However, these rating systems require registration costs, which add to the costs of development. The high cost of applying for a certification and the complexity of the certification system, are barriers to the supply of net zero carbon buildings ([17, 20].

The introduction of a simpler tool, such as Energy Performance Certificates, could overcome the aforementioned barriers. It is a legislative tool which requires the measurement of energy consumption in a building. Therefore, it supports the improved energy consumption of a building, which in turn helps owners, funders and investors understand the energy intensity and carbon emissions of a building [10, 14].

### 7.2 Net Zero Carbon Buildings not yet Pervasive

Net zero carbon buildings would appear to be seen as a ‘high aspiration’ green building approach, rather than an approach to green building which is simple to pursue. Conversely, when asked about the actual action of green building practices, all participants were clear that they are pursuing design and operational efficiency practices. This would seem to suggest that the underlying actions to achieve lower carbon emissions from buildings are in fact being undertaken. But, the participants are not necessarily choosing to see the link between their efficiency actions as meeting NZCB goals.

## 7.3 *Affordable Rental Housing/Build to Rent is an Under-Valued Asset Class*

An interesting outcome is that the affordable rental housing asset class has a 'low level' of certification and yet a high level of water and energy efficiency practices. A further finding on this matter is that the 'expectations' of the broad sector is that only 'office and industrial' buildings are seemingly expected to 'green' through certification, whereas affordable housing is green by operations. This is due to this sector's high level of metering of usage which is then recovered from users. Whereas commercial property practice is to recover water and electricity through pro-rata usage on square meters. What this is showing is that the affordable housing is far more likely to be operationally efficient, whereas commercial and industrial are more likely to be design efficient. This indicates that affordable rental housing seems to be 'getting off the expectations' hook and being an under targeted area for driving net zero carbon outcomes. Yet, due to the reuse of existing buildings and the high level of metered sqm of buildings, this asset class is in fact proving an opportunity for high performance.

## 7.4 *EPC's Could Help Align Projects and Financial Reporting*

The study found that net zero carbon buildings, due to the emphasis on the reliability of the data used to determine the claims of low energy and lowering of carbon emissions, are themselves being seen as a tool for meeting high ambition environmental objectives. This bodes well for the future of lower carbon development, as the residential sector (single family homes and build to rent/affordable) is by and large the dominant form of new developments being undertaken [4].

## 7.5 *Overall Conclusion*

Energy Performance Certificates could be a tool that influences the supply of net zero carbon buildings [3, 16, 18, 21] due to their attributes of:

Accuracy in measured energy usage; provision of base date for carbon emission calculation and lower cost of certification; alignment with the finding that 90% of the participants reported on measured energy usage; and the provision of standardized, highly accurate information for financial institutions which is being used in annual ESG reporting.

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## References

1. Bell E, Bryman A, Harley B (2022) Business research methods. Oxford University Press
2. City of Johannesburg (2021) Climate action plan. Retrieved from https://www.joburg.org.za/departments_/Documents/EISD/City%20of%20Johannesburg%20-%20Climate%20Action%20Plan%20%28CAP%29.pdf on 3 Apr 2022
3. De Graaf I (2016) Capitalising energy efficiency in housing markets: an investigation into the impact of energy performance certificates (EPCs) on transaction prices in selected European Countries. Signature 16
4. Elias NA (2021) An investigation into implementing net zero carbon new buildings: a case of the eThekwini Municipality, Kwazulu-Natal, South Africa. Doctoral dissertation
5. Feng Z, Wu Z (2021) ESG disclosure, REIT debt financing and firm value. J Real Estate Fin Econ, 1–35
6. Green Building Council of South Africa, Arup and Diversity Urban Property Fund (2021) Does location matter? A quantitative study on impact of housing development location on carbon emissions in Johannesburg, South Africa. Retrieved from https://gbcsa.org.za/wp-content/uploads/2021/09/30.09-Divercity_Carbon-Study_Final.pdf on 3 Apr 2022
7. Intergovernmental Panel for Climate Change (2022) Sixth assessment report, mitigation of climate change. Retrieved from https://www.ipcc.ch/report/ar6/wg3/ on 3 Apr 2022
8. Kallio H, Pietilä AM, Johnson M, Kangasniemi M (2016) Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. J Adv Nurs 72(12):2954–2965
9. National Treasury, National Business Initiative, Carbon Trust (2022) Briefing paper: developing a buildings taxonomy entry for South Africa. Retrieved from https://sustainablefinanceinitiative.org.za/wp-content/downloads/Briefing-Paper_Developing-a-Buildings-Taxonomy-Entry-for-South-Africa.pdf on 3 Apr 2022
10. National Treasury (2022) South African green finance taxonomy. Retrieved from https://sustainablefinanceinitiative.org.za/wp-content/downloads/SA-Green-Finance-Taxonomy-1st-Edition-Final-01-04-2022.pdf on 3 Apr 2022
11. Pham L (2018) A review of key paradigms: positivism, interpretivism and critical inquiry. University of Adelaide. Retrieved from https://www.researchgate.net/publication/324486854_A_Review_of_key_paradigms_positivism_interpretivism_and_critical_inquiry on 13 Sept 2022
12. RICS (2021) RICS guidance note: sustainability and ESG in commercial property valuation and strategic advice, 3rd edn. Retrieved from https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/regulation/valuation/sustainability-and-esg-guidance-note_december-2021_v1.pdf on 13 Sept 2022
13. Ramluckun R, Malumbazo N, Ngubevana L (2024) A review of the energy policies of the BRICS Countries: the possibility of adopting a just energy transition for South Africa. Sustainability 16(2):703

14. SANEDI (2022) Energy performance certificates guideline. Retrieved from https://www.sanedi.org.za/news/June%202022/EPC%20Guideline%20_%20FINAL%20_%20May2022.pdf on 3 June 2022
15. Saunders M, Lewis P, Thornhill A (2016) Research methods for business students. 7th ed, England: Pearson
16. TCDF (2022) Taskforce on climate-related financial risk: overview 2022. Available at: https://assets.bbhub.io/company/sites/60/2022/05/TCFD_Overview_Booklet_Digital.pdf (Accessed on 3 June 2022)
17. Terblanche R (2019) Achieving net zero status in South Africa. *IOP Conf Ser Earth Environ Sci* 323(1):012182. IOP Publishing
18. UNPRI (2021) United nations principles for responsible investment technical guidance: TCFD for real asset owners. Retrieved from https://www.unpri.org/download?ac=13337 on 10 Sept 2022
19. Warren-Myers G (2022) Valuing sustainability Part 2: Australian valuers' perception of sustainability in valuation practice. J Prop Invest Fin 41(4):351–379
20. Warren-Myers G, Hurlimann A, Bush J (2020) Barriers to climate change adaption in the Australian property industry. J Prop Invest Fin 38(5):449–462
21. Wilhelmsson M (2019) Energy performance certificates and its capitalization in housing values in Sweden. Sustainability 11(21):6101
22. World Green Building Council (2021) Beyond buildings: why an integrated approach to buildings and infrastructure is essential for climate action and sustainable development. Retrieved from https://www.worldgbc.org/sites/default/files/BB%20Report%20REDUCED%202021_0.pdf on 3 Apr 2022
23. Zuhaib S, Schmatzberger S, Volt J, Toth Z, Kranzl L, Maia IEN, Verheyen J, Borragán G, Monteiro CS, Mateus N, Fragoso R (2022) Next-generation energy performance certificates: end-user needs and expectations. Energy Policy 161:112723

# Embodied Carbon Emissions for Net-Zero Carbon Buildings: A Comprehensive Study of New Zealand

**Sateesh Pisini, Swetha Thammadi, and Suzanne Wilkinson**

## 1 Introduction

According to the findings of the sixth assessment report by the Intergovernmental Panel on Climate Change (IPCC), the collective GHG emissions from the building sector amounted to 12 gigatons of $CO_2$-equivalent in 2019, constituting 21% of the global GHG emissions for that year. In this figure, on-site direct $CO_2$ emissions accounted for 24%, whereas 18% were attributed to embodied emissions resulting from the production of cement and steel used in construction. In 2022, the dedicated production of steel, cement, and aluminum for building construction contributed 7% to the overall global emissions related to energy and industrial processes. Notably, steel and cement manufacturing were the primary contributors, comprising 95% of this share. This increase in emissions was driven by the demand for new building envelopes, requiring a total of 2 million metric tons of cement and 0.5 million metric tons of steel—a quantity double that of the year 2000 [21]. Building construction contributes to 20% of New Zealand's total emissions, presenting a significant challenge for the country's construction sector. Constituting around 9% of the nation's carbon emissions, it stands as the second-largest emissions source within the built environment [40]. Most of the carbon emissions associated with new construction projects from 2020 to 2050 are expected to stem from the initial upfront emissions

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[22]. The global demand for raw materials is projected to nearly double by 2060, as the world economy expands and living standards rise, aggravating the current environmental overload [32]. Despite its significant contribution to global GHG emissions, embodied carbon has not received adequate attention in strategies aimed at reducing building emissions [45]. The greatest potential to minimize embodied carbon emissions lies in the planning and design phases of project development [43].

In the USA, the construction industry stands as the third-largest contributor to GHG emissions [46]. Within the European Union, buildings emerge as the primary consumer of energy, constituting up to 40% of total energy consumption and approximately 36% of GHG emissions [13, 17]. In Australia, embodied carbon constituted 16% of the built environment emissions in 2019 [16]. The built environment represents 20% of New Zealand's carbon footprint [40]. Embodied carbon linked to the construction of the built environment contributes to approximately 20–23% of total global energy-related GHG emissions [20, 44]. Modeling conducted as part of New Zealand's Ministry of Business, Innovation, and Employment (MBIE) initiative Building for Climate Change (BfCC) program indicates that the sector is responsible for around 15% of the nation's annual GHG emissions [39].

Embodied energy refers to the total energy expended in the extraction, purification, processing, transportation, and production of a material or item, including structures. On the other hand, embodied carbon relates to the carbon emissions associated with materials and construction processes throughout the entire lifespan of a building or infrastructure project [47]. The goal by 2030 is for newly constructed structures, infrastructure projects, and renovations to exhibit at least a 40% reduction in embodied carbon, resulting in significant initial emissions reductions. By 2050, the objective is for all new construction, infrastructure developments, and renovations to achieve a state where their embodied carbon is net-zero [48]. According to the [42] report, carbon emissions linked to the construction and renovation of buildings presently contribute to 20% of emissions in the built environment. As emissions from the operational phase of buildings decrease, the anticipated trend suggests that by 2035, embodied carbon will constitute over 50% of emissions within the built environment.

Figure 1 depicts the compilation of potential estimates gathered from various countries, subsequently consolidated into regional and global projections for the year 2050. In-depth studies utilizing a bottom-up approach indicate a potential mitigation of up to 45% in Australia, Japan, and New Zealand by 2050 when compared to baseline projections. It is crucial to underscore that although these figures may experience occasional variations, the supporting evidence is robust, and there exists a substantial consensus among experts [22].

**Stages of a Building's Life Cycle**

A building is a complex industrial creation designed to endure several decades [2]. European standards (EN 15978:2011) and international standards (ISO 21931-1:2022 and ISO 21930:2017) delineate the life cycle of a building into distinct modules through the entire life carbon assessment information, as depicted in Fig. 2. Notably, these standards articulate the methodology for reporting impact scores

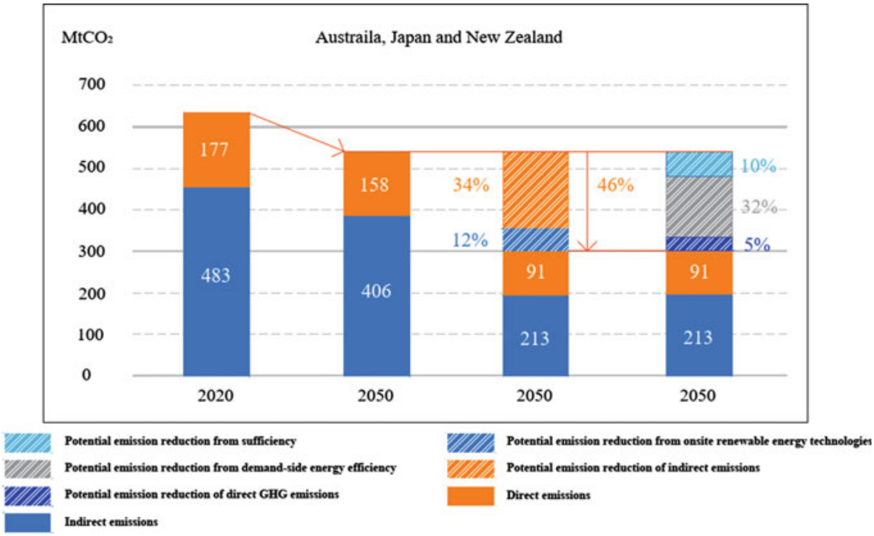


**Fig. 1** Global and regional (for Australia, Japan, and New Zealand) projections of GHG emissions in the building sector for both 2020 and 2050, along with their potential reductions by 2050 categorized by measures (sufficiency/energy efficiency/renewable energy) and direct/indirect emission sources. *Source* [22]

across the entire life cycle of a building, segmented into four distinct stages: product stage (Modules A1–A3), construction process stage (Modules A4–A5), use stage (Modules B1—B7), and end-of-life stage (Modules C1–C4). An additional stage encompasses the benefits and loads beyond the system boundary (Module D). Consequently, to calculate the building's embodied carbon (EC), five distinct system boundaries were established: "cradle (earth) to gate" (from raw materials extraction to the manufacturing factory gate), "cradle to site" (from raw materials to the construction site), "cradle to end of construction," "cradle to grave" (from raw materials to demolition), and even "cradle (earth) to cradle" (encompassing reuse, recycling, and recovery) [34].

Whole-of-life embodied carbon (WLEC) refers to the carbon emissions associated with materials and construction processes throughout the lifespan of a building. This calculation excludes carbon emissions linked to the building's operational energy and water usage (covered by Modules B6 and B7). WLEC includes upfront carbon, use-stage embodied carbon, and end-of-life carbon but does not encompass operational carbon. The inclusion of Module D (benefits and loads beyond the system boundary) depends on the specific standards being followed. However, in the case of green star ratings for non-residential buildings in New Zealand, Module D was considered. It is crucial to emphasize that upfront-embodied carbon emissions originating from the product and construction phases have the most significant impact on annual $CO_2$ emissions [9].

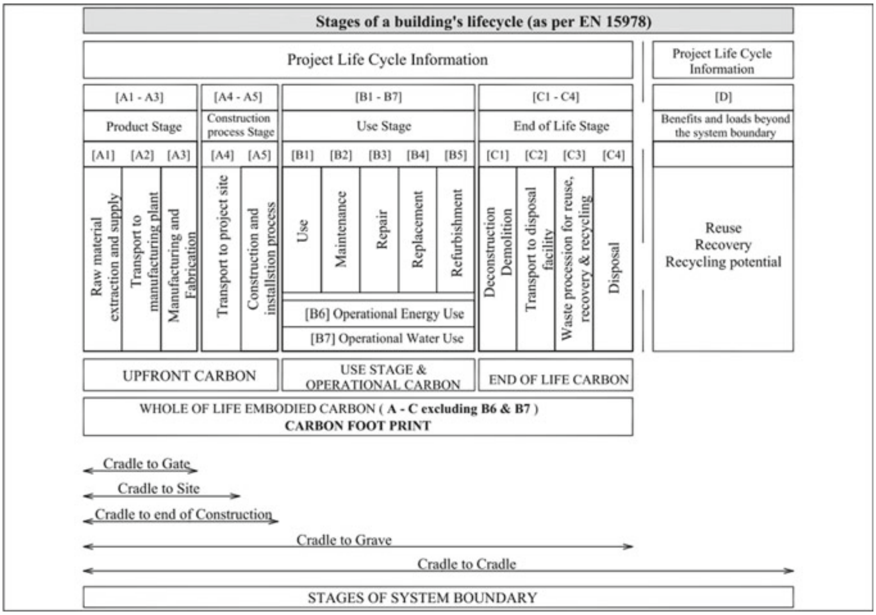


**Fig. 2** Stages of a building's life cycle. *Source* [34]

A thorough literature review was conducted to comprehend the extent of embodied carbon reduction through the utilization of low-carbon materials, carbon storage, construction strategies, and other relevant studies. This is a swiftly progressing field of research, and efforts have been made to grasp the background, available tools, and data for calculating embodied carbon emissions in New Zealand. Additionally, global frameworks and certification schemes adapted in the New Zealand context have been recognized. Overall, the focus is specifically on non-residential buildings, as this represents an emerging area of rating tools for upfront and WLEC reduction in New Zealand. Finally, potential gaps in this research area were identified, and the scope for future investigation was delineated.

## 2 Literature Review

Several studies have underscored the frequent utilization of life-cycle assessment (LCA) to scrutinize carbon emissions in buildings. When assessing carbon emissions throughout a building's life cycle, two key components are considered: embodied and operational carbon emissions [26]. Although standardized methods for evaluating operational carbon emissions have been established because of their significant impact on total carbon emissions over a building's life cycle, there has been comparatively less emphasis on measuring embodied carbon. Nevertheless, the significance of embodied carbon is increasing in relative terms, particularly as buildings become more energy efficient [14]. Ali and Xiao [3] categorized the relevant research into six groups. In this study, research dedicated to exploring various strategies aimed at reducing the embodied carbon of buildings were broadly classified into three main categories: (1) materials, (2) carbon storage, and (3) construction strategies.

## 2.1 Materials

To reduce the carbon footprint associated with construction, it is crucial to prioritize environmentally friendly decisions during the design stage, emphasizing adaptability and flexibility. This approach aims to extend the lifespan of buildings without requiring substantial modifications [1, 19]. Opting for local materials and suppliers can contribute to a reduction in transportation-related carbon emissions while simultaneously fostering a more regional economy. Moreover, strategic design involves integrating circular economy principles into both the construction process and end-of-life stages, with a focus on utilizing recycled and recyclable materials [15]. This facilitates the implementation of circularity principles aligned with sustainable development goals and climate change mitigation initiatives [11, 12]. Additionally, recycling waste materials and components is expected to conserve more energy than manufacturing entirely new elements, resulting in a decrease in embodied carbon emissions during the A1–A3 phases.

Keyhani et al. [23] conducted a study on the measurement and reduction of Embodied Carbon in educational buildings in the UK, employing a "low-carbon materials" strategy and assessing the total embodied carbon using Life-Cycle Assessment (LCA) along with three distinct data sources: Environmental Product Declarations (EPDs), the ICE database, and guidelines provided by the Royal Institution of Chartered Surveyors (RICS).

Design solutions to mitigate the environmental impact associated with building materials include reusing and recycling materials, selecting materials with a low-carbon footprint, sourcing materials locally, choosing durable and long-lasting materials, and minimizing the overall space and resources utilized [24]. Araujo et al. [5] conducted an assessment of GHG emissions associated with Earth-based Bamboo Bio-Concretes (EBBCs), incorporating varying proportions of earth as replacements for the cementitious component, intended for applications in the construction industry.

Substantial progress has been made in critical materials such as steel; for example, the Swedish company SSAB (Svenskt Stål AB) pioneered the world's first fossil-free steel. Engineers in Cambridge are leading the development of the world's first zero-emission cement. Additionally, advancements in carbon capture and storage techniques within concrete production, including low-carbon alternatives, are led by industry leaders, such as Heidelberg Cement and Holcim. Notably, Saint-Gobain achieved a milestone by becoming the first global company to attain zero carbon production for flat glass through the use of 100% recycled glass and the adoption of 100% green energy derived from biogas and electricity [48].

Circular design, recycling, and reuse opportunities exist throughout all building phases. However, individual stakeholder efforts to decarbonize will not succeed without policy and financial support across these phases. For instance, closing the supply demand gap for recycled materials requires building codes that mandate reusable components [43]. Overall, reducing the environmental impact of material production is imperative as part of the broader goal of achieving net-zero emissions.

## 2.2 Carbon Storage

Carbon storage in buildings can be optimized by transitioning to bio-based materials such as timber. For instance, the carbon stored in timber has the potential to counterbalance temporary reductions in forest carbon stocks, as forests can regenerate and resume carbon absorption. This transformation can convert buildings into urban carbon sinks, with carbon density increasing as building density rises, provided that wood is responsibly sourced [41]. Mass timber is a more sustainable alternative to concrete and steel, but sustainable sourcing and regulation are imperative. Numerous studies have indicated that bio-based materials store biogenic carbon and have lower embodied carbon footprints. However, the literature often lacks consistent consideration of negative contributions, with uncertainty regarding which module they affect [6, 10]. Bio-based materials offer the best alternative for achieving significant decarbonization by responsibly managing the carbon cycles. The transition to well-managed bio-based materials has the potential to result in cumulative emission reductions of up to 40 percent by 2050 in many regions, surpassing the reductions achievable through low-carbon concrete and steel [43].

Carbon offsetting is employed to counteract the embodied carbon in Modules A1–A5, B1–B5, and C by purchasing carbon credits to support green energy and reforestation projects, aiding global or local initiatives lacking financial resources. This aligns with weak sustainability and should be a last resort after exhaustively reducing operational and embodied carbon. Future regulations may mandate carbon reduction or offsetting through certified credits, possibly increasing their cost [19].

Embracing nature-based solutions (NbS) and materials that naturally sequester carbon due to the biogenic carbon absorbed throughout their growth and lifespan before manufacturing offers a promising path toward reaching NZCB goals [6]. Highly potential organic materials for $CO_2$ absorption and storage include wood, hemp, mycelium, straw, bamboo, cork, cellulose, and wool. These materials support circular economy principles, as they can be recycled, repurposed, or disposed of responsibly at the end of their life cycle [41].

Ximenes and Grant [49] utilized LCA to assess the GHG emissions associated with various building materials in Australia. They discovered that structural elements composed of concrete and bricks accounted for up to 31% and 17% of the total greenhouse gas impact, respectively. The authors also noted that incorporating timber in the sub-floor construction resulted in reductions in embodied GHG emissions ranging from 31 to 56%.

### 2.3 Construction Strategies

Advancing innovation in construction methods plays a pivotal role in the transition toward achieving net-zero emissions. Nexii, a participant in the net-zero carbon buildings Commitment, champions a modular and circular construction approach and has introduced a substitute for traditional concrete. This innovative solution allows their panels to possess both strength and lightness while maintaining low-carbon emissions, which are approximately 35% lower than those of conventional concrete. It also emphasizes minimal waste generation and embraces a circular approach across their projects.

Cement can be decarbonized by reducing the clinker-to-cement ratio, using more cement alternatives, switching to electric kilns powered by a clean, renewable energy grid, and exploring carbon capture and utilization during manufacturing. In primary steel production, a shift from blast furnace to direct reduced iron technology, along with electric arc furnaces powered by renewable energy, offers substantial emission reduction potential. This can be further enhanced by improving recycling and implementing carbon capture and storage. In the aluminum industry, the greatest emission reduction potential lies in decarbonizing the electricity grid due to its high-energy consumption [43].

The three-year Automating Concrete Construction Project (ACORN), which was concluded in April 2022, is dedicated to reducing carbon emissions in construction by reimagining the use of concrete in buildings. Collaborating with industry partners, the Universities of Bath, Cambridge, and Dundee leveraged offsite manufacturing processes, cost-effective robotics, and robust automation to achieve a remarkable 60% reduction in embodied carbon emissions compared with traditional flat-slab equivalents. Moreover, this approach utilized 75% less concrete offcuts [48].

### 2.4 Other Studies

Zani et al. [51] devised a methodology with the goal of diminishing the embodied carbon emissions of a building. This approach was implemented during both the early and advanced design development phases to evaluate and compare various facade design processes with the aim of establishing and meeting NZCB targets. Similarly, Alotaibi et al. [4] proposed a method and conducted a life-cycle assessment of a High-Rise Residential building, concentrating on the embodied carbon across the three phases of building construction, operation, and demolition.

Blay-Armahet al. [7] evaluated the impact of different databases on the estimation of end-of-life embodied carbon. Ekundayo et al. [14] carried out a comparative assessment of selected open-source tools for calculating embodied carbon in the UK. Hamza et al. [18] explored machine learning techniques for conducting life-cycle assessments of embodied carbon in buildings.

Rinnie et al. [35] scrutinized the environmental impacts of a five-story hybrid apartment building in comparison to timber and reinforced concrete counterparts. They utilized the software tool One Click LCA to estimate the environmental impacts related to building materials, assemblies, construction, and the end-of-life treatment over a 50-year period in Finland. Several studies have sought to quantify the risks associated with the overall environmental performance of buildings [36]. Additionally, there is a focus on promoting construction techniques that reduce the carbon footprint, such as the Industrialized Building System in Malaysia [25].

## 3 Embodied Carbon Emissions for Non-Residential Buildings in New Zealand

### *3.1 Background*

Aligned with global efforts to limit global warming to 1.5°C, Aotearoa New Zealand unveiled its emissions reduction plan in 2022, aiming for a near-zero level of building-related emissions in New Zealand by 2050. The primary focus is on reducing the embodied carbon of buildings, with key areas of emphasis including the reduction of embodied carbon in construction materials and the acceleration of the transition to low-carbon building practices. To facilitate this, the government is exploring the use of a climate innovation platform to foster the swift development and adoption of innovative low-emission building materials and approaches.

Both operational and embodied carbon emissions from buildings in New Zealand are substantial, and there is growing pressure on the building and construction sector to address them. In line with actions taken in other sectors, the New Zealand government is actively implementing measures to drive transformative change, including new regulations aimed at achieving these emission reductions. MBIE introduced the BfCC initiative with the aim of curbing emissions from the building and construction sector while enhancing the climate resilience of buildings. Within the BfCC framework, the whole-of-life embodied carbon (WLEC) emissions' reduction framework sets forth three primary objectives: improving the efficiency of new buildings, optimizing material usage, and reducing carbon intensity. These objectives were designed to reduce embodied carbon, as illustrated in Fig. 3, which outlines the method for calculating a building's embodied carbon.

The MBIE conducted an assessment of the embodied carbon within building components for ten non-residential construction projects in New Zealand. The analysis was based on data from projects that utilized the eTool methodology and software tool to present a detailed breakdown of the building's embodied carbon, as shown in Fig. 4 [39]. This analysis includes Modules A1–A3, B3–B4, C1–C3, and D.

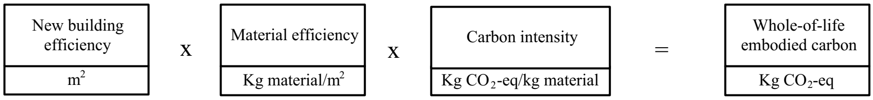


**Fig. 3** Proposed objectives of the WLEC framework [27]

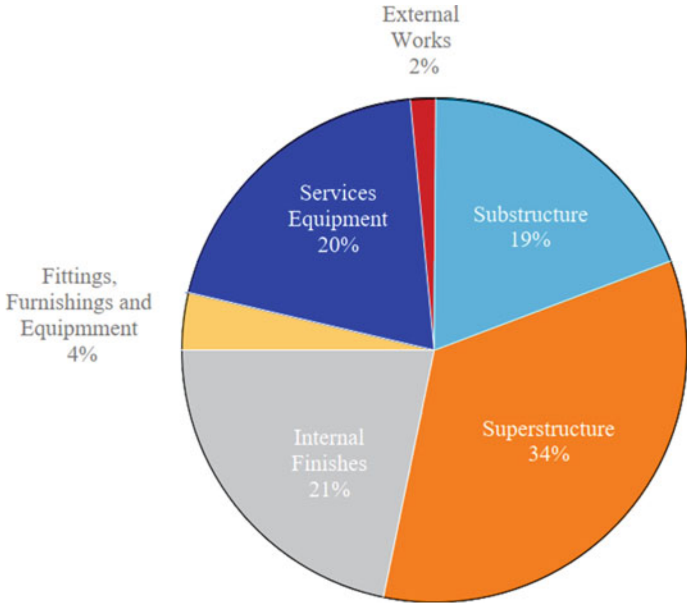


**Fig. 4** Breakdown of the embodied carbon of ten New Zealand buildings by element

## 3.2 *Available Tools and Data*

***Carbon footprint assessment***

The carbon footprint is a computational method that assesses the potential climate change implications of building designs and offers valuable insights for informed decision-making during the design phase. Additionally, it constitutes a crucial component of a broader evaluative process known as life-cycle assessment, encompassing various environmental considerations. Carbon footprint is defined as the sum of carbon emissions and carbon removal throughout the complete or partial product life cycle [28, 30, 31].

The carbon footprint tools developed by Building Research Association of New Zealand (BRANZ) include $CO_2$NSTRUCT, $CO_2$MPARE, and $CO_2$RE, as depicted in Fig. 5. $CO_2$NSTRUCT is an embodied carbon and energy dataset that provides information on greenhouse gas emissions and energy associated with construction materials and products. The data within $CO_2$NSTRUCT were sourced from various

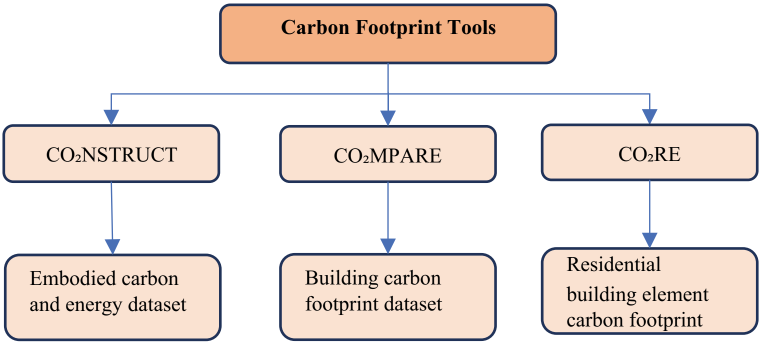


**Fig. 5** Flowchart showing the carbon footprint tools developed by BRANZ, New Zealand

references, with associated metrics indicating data quality. $CO_2$MPARE is a building carbon footprint dataset that provides average carbon footprint measurements for residential and office buildings in New Zealand, offering additional details, such as energy consumption intensity and key materials contributing significantly to greenhouse gas emissions. On the other hand, $CO_2$RE is a residential building element carbon footprint dataset calculating carbon footprints per square meter for roof, wall, and floor constructions in residential settings, sourced from the BRANZ House Insulation Guide (5th edition). This allows for prioritization based on the desired construction R-value.

In New Zealand, BRANZ developed a comprehensive framework for the entire building life cycle, aiming to provide resources, data, and insights to facilitate informed decisions in sustainable building design. The methodology involved employing carbon footprint analysis and life-cycle assessment techniques.

***Life cycle Assessment***

Thousands of building life-cycle assessments (LCAs) and carbon footprints have been completed worldwide since the 1990s [8, 38, 50]. Databases of past international building LCA studies have been compiled by several authors, notably the Carbon Leadership Forum [8], and Röck et al. [38].

The LCA tools used by BRANZ included LCAQuick and LCAPlay. Figure 6 illustrates a flowchart showing the LCA by BRANZ, New Zealand. These tools estimate not only the climate impact, but also consider additional environmental factors, such as eutrophication and fossil fuel depletion. Although LCAQuick is a freely available LCA tool for computing greenhouse gas emissions (along with other environmental effects) associated with building designs, LCAPlay is a user-friendly and quick-to-use tool for evaluating the potential greenhouse gas emissions (as well as other environmental repercussions) of alternative building choices. Other LCA tools accepted by NZGBC for calculating embodied carbon include eTool and One Click EC3. Figure 7 shows the method for estimating the total environmental impact of a building using LCA.

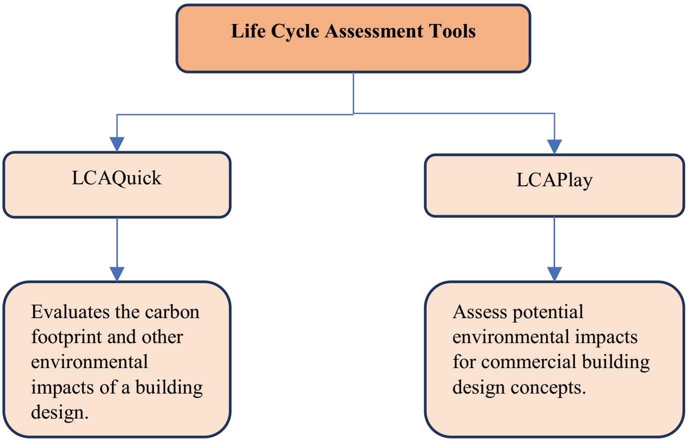


**Fig. 6** Flowchart showing the life-cycle assessment tools by BRANZ, New Zealand

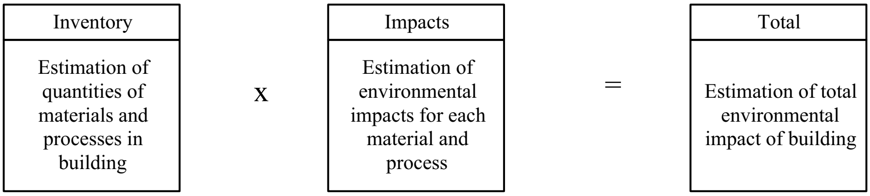


**Fig. 7** Method for estimating the total environmental impact of a building. *Source* [9]

## *3.3 Frameworks and Certification Schemes*

The commonly used rating tools developed and adapted in New Zealand as well as the international rating tools for non-residential buildings in New Zealand are summarized in Fig. 8. The frameworks for defining net-zero carbon in buildings include Carbon zero Building Operations (operational carbon) developed by NZGBC and Toitū Envirocare, Living Building Challenge (Construction and Operational carbon), Zero Carbon Certification (Construction and Operational carbon), and Zero Energy Certification (Planning and Operational carbon) [29]. Framework and project stages for net-zero carbon buildings in New Zealand are shown in Fig. 9. Cost-effective and innovative certification schemes and incentivized and dedicated financing efforts from case studies conducted globally were demonstrated by Pisini et al. [33].

Credits (19.1, 19.2, 19.3) in green stars and the built NZv1.1 designate a mandatory reduction of 10% for upfront carbon with 1 point for a 15% reduction to 6 points for a reduction of 40% through Credit 19.1. Credit 19.2 specifies 1, 2, and 3 points for

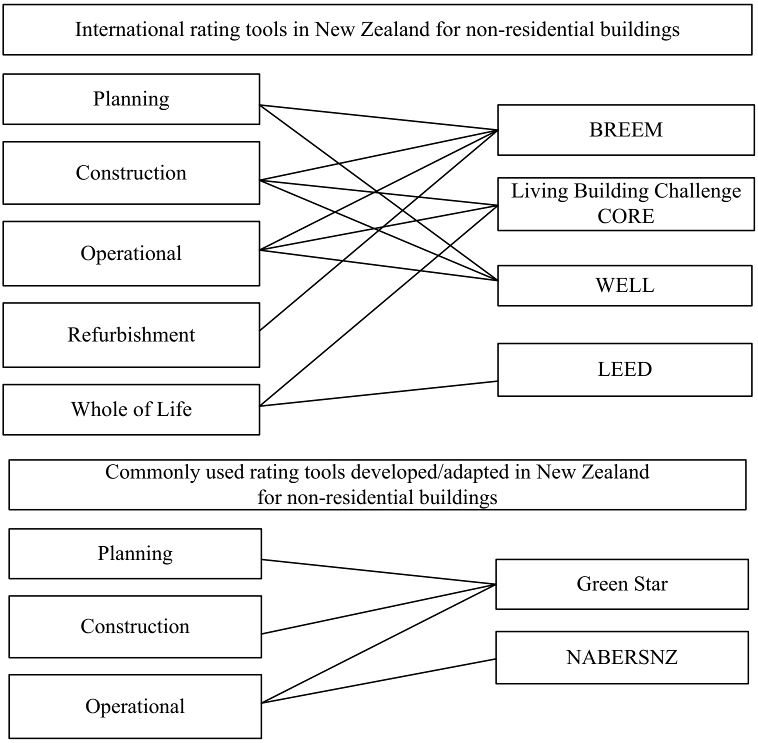


**Fig. 8** Frequently used rating tools designed for non-residential buildings in both the New Zealand and global contexts

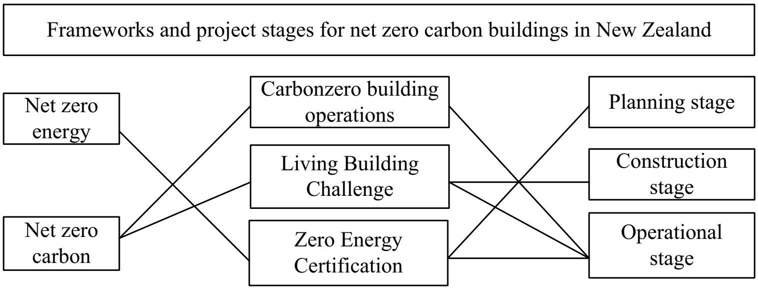


**Fig. 9** Frameworks and project stages for net-zero carbon buildings in New Zealand

10%, 20%, and 30% reduction through whole-life whole-building multi-indicator LCA. Credit 19.3 on Long-term Carbon Storage awards up to two points for carbon stored for more than 50 years. Overall, the green star rating system for non-residential buildings is compliant with the modular structure of EN 15978/EN 15804/ISO 21930 standards and draws on public data from BRANZ and EPDs.

Constructing low-emission office buildings between 2025 and 2050 in New Zealand could lead to an average annual reduction of 46,200 tons of $CO_2$-equivalent emissions, resulting in a cumulative reduction of 1.2 million tons of $CO_2$-equivalent emissions by 2050. If these office buildings were initiated in 2030, savings would amount to just under 970,000 tons [37].

## 4 Discussion and Conclusions

The built environment industry has predominantly concentrated on operational carbon reduction, emphasizing energy reduction targets in building regulations, planning requirements of local authorities, and sustainability assessment rating schemes (such as BREEAM and LEED). Embodied carbon assessment has received less attention, creating a research gap in exploring strategies to reduce embodied carbon emissions. Green star, a sustainability rating system for non-residential buildings in New Zealand, provides a well-defined embodied carbon methodology and calculator guide along with a life-cycle impact calculator guide. However, further research is required to understand the factors influencing embodied carbon emissions in New Zealand, with modeling tools such as STIRPAT being applicable.

The urgency of rapid urbanization calls for immediate policy actions to transition building material life cycles toward regenerative methods. The shifting of bio-based materials can significantly reduce emissions and promote biodiversity. While technological advances have enabled low-carbon materials, social acceptance remains challenging. Achieving net-zero emissions requires prioritizing renewable or reusable materials and investing in decarbonization methods, such as electrification and carbon capture. Developed economies should upgrade industry practices, repurpose old concrete, and invest in research on construction material recovery and processing equipment. Increased investment in research and development of design and secondary manufacturing techniques, along with the necessary equipment for recovering and processing construction, renovation, and demolition materials, is crucial. Designing structural elements with low embodied carbon is essential, and solutions that combine resilience and material efficiency should be explored to reduce building emissions.

In conclusion, it is imperative to promote a circular material economy that emphasizes reuse and recycling to prevent fresh extraction. The transition to emerging methods such as hybrid bio-based materials and other low-carbon alternatives may currently lack economic viability and require substantial investments from both established and emerging producers. This transition should be supported by incentives and enforceable building codes, and sustainable construction management practices should be identified through drivers within a hierarchical framework.

**Author Contributions** Sateesh Pisini played a role in conceptualization, methodology, analysis, drafting, and editing of the manuscript. Swetha Thammadi contributed to preparation of the draft manuscript, figure reproduction, and editing. Suzanne Wilkinson contributed to supervision, discussion, and technical editing. All authors have reviewed and approved the manuscript before submission and publication.

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## References

1. 3XN (2019) Building a circular future; 3XN: Copenhagen, Denmark, 3rd edn, 2018. https://gxn.3xn.com/wp-content/uploads/sites/4/2018/09/Building-a-Circular-Future_3rd-Edition_Compressed_V2-1.pdf
2. Airaksinen M, Matilainen P (2011) A carbon footprint of an office building. Energies 4:1197–1210. https://doi.org/10.3390/en4081197
3. Akbarnezhad A, Xiao J (2017) Estimation and minimization of embodied carbon of buildings: a review. Buildings 7(5). https://doi.org/10.3390/buildings7010005
4. Alotaibi BS, Khan SA, Abuhussain MA, Al-Tamimi N, Elnaklah R, Kamal MA (2022) Life cycle assessment of embodied carbon and strategies for decarbonization of a high-rise residential building. Buildings 12(1203). https://doi.org/10.3390/buildings12081203
5. Araujo A, da Silva N, Sá T, Caldas L, Toledo Filho R (2022) Potential of earth-based bamboo bio-concrete in the search for circular and net-zero carbon solutions to construction industry. IOP Conf Ser Earth Environ Sci 1122:012043. https://doi.org/10.1088/1755-1315/1122/1/012043
6. Besana D, Tirelli D (2022) Reuse and retrofitting strategies for a net zero carbon building in Milan: an analytic evaluation. Sustainability 14(23):16115. https://doi.org/10.3390/su142316115
7. Blay-Armah A, Bahadori-Jahromi A, Mylona A, Barthorpe M, Ferri M (2022) An evaluation of the impact of databases on end-of-life embodied carbon estimation. Sustainability 14(2307). https://doi.org/10.3390/su14042307
8. CLF (2017) Embodied carbon benchmark study—LCA for low carbon construction—part one. The Carbon Leadership Forum, Department of Architecture, University of Washington, Seattle. http://hdl.handle.net/1773/38017
9. CLF (2019) Life cycle assessment of buildings: a practice guide. The Carbon Leadership Forum, Department of Architecture, University of Washington, Version 1.0, 28 June 2018. http://hdl.handle.net/1773/41885
10. Carcassi OB, Habert G, Malighetti LE, Pittau F (2022) Material diets for climate-neutral construction. Environ Sci Technol 56:5213–5223. https://doi.org/10.1021/acs.est.1c05895
11. Cheshire D (2021) The handbook to building a circular economy. RIBA Publishing, London, UK. ISBN 9781859469545. https://www.routledge.com/The-Handbook-to-Building-a-Circular-Economy/Cheshire/p/book/9781859469545
12. Clark D (2019) What colour is your building? Measuring and reducing the energy and carbon footprint of buildings. RIBA Publishing, London, UK; Chapter 1–3. ISBN 9781859464472. https://www.routledge.com/What-Colour-is-your-Building-Measuring-and-reducing-the-energy-and-carbon/Clark/p/book/9781859464472
13. Díaz JJ, Wilby MR, González AB (2013) Setting up GHG-based energy efficiency targets in buildings: the ecolabel. Energy Policy 59:633–642. https://doi.org/10.1016/j.enpol.2013.04.021

14. Ekundayo D, Babatunde SO, Ekundayo A, Perera S, Udeaja C (2019) Life cycle carbon emissions and comparative evaluation of selected open-source UK embodied carbon counting tools. Constr Econ Build 19(2):220–242. https://doi.org/10.5130/AJCEB.v19i2.6692
15. Ellen MacArthur Foundation (2015) Towards a circular economy: business rationale for an accelerated transition. https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition
16. GBCA and thinkstep-anz (2021) Embodied carbon and embodied energy in Australia's buildings. Green Building Council of Australia and thinkstep-anz, Sydney. https://www.thinkstep-anz.com/assets/Whitepapers-Reports/Embodied-Carbon-Embodied-Energy-in-Australias-Buildings-2021-07-22-FINAL-PUBLIC.pdf
17. Grözinger J, Boermans T, John A et al (2014) Overview of member states information on NZEBs: background paper-final report. ECOFYS GmbH, Cologne, Germany. file:///C:/Users/21016382/Downloads/Overview_of_Member_States_information_on.pdf
18. Hamza EH, Ahmed K, Ibtissam B, Kamar O (2023) Machine learning for embodied carbon life cycle assessment of buildings. J Umm Al-Qura Univ Eng Archit. https://doi.org/10.1007/s43995-023-00028-y
19. Hill S, Dalzell A, Allwood M (2020) Net zero carbon buildings: three steps to take now. ARUP: London, UK. https://www.arup.com/perspectives/publications/research/section/net-zero-carbon-buildings-three-steps-to-take-now
20. Huang L, Krigsvoll G, Johansen F, Liu Y, Zhang X (2018) Carbon emission of global construction sector. Renew Sustain Energy Rev 81(2). ISSN 1364-0321. https://doi.org/10.1016/j.rser.2017.06.001
21. IEA (2022) World energy outlook 2022, International Energy Agency (IEA), Revised Version, November 2022. https://www.iea.org/reports/world-energy-outlook-2022
22. IPCC (2022) Climate change 2022: mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Camb Univ Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926
23. Keyhani M, Bahadori-Jahromi A, Mylona A, Janbey A, Godfrey PB, Taşeli B (2023) Measuring and mitigating embodied carbon in educational buildings: a case study in the UK. Eng Fut Sustain 1(2). https://doi.org/10.36828/efs.220
24. Khan SA, Alam T, Khan MS, Blecich P, Kamal MA, Gupta NK, Yadav AS (2022) Life cycle assessment of embodied carbon in buildings: background, approaches and advancements. Buildings 12(1944) https://doi.org/10.3390/buildings12111944
25. Lim PY, Yahya K, Aminudin E, Zakaria R, Haron Z, Mohamad Zin R, Redzuan AAH (2017) IOP Conf Ser Mater Sci Eng 271:012107. https://doi.org/10.1088/1757-899X/271/1/012107
26. Liu K, Leng J (2022) Quantitative research on embodied carbon emissions in the design stage: a case study from an educational building in China. J Asian Archit Build Eng 21(4):1182–1192. https://doi.org/10.1080/13467581.2022.2046003
27. MBIE (2020) Whole-of-life embodied carbon emissions reduction framework, building for climate change programme. mbie.govt.nz/dmsdocument/11794-whole-of-life-embodied-carbonemissions-reduction-framework
28. NZGBC (2023) Embodied carbon calculator guide, Version 1.0, May 2023. https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=62943
29. NZGBC (2022) NZGBC ratings snapshot: built environment sustainability frameworks commonly used in New Zealand, Version 1.0, September 2022. https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=62632
30. NZGBC (2023) Green star NZ embodied carbon methodology, Version 1.0, May 2023. https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=62939
31. NZGBC (2023) Life cycle impacts calculator guide, Version 1.0, May 2023. https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=62941

32. OECD (2019) Global material resources outlook to 2060: economic drivers and environmental consequences. OECD Publishing, Paris. https://doi.org/10.1787/9789264307452-en
33. Pisini S, Thammadi S, Wilkinson S (2023) Energy-efficient buildings for sustainable development. In: Kanwar S, Shukla V, John SK, Singh Kandra H (eds.) Sustainable civil engineering: principles and applications (1st ed.). CRC Press. https://doi.org/10.1201/9781003368335
34. RICS (2017) Whole life carbon assessment for the built environment. In: RICS professional standards and guidance, UK, 1st edn. file:///C:/Users/21016382/Downloads/whole_life_carbon_assessment_for_the_built_environment_1st_edition_rics%20(2).pdf
35. Rinne R, Ilgın HE, Karjalainen M (2022) Comparative study on life-cycle assessment and carbon footprint of hybrid, concrete and timber apartment buildings in Finland. Int J Environ Res Public Health 19(774). https://doi.org/10.3390/ijerph19020774
36. Robati M, Daly D, Kokogiannakis G (2019) A method of uncertainty analysis for whole-life embodied carbon emissions ($CO_2$-e) of building materials of a net-zero energy building in Australia. J Clean Prod 225:541–553. https://doi.org/10.1016/j.jclepro.2019.03.339
37. Robertson N, Dixon H (2022) Near zero emission houses and offices, New Zealand Green Building Council (NZGBC), Here-turi-kōkā 2022. https://www.nzgbc.org.nz/Attachment?Action=Download&Attachment_id=62637
38. Röck M, Saade MR, Balouktsi M, Rasmussen FN, Birgisdottir H, Frischknecht R, Passer A (2020) Embodied GHG emissions of buildings—the hidden challenge for effective climate change mitigation. Appl Energy 258:114107. https://doi.org/10.1016/j.apenergy.2019.114107
39. Symons K, Critchley J (2021) The embodied carbon of buildings in New Zealand: proposals for future regulation, and the role of increased seismic resilience, structural engineering society New Zealand (Inc.). In: SESOC conference 2021. https://2021conf.sesoc.org.nz/PDFs/S3A%20P2%20-%20Symons_Critchley.pdf
40. Thinkstep anz (2018) The carbon footprint of New Zealand's built environment: Hotspot or not?, v1.0, 14 May 2018. https://www.thinkstep-anz.com/resrc/reports/the-carbon-footprint-of-new-zealands-built-environment/
41. Tirelli D, Besana D (2023) Moving toward net zero carbon buildings to face global warming: a narrative review. Buildings 13:684. https://doi.org/10.3390/buildings13030684
42. UKGBC (2021) Net zero whole life carbon roadmap: a pathway for the UK built environment. UK Green Building Council, London, UK. https://ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-A-Pathway-to-Net-Zero.pdf
43. UNEP (2023) Building materials, and the climate: constructing a new future. https://wedocs.unep.org/20.500.11822/43293
44. UNEP (2021) United Nations environment programme 2021 global status report for building and construction: toward zero-emissions, efficient and resilient buildings and construction sector. https://globalabc.org/sites/default/files/2021-10/GABC_Buildings-GSR-2021_BOOK.pdf
45. UNEP (2022) Global status report for buildings and construction: towards a zero-emission, efficient and resilient buildings and construction sector. ISBN No: 978-92-807-3984-8. file:///C:/Users/21016382/Downloads/Building_Construction_2022.pdf
46. US EPA (2009) Potential for reducing greenhouse gas emissions in the construction sector. https://archive.epa.gov/sectors/web/pdf/construction-sector-report.pdf
47. WorldGBC (2019). Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon, September 2019. https://worldgbc.s3.eu-west-2.amazonaws.com/wpcontent/uploads/2022/09/22123951/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf
48. WorldGBC (2023). Advancing net zero status report 2023. https://worldgbc.org/wp-content/uploads/2023/07/WorldGBC-ANZ-Status-Report-2023_FINAL-compressed_1.pdf

49. Ximenes FA, Grant T (2013) Quantifying the greenhouse benefits of the use of wood products in two popular house designs in Sydney, Australia. Int J Life Cycle Assess 18(4):891–908. https://doi.org/10.1007/s11367-012-0533-5
50. Yu M, Wiedmanna T, Crawford R, Tait C (2017) The carbon footprint of Australia's construction sector. Procedia Eng 180:211–220. https://doi.org/10.1016/j.proeng.2017.04.180
51. Zani A, Ladipo O, D'Aquilio A, Galante CG, Tee M, Vargas TC (2021) Facade design process to establish and achieve net zero carbon building targets. J Phys Conf Ser 2069:012199. https://doi.org/10.1088/1742-6596/2069/1/012199

# Performance of Sustainable Reinforced Concrete Beams Containing Fine Plastic Waste Aggregate and Their Life-Cycle Costing

**Svetlana V. Samchenkoa, Oksana A. Larsena, Alaa Jaleel Naji, Dheyaa A. N. Alobaidi, Asser Elsheikh, and Alexey S. Markovich**

## 1 Introduction

The global plastic production in 2020 was nearly 381 million tons [4]. By 2050, this amount is predicted to rise to 1100 million tons [27]. Plastic products generated an estimated 44 metric tons of plastic waste in the USA in 2019; approximately 86% was buried, 9% was combusted, and 5% was reused. Buried plastics represented considerable losses, with a market value of about US$7.2 billion [20]. Due to the extremely rapid consumption of plastic products, the generation of plastic waste increased. Therefore, one of the major issues threatening both the environment and humans is the exponential rise in the consumption of plastic products [16]. Recycling is the perfect option to reduce the accumulation of plastic waste compared with other options like burning, burying, or throwing it into rivers and seas, polluting the air, soil, and water [5].

The growth in the global construction sector is witnessing a significant increase. For instance, 230 billion square meters of new construction around the world are expected every single week [9]. Not only the cement but also the natural fine and

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coarse aggregate are the main components of the concrete matrix. Generally, they are around 77% of the total volume of concrete, therefore, the investigation of alternative materials is gaining more attention [14].

Recently, the production of renewable materials has received increased attention for economic and environmental reasons, with the use of plastic waste material in concrete being an important step toward sustainable concrete production [24]. The scientists investigate innovative and sustainable means to reuse or recycle the plastic waste in the construction sector to minimize its negative effects on the environment. In addition, provide alternatives to replace the coarse and fine aggregates in the concrete [18].

The experimental study had been published and described the behavior of high-strength concrete beams containing coarse plastic waste aggregate made from high-density polyethylene (HDPE) by utilizing vegetable boxes with 10%, 20%, and 30% ratios. The crack resistance and failure time for the 30% replacement ratio were similar to the control beam, and the stiffness increased by 24% while the ultimate load decreased by 7% [23].

The compressive strength of concrete mixes with coarse plastic particles made from plastic waste boxes was tested. The study conducted the ratios (20, 40, 60, and 80%) of partial substitution for natural coarse aggregate, and the findings referred to a decrease in compressive strength [13].

Some studies investigated the influence of utilizing recycled coarse aggregates on the long-term deformations of reinforced concrete beams; the results indicated that recycled concrete showed higher deformations than recycled concrete. In addition, recycled aggregate content affects concrete behavior in terms of deflection recovery over time [2, 25].

Numerous researchers have examined the behavior of reinforced concrete beams strengthened with plastic waste fibers that are recycled from plastic waste bottles (polyethylene terephthalate); the results showed an improvement in the compressive strength [1, 3, 26].

Both an experimental and numerical investigation focused on the effects of utilizing plastic mesh layers manufactured from wastewater plastic gallons on the flexural behavior of non-structural concrete beams, whose dimensions were 80 mm $\times$ 280 mm. The mesh void ratio effects and the effective width of the mesh have been checked. The results showed that using the plastic fiber mesh had improved the ductility compared with the reference specimens, and the ultimate load of the member increased as the effective width of the mesh increased [12].

This study carried out an experimental investigation on the utilization of fine plastic waste aggregate as a substitute for fine natural aggregate and its impact on the properties of concrete, the structural behavior of RC beams, and life-cycle cost.

**Table 1** Gradation of coarse aggregate and properties

| Size of sieve (mm) | Percent passing % of coarse agg | Limits (45: 1984) |
|---|---|---|
| 37.5 | 100 | 100 |
| 20 | 100 | 95–100 |
| 9.5 | 53 | 30–60 |
| 4.75 | 0 | 0–10 |
| SO3 content (%) | 0.08 | $\leq$ 0.1 |

**Table 2** Gradation of fine aggregate and properties

| Size of sieve (mm) | Percent passing % of fine agg | Limits (45: 1984) |
|---|---|---|
| 9.5 | 100 | 100 |
| 4.75 | 94 | 90–100 |
| 2.36 | 94 | 85–100 |
| 1.18 | 77 | 75–100 |
| 0.6 | 63 | 60–79 |
| 0.3 | 31 | 12–40 |
| 0.15 | 0 | 0 |
| SO3 content (%) | 0.27 | $\leq$ 0.1 |

# 2 Experimental Work

## *2.1 Concrete Materials*

The materials utilized in the reference concrete mixes in this experiment were sulfur-resistant Portland cement, meeting Iraqi Standard No. 5/1984 [15]. Table 1 shows sieve analysis and properties for neutral coarse aggregate. Table 2 shows the sieve analysis and properties of neutral sand aggregate.

Several trial concrete mixes (listed in Table 3) were prepared in the laboratory to determine the optimum plastic content. The total volume of fine aggregate remained unchanged; that is, the amount of sand decreased and the amount of plastic increased by the same volume. The compressive strength of all concrete mixes is shown in Table (3).

## *2.2 Fine Plastic Waste Aggregate*

The fine plastic waste aggregate was manufactured in this study using vegetable plastic boxes made from high-density polyethylene (HDPE). The boxes were

**Table 3** Mix proportion (kg/m$^3$)

| Mixes | Cement | Fine agg | Plastic fine agg | Coarse agg | W/ C |
|---|---|---|---|---|---|
| $M_R$ | 375 | 670 | 0 | 1150 | 180 |
| $M_1$ | 375 | 603 | 67 | 1150 | 180 |
| $M_2$ | 375 | 536 | 134 | 1150 | 180 |
| $M_3$ | 375 | 469 | 201 | 1150 | 180 |
| $M_4$ | 375 | 402 | 268 | 1150 | 180 |
| $M_5$ | 375 | 335 | 335 | 1150 | 180 |

collected and shredded into small pieces, which were then filtered through a 4.75-mm sieve. Additionally, recycled plastic pieces were washed and air-dried before use. Figure 1 illustrates the process of manufacturing the fine plastic waste aggregate: (a) collection of the vegetable plastic boxes; (b) shredding of the plastic boxes; (c) washing plastic waste aggregate; and (d) drying of the plastic waste aggregate. According to Radhi, M. M. et al., the properties of plastic waste aggregate are as follows: density 0.949 kg/m$^3$, water absorption zero, modulus of elasticity 358.7 (MPa), compressive strength 26.4 (MPa), tensile strength 7.7 (MPa), and flexural strength 878.3 (MPa) [23].

## 2.3 Specimens' Design

The two reinforced concrete beams in this investigation were designed according to ACI 318M-14 [7] to fail in flexure. The cross-section of beams shown in Fig. 2 was 150 mm in width and 250 mm in depth, with 1200 mm as the total length of the beam. The reinforcement details of the beams were 2Ø10 mm bottom tension and 2Ø10 mm top bars. The spacing distributed along the shear spans was 10 mm closed stirrups of 100 mm center-to-center to prevent shear. The first beam (S1S) was cast with 100% natural fine aggregate from the concrete mix (MR). The second beam was cast with the mix (M3) which contained 30% fine plastic waste aggregate.

## 2.4 Test Methods

Figure 2 illustrates the test setup for the three-point bending; 1080 mm was the test span. The load was applied gradually by the hydraulic testing machine. A linear variable differential transformer (LVDT) was used to record deflection at the span's center, while a digital image correlation approach was used to track cracks on the reinforced concrete beam's surface at each load step until failure. The main principle of DIC is to take an image of the specimen before loading and an image after the

(a) Raw vegetable plastic boxes. (b) Shredding the plastic boxes.

(c) washing plastic waste aggregate (d) drying the plastic waste aggregate.

**Fig. 1.** **a** Raw vegetable plastic boxes. **b** Shredding the plastic boxes. **c** Washing plastic waste aggregate. **d** Drying the plastic waste aggregate

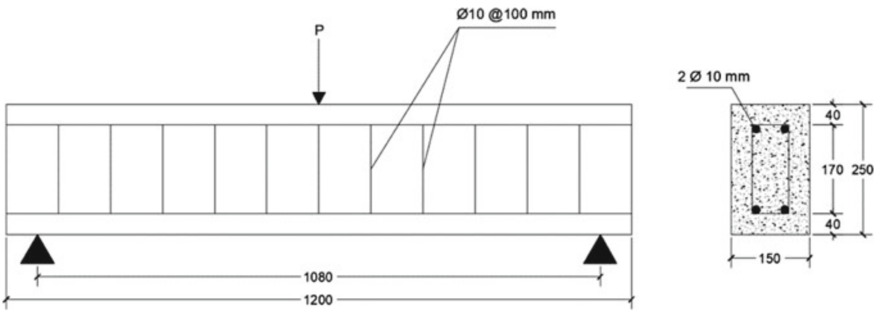



**Fig. 2** Testing and details of the reinforced concrete beams


**Fig. 3** Experimental setup of digital image correlation technique

specimen is loaded to confirm a reliable image correlation. The surface of the specimen should be covered with a random gray intensity distribution (speckled pattern) as shown in Fig. 3. The vision-based measurement system needs a camera and software for image acquisition and processing for the estimation of the crack width. In this work, the distribution of scale values in the image in the undeformed state and those in the deformed state is compared as the basis for the DIC approach. As a result, the function $g\ (x, y)$ in the undeformed image represents the initial gray-level distribution, whereas $g\ (xt; yt)$ in the deformed image [17].

## 3 Results and Discussion

### *3.1 Fresh Concrete Workability*

Workability of concrete mix is freshly mixed concrete that can be mixed, cast, and finished with less homogeneity loss. Workability is a property that directly affects strength, quality, and even the cost of labor for casting and finishing operations. In accordance with ASTM C143, the slump test is most commonly used to check the consistency of the concrete mix [21]. In this study, it was used to notice the influence of the fine plastic waste aggregate on workability. In general, the densities of the concrete mixes decreased as the replacement ratio increased. Since fine waste plastic aggregate has a lower specific gravity than fine natural aggregate, the mixture becomes stiffer. Also, the plastic particles cause an increase in the friction between the particles of the concrete and act as a barrier to the flow of the concrete.

**Table 4** Compressive strength mixes

| Plastic waste % | Comp strength (fcu) MPa | Split tensile strength (fs) MPa | Changing in comp. strength (%) | Decreasing in tensile strength (%) | Slump (mm) |
|---|---|---|---|---|---|
| 0 | 30 | 2.94 | 0 | 0 | 140 |
| 10 | 28 | 2.83 | −6.66 | −3.74 | 131 |
| 20 | 25 | 2.71 | −16.66 | −7.82 | 123 |
| 30 | 21.5 | 2.08 | −28.333 | −29.25 | 108 |
| 40 | 20 | 2.03 | −33.33 | −44.82 | 104 |
| 50 | 17 | 1.85 | −43.33 | −37.07 | 97 |

### *3.2 Compressive Strength*

The compressive strength of concrete is the most significant characteristic that is used to estimate the quality of the material. Concrete compressive strength is the ability of a concrete structural member to withstand pressure applied to its surface without cracking or deflection. Fifteen-cm-cubic specimens were investigated to evaluate the compressive strength of concrete mixtures with various ratios of fine plastic aggregate. Table 4 illustrates the effect of utilizing fine plastic aggregate on compressive strength after 28 days for each mix. Using fine plastic waste aggregate made from vegetable plastic box waste as a replacement for natural fine aggregate in concrete mixtures resulted in a decrease in compressive strength with an increasing replacement ratio. The lower compressive strength is due to the fact that plastic particles create additional pores in concrete, and bonds are weakened by the weak arrangement around them. These results are consistent with the outcomes reported by Hussain et al. (2018).

### *3.3 Split Tensile Strength*

The tensile strength of concrete is one of its vital properties that greatly influences the extent and dimension of cracking in structures. Besides, due to its brittle nature, concrete is highly susceptible to tensile forces [21]. To determine the tensile strength of concrete, cylinders with a diameter of 100 mm and a height of 200 mm were tested after 28 days. Figure 4 depicts the tensile strength graphed for all concrete mixes. It illustrated that when increasing the replacement ratio of fine plastic waste aggregate in concrete, the splitting tensile decreases. In high replacement ratios of fine plastic aggregate, the tensile strength decreases as a result of an increase in voids present within the concrete. The reduction in tensile strength was clearly. Such a reduction is also the findings of [3]. The utilizing of fine plastic waste aggregate in the concrete decreases the bond strength between the ingredients.

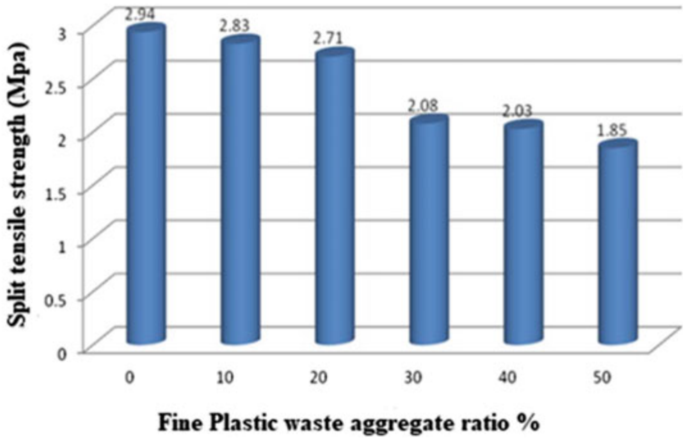



**Fig. 4** Split tensile strength

## 3.4 Flexural Strength

The resisting ability to fail in bending a structural member is described as flexural strength, which is usually calculated by a three- or four-point loading test. The flexural tests in Fig. 3 were performed on cross-section details to test the influence of substituting 30% fine plastic waste aggregate on the behavior of reinforced concrete beams. Figure 5 shows load–deflection curves for all specimens of flexurally reinforced concrete beams. The results exhibited better flexural strength for reinforced concrete beams with 30% fine plastic waste aggregate than the reference. Also, load–deflection curves exhibited comparable behavior for the flexible material before cracking. The test results indicated that the direct effect of the use of fine plastic waste aggregate in reinforced concrete beams led to a reduction in the ultimate load capacity. But, it showed better flexural strength and resistance to the cracks than the reference.

## 3.5 The Digital Image Technique and Cracking Patterns

Because of the determinants of direct image-based crack measurements, the digital image correlation approach (DIC) has recently been applied to a large extent to check crack patterns in experimental studies [11]. The digital-image technique (DCI) is a non-contact and optical measurement method that has been applied as a useful method to measure numerous parameters like deformation, strain, and cracking on concrete surfaces as a result of the rapid development of digital imaging and data-processing techniques. The digital image correlation (DIC) method procedure includes converting the recorded video to digital images using converter software

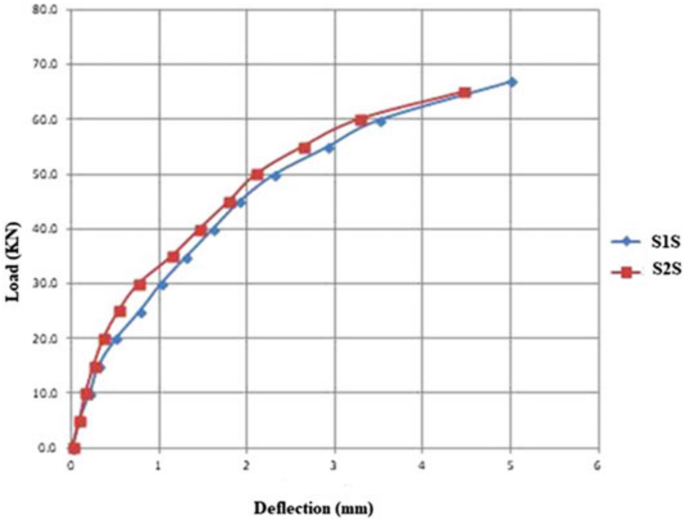
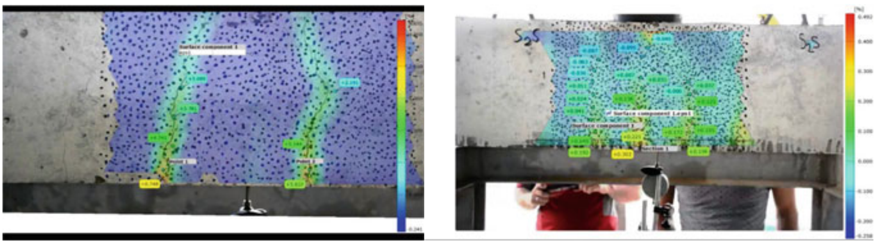



**Fig. 5** Load deflection curve

[22], which refers to the value of frames per second (FPS). Figure 3 illustrates the setup of the digital image correlation technique and the result in Fig. 6. The crack patterns are observed using a digital image correlation approach. The cracks began to form in the middle of the beams; they started at the bottom and expanded to the top during increased failure loads. Another notice was that cracks formed on the reference specimens earlier than on the beam, which contained fine plastic waste aggregate. In comparison to the reference beam, the specimen, which included fine plastic waste aggregate, had greater crack strength.



(a) Crack patterns for beam S1S. (b) Crack patterns for beam S2S.

**Fig. 6** **a** Crack patterns for beam S1S. **b** Crack patterns for beam S2S

### 3.6 Life-Cycle Cost Analysis of Reinforced Beams Containing Plastic Waste Aggregate

Life-cycle cost (LCA) is a common method used to assess the cost performance of materials, services, or products. Furthermore, it can be used to inform decision-makers about alternatives [28]. The life-cycle cost approach allows the designer to choose any construction material that satisfies the project's performance requirements. Not only evaluating construction materials but also their life-cycle costs is a method for comparing and choosing a cost-effective construction material [10]. The life-cycle cost (LCC) is mainly composed of three essential categories: construction cost, operation and maintenance cost, and end-of-life cost [19].

$$\boldsymbol{LCC = C_c + C_r + C_e}. \tag{1}$$

Construction costs ($C_c$) include three main categories: material, labor, and equipment. Reinforced concrete materials consist of sand, gravel, cement, and rebar, while equipment covers formwork, transportation, and the setup of rebar. The meter cube is the relevant unit of measurement pertaining to the concrete beams, and the total cost of each type of RC beam utilizing natural aggregates and plastic waste aggregates was accounted for as listed in Table 5. Based upon the average market rates at the time of preparing this study, all costs have been calculated. The total cost for natural aggregate is (20$) for one cubic meter, while the total cost for plastic waste aggregate is (30$) for one cubic meter. According to recent prices, the construction cost and market rates were estimated. The fine aggregate often covers about 30% of the unit rate of concrete; hence, the cost of the plastic waste aggregate was discounted and replaced with 30% of the unit rate.

Maintenance cost ($C_r$) includes all the needed labor, materials, or tools, as well as other relevant fees, to keep a structure or its parts in a condition in which they can perform their in-demand jobs. Maintenance and operation cover running and managing the facility, conducting corrective or responsive maintenance, and including all related administration, such as scrub, servicing, rehabilitation, repainting, and part replacement, where necessary to allow the created asset to be used for its intended purposes. According to Al-Qahtani et al., the rated cost of maintenance is assumed to account for 30% of the construction cost [6].

According to ISO 15686-5:2017, end-of-life costs ($C_e$) are the net cost or fee for disposing of a material, product, or piece of equipment at the end of its useful life. It is comprised the demolition of a building, disposal of components and materials,

**Table 5** Life-cycle cost analysis of reinforced beams

| Types of beams | Construction cost | Maintenance operation cost | End-of-life cost |
|---|---|---|---|
| S1S | 400 ($/m$^3$) | 120 ($/m$^3$) | – |
| S2S | 400 ($/m$^3$) | 120.9 ($/m$^3$) | – |

scrap value, site remediation, recycling, recovery, transport, and regulatory costs [8]. Both types of concrete are assumed to have the same landfill cost.

Although the price of the fine plastic waste aggregates is currently higher than that of comparable natural sand aggregates, the life-cycle cost of RC beams using the fine plastic waste aggregate is almost similar to that of beams using natural aggregates. In order to enhance the compressive strength of RC beams containing fine plastic waste aggregate, chemical additives and a lower water-to-cement ratio may be used.

## 4 Conclusion

An experimental study on the fresh and mechanical properties of concrete with fine plastic waste aggregate manufactured from vegetable plastic boxes as sustainable concrete was presented in this paper. Also, investigate the flexural behavior of reinforced concrete beams that contain 30% fine plastic waste aggregate. Besides, a digital image correlation approach is used to track the cracks on the surface of the reinforced concrete beams. Also, to assess the life-cycle cost implications of using fine plastic waste aggregates in reinforced concrete beam structures, the findings of this study are listed below:

- As the percentage of replacements increases, the densities of the concrete mixes decrease as a result of the lower specific gravity of fine plastic waste aggregate compared to natural fine aggregate, and the mixture stiffens. Also, the plastic particles cause an increase in the friction between the particles of the concrete and act as a barrier to the flow of the concrete.
- The increase in the replacement ratio of fine plastic waste aggregate in concrete mixes makes for a reduction in splitting tensile strength due to an increase in voids inside the concrete.
- Utilizing fine plastic waste aggregate in the concrete mixes makes for a reduction in the compressive strength of the mixes with an increasing replacement ratio. The lower compressive strength is due to the fact that plastic particles create additional pores in concrete, and bonds are weakened by the weak arrangement around them.
- The test results indicated that the direct effect of the use of fine plastic waste aggregate in reinforced concrete beams led to a reduction in the ultimate load capacity. But, it showed better flexural strength and resistance to the cracks than the reference.
- The results of the assessment of life-cycle cost support the utilization of fine plastic waste aggregates as an alternative to neutral fine aggregate to conserve natural resources and minimize the environmental effects of both the concrete and plastic industries.
- In order to enhance the compressive strength of RC beams containing fine plastic waste aggregate, chemical additives and a lower water-to-cement ratio may be used.

- This study supports the production of renewable materials for economic and environmental reasons, with the use of plastic waste material in concrete being an important step toward sustainable concrete production.

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## References

1. Adnan HM, Dawood AO (2020) Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers. Case Stud Constr Mater 13:e00367
2. Ahmad J, Majdi A, Babeker Elhag A, Deifalla AF, Soomro M, Isleem HF, Qaidi S (2022) A step towards sustainable concrete with substitution of plastic waste in concrete: overview on mechanical, durability and microstructure analysis. Crystals 12(7):944
3. Albano C, Camacho N, Hernandez M, Mathreus A, Gutierrez A (2009) Influence of content and particle size of waste pet bottles on concrete behaviour at different w/c ratios. Waste Manage (Oxford) 29:2707–2716. https://doi.org/10.1016/j.wasman.2009.05.007
4. Almeshal I, Tayeh BA, Alyousef R, Alabduljabbar H, Mohamed AM, Alaskar A (2020) Use of recycled plastic as fine aggregate in cementitious composites: A review. Constr Build Mater 253:119–146
5. Almohana AI, Abdulwahid MY, Galobardes I, Mushtaq J, Almojil SF (2022) Producing sustainable concrete with plastic waste: a review. Environ Challenges 100626
6. Alqahtani FK, Abotaleb IS, ElMenshawy M (2021) Life cycle cost analysis of lightweight green concrete utilizing recycled plastic aggregates. J Build Eng 40:102670
7. ASTM International (2012) Standard test method for slump of hydraulic-cement concrete (ASTM C143/C143M-12). West Conshohocken, PA
8. BSI. British Standards Institution (2017) BS ISO 15686-5: buildings and constructed assets-service life planning-part 5-life-cycle costing. BSI
9. EEA (2016) Environmental indicator report (2016). In support to the monitoring of the 7th environment action programme. https://doi.org/10.2800/76896
10. Ehlen MA (1997) Life-cycle costs of new construction materials. J Infrastruct Syst 3(4):129–133
11. Gehri N, Mata-Falcón J, Kaufmann W (2020) Automated crack detection and measurement based on digital image correlation. Constr Build Mater 256:119383
12. Ghanem H, Chahal S, Khatib J, Elkordi A (2022) Flexural behavior of concrete beams reinforced with recycled plastic mesh. Buildings 12(12):2085
13. Hussein AA, Breesem KM, Jassam SH, Heil SM (2018) Strength properties of concrete including waste plastic boxes. IOP Conf Ser Mater Sci Eng 454(1):012044
14. Ibrahim AA, Najla'a H, Jaber MH, Hassan RF, Hussein HH, Al-Salim NH (2022) Experimental investigation of flexural and shear behaviors of reinforced concrete beam containing fine plastic waste aggregates. Structures 43:834–846
15. Iraqi Specifications No. (45), 1984 for Aggregates of Natural Resources used for Concrete and Construction
16. Irmawaty R, Djamaluddin R (2022) Flexural behavior of monolith and hybrid concrete beams produced through the partial replacement of coarse aggregate with PET waste. Structures (43):1134–1144

17. Jing G, Yunchang D, You R, Siahkouhi M (2022) Comparison study of crack propagation in rubberized and conventional prestressed concrete sleepers using digital image correlation. Proc Inst Mech Eng Part F J Rail Rapid Transit 236(4):350–361
18. Lamba P, Kaur DP, Raj S, Sorout J (2022) Recycling/reuse of plastic waste as construction material for sustainable development: a review. Environ Sci Pollut Res 29(57):86156–86179
19. Liu G, Hua J, Wang N, Deng W, Xue X (2022) Material alternatives for concrete structures on remote islands: based on life-cycle-cost analysis. Adv Civ Eng
20. Milbrandt A, Coney K, Badgett A, Beckham GT (2022) Quantification and evaluation of plastic waste in the United States. Resour Conserv Recycl 183:106363
21. Mozumder RS, Abedin MM, Islam MT (2023) Experimental study on light weight concrete using plastic waste as a partial replacement of fine aggregate. Research Square
22. Quanjin M, Rejab MRM, Halim Q, Merzuki MNM, Darus MAH (2020) Experimental investigation of the tensile test using digital image correlation (DIC) method. Mater Today Proc 27:757–763
23. Radhi MM, Khalil WI, Shafeeq S (2022) Flexural behavior of sustainable reinforced concrete beams containing HDPE plastic waste as coarse aggregate. Cogent Eng 9(1):2127470
24. Rafiq AH, AL-kamaki YSS (2022) The effect of adding waste plastic fibers on the concrete properties and shear strength of rc beams: a review. J Duhok Univ 25(2):507–530
25. Seara-Paz S, González-Fonteboa B, Martínez-Abella F, Eiras-López J (2022) Deformation recovery of reinforced concrete beams made with recycled coarse aggregates. Eng Struct 251:113482
26. Suksiripattanapong C, Phetprapai T, Singsang W, Phetchuay C, Thumrongvut J, Tabyang W (2022) Utilization of recycled plastic waste in fiber reinforced concrete for eco-friendly footpath and pavement applications. Sustainability 14(11):6839
27. UN Environment Programme. UNEP. Available online: https://www.unep.org/interactives/beat-plastic-pollution/. Accessed on 25 Aug 2022
28. Zhang M, Gong H, Xiao R, Jiang X, Ma Y, Huang B (2023) Life-cycle cost analysis of rehabilitation strategies for asphalt pavements based on probabilistic models. Road Mater Pave Des 24(1):121–137

# Review of the Critical Success Factors for Stakeholders' Management in Sustainable Building Projects

**Osabhie Paul Esangbedo, Bilge Erdogan, and Yasemin Nielsen**

## 1 Introduction

The construction industry comprises of large number of participants called stakeholders who work within the project success criteria. These stakeholders are referred to as entities, having stakes in a project, or who can be affected by the project in fulfilling its objectives [29]. According to Oppong et al. [30], each of the numerous stakeholders on a project often present a wide range of interests to enhance project success which are to be met through project delivery. Phung et al. [33] stated that project success is viewed as a combination of the triple bottom line criteria of sustainability (social, economic, and environmental), project performance (cost, time, and quality), and stakeholder satisfaction. To improve sustainability, Hwang and Ng [18] was of the view that project stakeholders can incorporate these goals into their roles during project lifecycle since they are the actors who guarantee that project objectives are delivered. According to Ibrahim et al. [19], a well-integrated and managed team will result in a successful sustainable building project. Relationship between project stakeholders is central to the success of projects [20].

Smart collaboration enhances multi-stakeholder partnership for sustainable development which makes sustainable building projects complex and difficult to manage as diverse construction professionals with varying background, level of training and experience, collaborate to ensure project objectives are delivered successfully. This collaborative approach should manage risks and provide good governance

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tools through flexible institutional arrangements based on technological innovations. However, multi-stakeholder partnerships enable shared knowledge, expertise, technology and financial resources to support the achievement of sustainable goals thereby making the building construction process complex with poor coordination and management leading to participants unsatisfied with project outcomes [14, 16]. Therefore, proper understanding of project complexity is essential to ensure effective management and establishing a management system of multi-stakeholders who are involved on a project. This will ensure delivery of building projects that meets the needs and expectations of stakeholders who raise concern in line with their interest during the execution of the project. Failure to meet such concerns could led to litigations or protest which are indications of the dissatisfaction of project stakeholders.

Molwus et al. [27] established the relationships between the critical success factors for stakeholders' management and construction project success based on an exploratory grouping. The study developed a framework for generic construction projects and found out that stakeholders' engagement has direct impact on project success. A study by Phung et al. [33] developed a model for sustainable project management of which stakeholder management was one of the five components.

Although there have been a number of research efforts on stakeholder management and construction sustainability, there is no specific focus on different type of projects. Building projects have complex stakeholder structures which are prone to contradictions and conflict, and high sustainability expectations. It is necessary to have a specific investigation on the impact of the critical success factors of stakeholder management to achieve sustainable building projects. Therefore, there is need to set up a management structure of multi-stakeholders who collaborate to achieve sustainable building project. This study aims at conducting a thorough analysis of the pertinent literature on the critical success factors (CSFs) for stakeholder management that can result in sustainable building projects. The research questions are:

(1) What are the issues associated with sustainable construction which effective management of stakeholders can be a panacea?
(2) What are the outcomes of previous literature about stakeholder management and sustainable construction?

## 2 Literature Review

### 2.1 Stakeholder Management and Sustainable Building Projects

According to Marcelino-Sádaba and Pérez-Ezcurdia [23], a way to achieve sustainability, is to recognise projects and their management therefore, it is necessary to focus on stakeholders who originate, approve, finance and participate in its execution. Stakeholder management throughout the life cycle involves processes necessary to identify stakeholders and analyse those who could influence the project [21].

The analysis enhances the development of appropriate strategies to manage the project team and their activities. In the course of managing stakeholders, their attitude can ascertain the level of contribution the project will attain in improving sustainable development and compliance with sustainable principles. Sustainability ensures that financial, social and nature responsibility factors integrates in order for the resources to be judiciously utilised [38]. Though project management frameworks do not effectively take social and environmental issues into account, integrating sustainability and project management is vital in order to achieve project success as project management methodologies are not excluded from the sustainability. It has been argued that current project management frameworks do not effectively take social and environmental issues into account, and thus require revision [7]. Few researchers like-Silvius [35], Martens and Carvalho [24], Fernández-Sánchez and Rodríguez-López [13], Sanchez [34], Vifell and Soneryd [39] have made attempt to integrate sustainability and project management. Singh et al. [36] stated that in order to guarantee that projects are handled in a way that would support sustainable development, indicators must be created that can be utilised in decision-making to align with operational processes.

Moreover, the motivation for incorporating sustainability principles may be both value and business based. Achieving a balance between the triple bottom line criteria of sustainability involves multi-disciplinary participation of different stakeholders who collaborate to execute these projects.

According to Molwus [26], individuals, organisations or organisations with a stake in the project and the ability to participate are known as stakeholders in construction projects.

Stakeholders could be categories as internal and external. Srinivasan and Dhivya [37] stated that internal stakeholders are directly involve in organisation's decision-making process while external stakeholders are people who gets affected by the organisation's act. These stakeholders have different priority requirements for sustainability. However, proper stakeholder management is essential for sustainable initiatives to succeed in balancing these different requirements [33]. This enables the use of good project management approach to keep balance between the interest of stakeholders in sustainable building projects [15].

### 2.2 Critical Success Factors (CSFs) of Stakeholder Management to Achieve Sustainable Building Projects

Success factors are variables that affect the accomplishment of success criteria used in evaluating project performance. Therefore, for the success criteria of sustainability to be achieved, the success factors for managing stakeholders needs to be analysed to control stakeholders' interactions.

Several success factors for stakeholder management have previously been discovered by academics. The CSFs affecting stakeholder management in construction project was investigated by Waghmare et al. [40] and identified 30 success factors. However, Eyiah-Botwe et al. [12] investigated the CSFs to improve the management of stakeholders in the Ghana construction industry using questionnaire survey and evaluated 35 CSFs. Molwus et al. [27] grouped the identified 23 factors of stakeholder into four (4) with emphasises on the procurement route in the life cycle of construction projects. Though stakeholder management has been broadly discussed amongst previous studies, no study has explored stakeholder management to achieve sustainability.

Therefore, literature review on the key success elements for achieving sustainable buildings served as the foundation for this study. The review focussed on issues surrounding stakeholder management on construction projects that have been covered in scholarly works and papers presented at conferences. Due to its recovery precision and performance accuracy, this method has always been used to locate important papers for investigations [31]. The search criteria term used in this study are as follows: 'Stakeholder management', 'sustainable building', 'critical success factors for stakeholder management' and 'collaborative working'. Finding the CSFs of managing stakeholders to achieve sustainable building was the study's goal, hence it was important to screen out factors that were irrelevant.

Significant contributions to the identification of CSFs for the management of stakeholders came from Yang et al. [42], El-Sawalhi and Hammad [11], Nauman and Piracha [28], Amoatey and Hayibor [3], Oyeyipo et al. [32], Wasiu Adeniran et al. [41], Mashali et al. [25]. After reviewing CSFs proposed by several researchers, this study proposed 25 critical success factors for stakeholder management in sustainable construction projects and grouped them into four (4) constructs, namely: Stakeholder characteristics and project characteristics (SCPC), Stakeholder analysis (SA), Stakeholder Dynamics (SD) and Stakeholder Engagement (SE). A list of 25 CSFs is compiled as follows:

1. Clearly defining the project mission and shared goals
2. Ensuring the use of a favourable procurement strategy
3. Proper identification of project stakeholders
4. Clearly defining the roles and responsibilities of various professionals
5. Stakeholders' knowledge and expertise of sustainability
6. Competence of project manager
7. Identifying the areas of stakeholders' interest
8. Evaluating stakeholders' attributes (power, legitimacy, proximity, Urgency)

9. Identifying and analysing possible conflicts and coalitions
10. Mapping stakeholders' behaviour towards the project
11. Establishing an effective conflict resolution strategy
12. Assessing the influence (low, medium, high) of stakeholders on project decisions
13. Conduct sustainability risk impact assessment
14. Evaluation of potential solutions by stakeholders to project problems
15. Manage changes (attributes, interest, influence, relationship) in stakeholders
16. Continuous evaluation of stakeholders' expectations and satisfaction
17. Manage effects of project decisions on stakeholders
18. Manage conflict and controversy between diverse stakeholders
19. Participation and collaboration of stakeholders throughout project life cycle
20. Client and end-users' involvement
21. Early engagement of external stakeholders
22. Frequently communicating with stakeholders
23. Fostering and maintaining positive relationships between stakeholders
24. Stakeholder participation in decision-making
25. Ensuring corporate social responsibilities towards stakeholders.

## 3 Presentation of Results

### *3.1 Stakeholders Characteristics and Project Characteristics (SCPC)*

Stakeholders' characteristics and project characteristics is an important phase authorising a new project and should be carried out before engagement. This stage includes decisions to kick start a new project. Project objectives are developed in a fast changing environment which needs the vision and project goals to be considered in a wider perspective of different teams and stakeholders [22]. Therefore, it is an approach of determining the ends (set of project goals), means (set of process actions and decision rules) and how stakeholders with similar interests or rights each form a group and their effects on project objectives.

### *3.2 Stakeholder Analysis (SA)*

According to Atkin and Skitmore [4], different stakeholders have different levels and type of investment and interest in projects [6]. As a result of the complex nature of construction project, quite a considerable number of stakeholders are involved in building projects and their needs, power, and influence should be mapped out. This is to enable their potential impacts on the project to be better understood [11]. This is essential as it helps project managers read the project environment in order to ascertain the appropriate action for every stakeholder by considering their interest [1].

### 3.3 Stakeholders' Dynamics

The stakes of construction stakeholders are diverse which are dynamics over the project life cycle [9]. The tendency for the interest to change as the project progresses is high and appropriate strategies should be considered based on the analysis [2].

### 3.4 Stakeholders' Engagement (SE)

Stakeholder engagement is a fundamental component of stakeholder theory and is crucial when complex stakeholder networks, requirements, and expectations change during the course of a project [43]. Chinyio and Olomolaiye [8] pointed out that stakeholders can be allies in achieving objectives and adversaries in opposing the mission. Stakeholders can affect the functioning of an organisation by supporting the vision and objectives of the project which leads to success. Engaging stakeholders is a key aspect of managing stakeholders in order to deliver sustainable project outcomes. A well-managed stakeholder engagement approach facilitates collaboration amongst project stakeholders to improve comfort and quality of life, while reducing adverse environmental effects and boosting the project's economic viability [5]. However, a lack of communication between project managers and stakeholders can lead to a number of risk [17].

## 4 Discussion

The selected articles show the increased research interest in the topic. There is a growing interest in managing stakeholders in sustainable construction projects. The increase can be attribute to the demand of environmental responsibility, social awareness, and economic profitability. The obtained results in this study showed that there are twenty-five core success factors for managing stakeholders to achieve sustainable construction projects delivery. An effective stakeholder management will improve the quality of the project as project stakeholders will effectively collaborate on the project. Collaboration between numerous parties with disparate interests is required to complete sustainable building projects. All along the project's life cycle, these stakeholders should be engaged and communicated with. Setting sustainability objectives such as energy efficiency targets, incorporating renewable sources, and choosing sustainable materials and technology is vital. The results appear to be both insightfully aligned with and different from other research on the success of construction projects. In terms of the alignment, it can be argued that the obtained results in this study are somewhat in line with the identified success factors for stakeholder management in the previous studies. The ability of project teams to accurately describe the stakeholder environment depends on their ability to identify stakeholders and the characteristics of the project, and this ability should be addressed before performance measures are chosen [1]. By mapping and analysing stakeholders' characteristics and conduct, these aims are analysed. Possible disputes and coalition concerns are addressed once the requirements and expectations of stakeholders have been recognised. According to Atkin and Skitmore [4], diverse parties participating in construction projects invest to varying degrees and with distinct types of interests. Stakeholders can locate the project's trouble spot and create fixes for the issues they find [21]. Therefore, stakeholders' engagement involves all project stakeholders in planning, decision-making, and project implementation in order to decrease disputes [10]. Participation lowers project opposition while stakeholder involvement entails sharing information and seeking input. It is therefore crucial to involve stakeholders on construction project in order to create sustainable buildings that can be designed, built, and operated in a way that fits the needs of their users while also being good for the environment and the larger community.

## 5 Conclusion

The study aimed to explore the CSFs of stakeholders' management that can result in sustainable building projects. This was performed through conceptualising a success model for stakeholder management. This model includes the core success factors for managing stakeholders, structured based on their conceptual relevance to sustainability considerations into design and construction-related activities. The obtained result in this study, which were discussed earlier, showed that construction stakeholders are effectively managed through a combination of four constructs, namely: stakeholder characteristics and project characteristics, stakeholder analysis, stakeholder dynamics and stakeholder engagement. To achieve sustainability goals, it is crucial to identify stakeholders' beliefs, issues, and interests in the project. Stakeholders can be included in the decision-making process to achieve sustainability-related performance by being identified according to their level of interest and influence. Different stakeholders may approach sustainability differently.

The findings of this study contributed to the existing body of knowledge by exploring the CSFs of stakeholder management to achieve sustainable building project. It is noted that this study has limitations and that using specific keywords to find relevant papers in databases may have limited the study's reach and maybe compromised its validity and reliability. Like all new ideas, the developed success model must be validated before it can be taken for granted. As a result, this is a possible topic for more study.

## References


1. Aaltonen K (2011) Project stakeholder analysis as an environmental interpretation process. Int J Proj Manage 29(2):165–183. https://doi.org/10.1016/j.ijproman.2010.02.001
2. Aaltonen K, Kujala T (2008) Stakeholder salience in global projects. Int J Proj Manage 26(5):509–516. https://doi.org/10.1016/j.ijproman.2008.05.004
3. Amoatey C, Hayibor MVK (2017) Critical success factors for local government project stakeholder management. Built Environ Proj Asset Manage 7(2):143–156. https://doi.org/10.1108/bepam-07-2016-0030
4. Atkin B, Skitmore M (2008) Editorial: stakeholder management in construction. Constr Manage Econ
5. Bal M, Bryde D, Fearon D, Ochieng E (2013) Stakeholder engagement: achieving sustainability in the construction sector. Sustainability 5(2):695–710. https://doi.org/10.3390/su5020695
6. Barima OKB (2010) Examination of the best, analogous, competing terms to describe value in construction projects. Int J Proj Manage 28(3):195–200. https://doi.org/10.1016/j.ijproman.2009.05.009
7. Brent A, Labuschagne C (2006) Social indicators for sustainable project and technology life cycle management in the process industry (13 pp + 4). Int J Life Cycle Assess 11(1):3–15. https://doi.org/10.1065/lca2006.01.233
8. Chinyio E, Olomolaiye P (2010) Construction stakeholders management. In: Construction stakeholder management. United Kingdom Wiley-Blackwell, pp 1–12
9. Chinyio EA, Akintoye A (2008) Practical approaches for engaging stakeholders: findings from the UK. Constr Manage Econ 26(6):591–599. https://doi.org/10.1080/01446190802078310
10. Deegan B, Parkin J (2011) Planning cycling networks: human factors and design processes. Proc Inst Civ Eng Eng Sustain 164(1):85–93. https://doi.org/10.1680/ensu.1000018
11. El-Sawalhi NI, Hammad S (2015) Factors affecting stakeholder management in construction projects in the Gaza Strip. Int J Constr Manage 15(2):157–169. https://doi.org/10.1080/15623599.2015.1035626
12. Eyiah-Botwe E, Aigbavboa CO, Thwala WD (2016)Critical success factors for enhanced stakeholder management in Ghana. Socioeconomica Sci J Theor Pract Socio-economic Dev 5(10):153–170
13. Fernández-Sánchez G, Rodríguez-López F (2010) A methodology to identify sustainability indicators in construction project management—Application to infrastructure projects in Spain. Ecol Ind 10(6):1193–1201. https://doi.org/10.1016/j.ecolind.2010.04.009
14. Garbharran H, Govender J, Msani T (2012) Critical success factors influencing project success in the construction industry. Acta Structilia 19(2):90–108
15. Goodijk R (2002) Partnership at corporate level: the meaning of the stakeholder model. J Change Manage 3(3):225–241. https://doi.org/10.1080/714042537
16. Gudienė N, Banaitis A, Podvezko V, Banaitienė N (2014) Identification and evaluation of the critical success factors for construction projects in lithuania: AHP approach. J Civ Eng Manage 20:350–359. https://doi.org/10.3846/13923730.2014.914082
17. Hatamleh MT, Moynihan GP, Batson RG, Alzarrad A, Ogunrinde O (2022) Risk assessment and ranking in the developing countries' construction industry: the case of Jordan. Eng Constr Archit Manage 30(4):1344–1364. https://doi.org/10.1108/ECAM-06-2021-0489
18. Hwang B-G, Ng WJ (2013) Project management knowledge and skills for green construction: overcoming challenges. Int J Proj Manage 31(2):272–284. https://doi.org/10.1016/j.ijproman.2012.05.004
19. Ibrahim KI, Costello SB, Wilkinson S (2013) Key practice indicators of team integration in construction projects: a review. Team Perf Manage 19(3–4):132–152. https://doi.org/10.1108/TPM-10-2012-0033
20. Jergeas GF, Williamson E, Skulmoski GJ, Thomas JL (2000) Stakeholder management on construction projects. AACE Int Tran 12(3):121–126

21. Klaus-Rosińska A, Iwko J (2021) Stakeholder management—one of the clues of sustainable project management—as an underestimated factor of project success in small construction companies. Sustainability (Basel, Switzerland) 13(17):9877. https://doi.org/10.3390/su13179877
22. Laursen M, Svejvig P (2016) Taking stock of project value creation: a structured literature review with future directions for research and practice. Int J Proj Manage 34(4):736–747. https://doi.org/10.1016/j.ijproman.2015.06.007
23. Marcelino-Sádaba S, González-Jaen LF, Pérez-Ezcurdia A (2015) Using project management as a way to sustainability. From a comprehensive review to a framework definition. J Clean Prod 99:1–6. https://doi.org/10.1016/j.jclepro.2015.03.020
24. Martens ML, Carvalho MM (2016) The challenge of introducing sustainability into project management function: multiple-case studies. J Clean Prod 117:29–40. https://doi.org/10.1016/j.jclepro.2015.12.039
25. Mashali A, Elbeltagi E, Motawa I, Elshikh M (2023) 'takeholder management challenges in mega construction projects: critical success factors. J Eng Des Technol 21(2):358–375. https://doi.org/10.1108/JEDT-09-2021-0483
26. Molwus JJ (2014) Stakeholder management in construction projects: a life cycle based framework. Heriot-Watt University, Edinburgh
27. Molwus JJ, Erdogan B, Ogunlana S (2017) Using structural equation modelling (SEM) to understand the relationships among critical success factors (CSFs) for stakeholder management in construction. Eng Constr Archit Manage 24(3):426–450. https://doi.org/10.1108/Ecam-10-2015-0161
28. Nauman S, Piracha MSS (2016) Project stakeholder management—a developing country perspective. J Qual Technol Manage 12(2):1–24
29. Olander S, Landin A(2008) A comparative study of factors affecting the external stakeholder management process. Constr Manage Econ 26(6):553–561. https://doi.org/10.1080/01446190701821810
30. Oppong GD, Chan APC, Dansoh A (2017) A review of stakeholder management performance attributes in construction projects. Int J Proj Manage 35(6):1037–1051. https://doi.org/10.1016/j.ijproman.2017.04.015
31. Osei-Kyei R, Chan APC (2015) Review of studies on the critical success factors for public–private partnership (PPP) projects from 1990 to 2013. Int J Proj Manage 33(6):1335–1346. https://doi.org/10.1016/j.ijproman.2015.02.008
32. Oyeyipo O, Odeyinka H, Owolabi J, Afolabi A (2019) Factors inhibiting stakeholder management of mega construction project. Int J Civ Eng Technol (IJCIET) 10(3)
33. Phung Q, Erdogan B, Nielsen Y (2022) Project management for sustainable buildings: a comprehensive insight into the relationship to project success. Eng Constr Archit Manage. https://doi.org/10.1108/ECAM-09-2021-0766
34. Sanchez MA (2015) Integrating sustainability issues into project management. J Clean Prod 96:319–330. https://doi.org/10.1016/j.jclepro.2013.12.087
35. Silvius G (2017) Sustainability as a new school of thought in project management. J Clean Prod 166:1479–1493. https://doi.org/10.1016/j.jclepro.2017.08.121
36. Singh RK, Murty HR, Gupta SK, Dikshit AK (2012) An overview of sustainability assessment methodologies. Ecol Ind 15(1):281–299. https://doi.org/10.1016/j.ecolind.2011.01.007
37. Srinivasan NP, Dhivya S (2020) An empirical study on stakeholder management in construction projects. Mater Today Proc 21:60–62. https://doi.org/10.1016/j.matpr.2019.05.361
38. Turlea C, Roman TD, Constantinescu DG (2010) The project management and the need for sustainable development. Metalurgia Int 15:121–125
39. Vifell ÅC, Soneryd L (2012) Organizing matters: how 'the social dimension' gets lost in sustainability projects. Sustain Dev (Bradford, West Yorkshire, England) 20(1):18–27. https://doi.org/10.1002/sd.461
40. Waghmare YM, Bhalerao N, Wagh SV (2016) Analysis of the factors affecting the stakeholder management process in building construction project. Int J Innov Stud Sci Eng Technol 2(7)

41. Wasiu Adeniran O-A, Aisha A, Ganiyu Olarewaju B, Luqman Oyekunle O (2021) Critical success factors for effective internal construction stakeholder management in Nigeria. Acta Structilia 28(1):1–31. https://doi.org/10.18820/24150487/as28i1.1
42. Yang J, Shen GQ, Ho M, Drew DS, Chan APC (2009) Exploring critical success factors for stakeholder management in construction projects. J Civ Eng Manage 15(4)
43. Zarghami SA, Dumrak J (2021) Reimaging stakeholder analysis in project management: network theory and fuzzy logic applications. Eng Constr Archit Manage 28(9):2426–2447. https://doi.org/10.1108/ECAM-06-2020-0391

# Key Indoor Environmental Quality Indicators for Students' Satisfaction in Residences Built from ISBU

**Noluthando Maphongwane, Clinton Aigbavboa, and Matthew Ikuabe**

## 1 Introduction

The suitability of the living environment to the needs of the residents is very important. A building is essential because it provides shelter and facilities for individuals to perform daily tasks [24]. Over the years, there has been an increased demand for comfort in residential buildings. It is found that energy consumption depends largely on the occupants' comfort requirements, which is affected by the thermophysical properties of the construction materials, architecture, and performance of utility systems [29]. Furthermore, student residence is an important facility provided by universities provident develop and grow academically [31]. The quality of student residence plays an important role in a student's academic success [23]. 1994 post-apartheid South Africa saw increased demand for higher education to address socio-politico historical inequalities [16]. There is a significant increase in student intake at universities, and as a result, the demand for student residence is increasing, and most universities cannot provide accommodation [17]. The shortage of student residences at universities in South Africa has led to the consideration of shipping containers or Intermodal Steel Building Units (ISBU) as an alternative building method to try and address the residence backlog. The conversion of shipping containers to buildings has been witnessed in the construction of social, domestic, and commercial facilities [15] such as youth centres, classrooms, office space, artists' studios, living space, workspace, nurseries and retail space. Hence, it becomes imperative to evaluate the

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indoor environmental quality indicators of the use of ISBU, as Aigbavboa et al. [2] noted that good quality services and other associated features determine students' residential satisfaction. The outcome of the study would make immense contributions to the growing call for a sustainable environment, on the one hand, while also aiding the living standards of students to improve their academic performance.

## 2 Related Literature

Manuscripts Shipping containers are of great use during post-disaster, military and mining scenarios. They have been viewed favourably as they have proven to be easily transported and rapidly redeployed [18]. A typical International Standardisation Organisation (ISO) shipping container is made from weathering steel, also known as Corten steel, a unique steel alloy more corrosion-resistant than standard steel [33]. There are 17 million shipping containers in circulation, and because of the imbalances in international trade, more than half of these containers never return to their point of origin [36]. These shipping containers flood the destination ports, making them readily available [15]. ISO shipping containers used for building construction purposes are termed Intermodal Steel Building Units (ISBU). For the construction of residential buildings, the 6 m and 12 m long shipping containers with a height of 2.71 m are used [7]. Containers with a height of 2.71 m are called High Cube (HC), commercially called 20'HC (6.0 m or 20 feet long) and 40'HC (12.0 m or 40 feet long) [7].

Over the years, there has been an increased demand for comfort in residential buildings. It is found that energy consumption depends mainly on the occupants' comfort requirements, which is affected by the thermo-physical properties of the construction materials, architecture, and performance of utility systems [29]. Consequently, the index of indoor environment quality (IIEQ) is proving to be an essential indicator useful for architects and engineers, both in the design phase and with the modernisation of construction [12]. Bluyssen [8] defines indoor environmental quality (IEQ) as the quality of the building's environment in terms of the well-being and health of the occupants. As student accommodation is where reading, studying and writing take place, IEQ plays a vital role in determining the ability of the occupants to undertake these tasks optimally. IEQ also allows for the appreciation of the energy efficiency of a building by analysing the energy consumption [8].

Catalina and Iordache [12] state that there is an interconnection between the parameters that influence the environment, where a specific comfort component can result in a space not being used for certain activities. For example, insufficient light leads to concentration and attention problems, even though there are no problems with indoor temperature, noise or ventilation, while increasing light quantity may improve logical thinking and concentration processes [10]. Catalina and Iordache [12] also found that modifying operative temperature between 23 °C and 29 °C by one degree Celsius has the same effect on comfort as a change in the noise of cu 3.9 decibels. When the space is not ventilated, the result could be headaches or excessive fatigue. IEQ measurement involves equipment with a few sensors that can measure indoor environmental parameters and then analyse a large amount of information quickly [20]. Although standards of IEQ were established in different laboratories [5], the method is quite challenging to implement due to measurement procedures, and the equipment is expensive [20].

Indoor environments are complex, and the occupants of the buildings may be exposed to a variety of contaminants, like gases from office machines [2], carpets and furnishings, perfume, cleaning products, construction activities, smoke from cigarettes, water -damaged building materials, microbial growth (fungi, mould and bacteria), insects and pollution [20]. Other factors include indoor temperature, relative humidity and ventilation levels, which can also affect how occupants respond to the indoor environment. If the source of indoor environmental contaminants is understood and controlled, it can help prevent or sometimes resolve symptoms related to the building that affect students [2].

## 3 Methodology

A quantitative research technique was used for the study to evaluate the satisfaction with IEQ in residences built from intermodal steel building units. The quantitative approach is naturally deductive, observing phenomena and conducting experiments by attempting to adopt an impartially detached approach [26]. This research made use of snowball sampling. This was employed as initial respondents aided the identification of other respondents who participated in the survey. One hundred five structured questionnaires were distributed to students occupying ISBU residences, using Johannesburg as the study area. Ninety-four responses were received, which amounts to a 90% response rate. The method of data analysis employed was exploratory factor analysis (EFA). This is used to obtain information about the interrelationships among a group of variables. While principal component analysis (PCA) was used as the extraction method as used by Ikuabe et al. [22]. According to Pallant [28], PCA is conducted to gather information about the factors' uni-dimensionality to yield their factor analysability. Also, the reliability and validity of the questionnaire were put to test using Cronbach's alpha test. This gave a value of 0.8726, thus affirming the reliability and validity of the research instrument [35].

## 4 Results

The outcome of the analysis conducted using EFA presented variables with similar underlying dimensions given in clusters. Thereby leading to a reduction in the number of variables and outlining them in a well-defined and better-understood framework. To achieve this, an assessment of the appropriateness of the dataset was conducted using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's

**Table 1** KMO and Bartlett's test

| | | |
|---|---|---|
| Kaiser–Meyer–Olkin measure of sampling adequacy | | 0.797 |
| Bartlett's test of sphericity | Approx. chi-square | 1466.047 |
| | D*f* | 253 |
| | Sig | 0.000 |

test of sphericity. These were used in ascertaining the factorability of the dataset used in the study. Pallant [28] noted that for a dataset to be affirmed suitable for analysis, Bartlett's test of sphericity should be significant ($p < 0.05$). As shown in Table 1, the result of Bartlett's sphericity test is significant, with a p-value of 0.000. Moreover, the KMO ought to have a value beyond the threshold of 0.6 to be considered appropriate for the conduct of factor analysis, as recommended by past studies [1, 21]. The outcome of the analysis presented a KMO value of 0.797. These results give confidence to the suitability of the dataset for the EFA.

Principal component analysis with varimax rotation was conducted to assess the underlying structure for twenty-three (23) Indoor Environmental Quality Factors items. The assumption of independent sampling was met. The premises of normality, linear relationships between pairs of variables, and the variables being correlated at a moderate level were checked. This revealed the presence of six (6) factors with eigenvalues above 1 since the items were designed to index six factors, namely: Factor 1—ergonomics; Factor 2—lighting; Factor 3—indoor air quality; Factor 4—finishes; Factor 5—environmental space; Factor 6—appearance. After rotation, the first factor accounted for 16.75% of the variance, the second factor for 16.68%, the third factor for 11.15%, the fourth factor for 7.03%, the fifth factor for 6.91% and the sixth factor for 6.41%. Table 2 displays the items and factor loadings for the rotated factors, with loadings less than 0.30 omitted to improve clarity.

## 5 Discussion of Findings

Factor 1: Ergonomics

The first factor had seven factors of indoor environmental qualities, which were: the ability to adjust or move your furniture to meet your needs (87.4%), the amount of space available for individual daily activities, e.g. storage, recreation (75.8%), the extent to which furniture is designed to facilitate work while minimising stress and strain on the body(74.3%), the comfort of the furniture (68.8%), the degree of adjustability of the desk to allow a safe working posture (57.9%), the degree of adjustability of the chairs (51.7%), and the ability to have conversations without neighbours overhearing (48.0%) as shown in Table 1. This factor accounted for 16.75% of the variance. These criteria share a common link to ergonomics. As [30]

**Table 2** Rotated component matrix

| Indicators | Factor | | | | | | Comm |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| The ability to adjust or move your furniture to meet your needs | 0.874 | | | | | | 0.79 |
| The amount of space available for individual daily activities | 0.758 | | | | | | 0.724 |
| The extent to which furniture is designed to facilitate work while minimising stress and strain on the body | 0.743 | | | | | | 0.692 |
| The comfort of the furniture | 0.688 | | | | | | 0.792 |
| The degree of adjustability of the desk allows a safe working posture | 0.579 | | | | | | 0.67 |
| The degree of full adjustability of the chairs | 0.517 | | | | | | 0.552 |
| The ability to have conversations without neighbours overhearing | 0.48 | | | | | | 0.371 |
| The visual comfort of the lighting | | 0.822 | | | | | 0.885 |
| The Has uniformity of light to perform tasks and improve performance | | 0.807 | | | | | 0.799 |
| The amount of light in your unit is adequate | | 0.708 | | | | | 0.794 |
| The accessibility of control to both natural and artificial lighting | | 0.681 | | | | | 0.754 |
| The degree to which the backrest of the chair provides support for student's lower back | | 0.652 | | | | | 0.62 |
| The extent to which a student's head/neck is upright and centred over their shoulders when using the computer | | 0.504 | | | | | 0.582 |
| The level of air circulation sufficient | | | 0.896 | | | | 0.552 |
| The level to which air is well ventilated to prevent toxins, contaminants and odours | | | 0.869 | | | | 0.482 |

(continued)

**Table 2** (continued)

| Indicators | Factor | | | | | | Comm |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| The air quality in your unit, i.e. stuffy/stale air, cleanliness, odours | | | 0.781 | | | | 0.73 |
| The room has high quality of the fluorescent ceiling-mounted light fixture | | | | 0.728 | | | 0.777 |
| The extent to which the matte finish on the desk's surface has a matte finish to reduces light reflection and glare | | | | 0.703 | | | 0.851 |
| The amount of elbow room at the desk | | | | | 0.782 | | 0.815 |
| The distance between top of a student's legs and the desk table | | | | | 0.722 | | 0.679 |
| The general cleanliness of the building | | | | | | 0.666 | 0.608 |
| The colours and textures of flooring, furniture and surface finishes | | | | | | 0.638 | 0.454 |
| Eigenvalues | 3.853 | 3.837 | 2.565 | 1.617 | 1.588 | 1.474 | |
| % of Variance | 16.75 | 16.681 | 11.153 | 7.029 | 6.905 | 6.409 | |
| Note. Loadings < 0.30 are omitted | | | | | | | |
| Extraction Method: Principal Component Analysis | | | | | | | |

argued, ergonomics applies information on human behaviour, abilities and limitations to the design of tools, machines, tasks, jobs and environments for productive, safe, comfortable and effective human use. Ergonomics find ways work can be done without disturbing the body by studying a person's comfort, efficiency, health, and safety [27].

Factor 2: Lighting

Six factors were extracted for factor 2, as shown in Table 1. These are the visual comfort of the lighting, e.g. glare, reflections, contrast (82.2%), the uniformity of light to perform tasks and improve performance (80.7%), the adequacy of light in the unit (70.8%), control of both natural and artificial lighting (68.1%), the degree to which the backrest of the chair provides support for student's lower back (65.2%), and the extent to which a student's head/neck is upright and centred over their shoulders when using the computer (50.4%). This factor accounted for 16.68% of the variance. Poor lighting poses challenges to human health by increasing the rate of visual fatigue and general tension, resulting in poor posture to improve vision [13]. Most design professionals often omit lighting requirements at the initial design stage. This oversight may cause a deterioration in the health of the students as well as a decline in their academic excellence [13]. De Carli and De Giuli [13] suggested that daytime lighting should also be considered because if it is not addressed correctly, the student may suffer from problems such as itchy skin. Student accommodations have rooms for different activities, such as the computer room, laundry room, study area and television room, each requiring different amounts of light [4].

Factor 3: Indoor Air Quality

This factor accounted for 11.15% of the variance, and three factors were extracted, namely: a sufficient level of air circulation (89.6%), the level to which air is well ventilated to prevent toxins, contaminants and odours (86.9%) and the air quality in your unit, i.e. stuffy/stale air, cleanliness, odours (78.1%). The indoor air's physical, chemical and biological characteristics determine indoor air quality (IAQ). Indoor air is a multifaceted environment with visible and invisible airborne toxins [6]. If the building is not evaluated for an extended period, the air quality deteriorates, leading to poor ventilation and pests, which are harmful to humans [8]. The air is then polluted due to poor indoor air. Carbon dioxide, for example, is a colourless, odourless gas which causes a blockage of the transportation of oxygen in the human body [8]. Energy-saving mechanisms are applied in some residences to save on energy costs, resulting in minimum access to natural air [14]. Reduced access to natural air is a major factor in the build-up of indoor toxins and air pollutants, ultimately leading to the 'sick building syndrome' [11].

Factor 4: Glare

This factor accounted for 7.03% of the variance, and two factors of indoor environmental qualities were extracted. The factors were: the presence of a high-quality fluorescent ceiling-mounted light fixture (72.8%) and the extent to which the matte finish on the desk's surface reduces light reflection and glare (70.3%). Students would need 500 to 700 lx on their study tables, as too bright lighting (over 1000 lx) can lead to visual strain caused by reflections, high glare, and the contrast between light and shadow [9]. If the lighting is too dim (less than 500 lx), the student will suffer from eyestrain which will cause stress and dizziness [3]. Lighting levels depend on the visual acuity required to carry out the task.

Factor 5: Furniture

This factor accounted for 6.91% of the variance, and two factors of indoor environmental qualities were extracted: the amount of elbow room at the desk (78.2%) and the distance between the top of a student's legs and the desk table (72.2%). Furniture is defined as the movable, functional objects that support humans in executing their tasks, such as beds, chairs, wardrobes, tables and sofas. Different types of furniture are designed for different tasks [19]. Smardzewski [34] states that furniture can be classified according to features such as the materials from which it is made, the function, craftsmanship and style. Other categories include status, belief, culture, era and psychographic and demographic factors. Contemporary or current designs vary because of the new needs, trends, and ergonomic advances [32]. Student accommodation must provide basic furniture like a wardrobe, bed, study desk, chair and cupboard.

Factor 6: Appearance

Factor 6 has two indicators: the general cleanliness of the building (66.6%) and the colours and textures of flooring, furniture and surface finishes (63.8%). The physical environment is seen as the potent predictor of residential satisfaction. Khozaei et al. [25] recognised some predictors of student residence satisfaction, including cleanliness of the housing, safety of the housing (including security measures), hall programmes and activities provided while residing there. Aigbavboa et al. [2] confirm that satisfaction with student accommodation comes with more than the building features. When the student receives good, quality services if the services rendered meet or exceed their expectations and if the student is happy, then satisfaction with accommodation is greater [2].

## 6 Conclusion

This study examined student satisfaction with indoor environmental quality in residences built from intermodal steel building units in Johannesburg. Data for the analysis were obtained from students living in residences built by ISBUs. A detailed review of extant literature identified twenty-two indoor environmental quality indicators that influence students' satisfaction using ISBUs. Adopting a quantitative technique, the study elicited data from the target respondents while retrieved data was analysed using exploratory factor analysis. Based on the factor analysis, influential indicators that contribute to students' satisfaction with indoor environmental quality were grouped into six (6) factors: ergonomics; lighting; indoor air quality; finishes; environmental space; and appearance. The study contributes to the body of knowledge by unravelling the required parameters for students' satisfaction in ISBUs. Based on the findings of the study, it is recommended that container buildings can be designed very similarly to conventional buildings and should be heavily considered in today's market to address the backlog of student accommodation in Johannesburg. Also, there is a need for relevant stakeholders saddled with the responsibility of setting up student accommodation using ISBU to prioritise the critical indicators showcased in this study. It is essential to state that this study was conducted in Johannesburg, Gauteng province; hence care must be made to generalise its findings. Further studies can be conducted in other provinces to provide a more robust outcome from a national perspective.

## References

1. Aghimien DO, Aigbavboa CO, Meno T, Ikuabe MO (2021) Unravelling the risks of construction digitalisation in developing countries. Constr Innov 21(3):456–475. https://doi.org/10.1108/CI-02-2020-0026
2. Aigbavboa CO, Thwala WD, Eke CC (2014) An evaluation of students' satisfaction with university hall of residence. In: Yang D, Qian Y (eds) Proceedings of the 18th international symposium on advancement of construction management and real estate, Johannesburg, date, pp 703–711
3. Al-Anzi NM (2009) Workplace environment and its impact on employee performance. MBA thesis submitted to Open University of Malaysia
4. Andre D, Lauren B (2001) Post-occupancy evaluation. Austr Planne 38(3–4):178–181
5. ASHRAE (2020) IAQ 2020: Indoor environmental quality performance approaches. Retrieved from https://www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performanceapproaches [Accessed on 22/09/2022]
6. Baecher C, Sohui F, Ball L, Masson O (2020) Indoor air quality: a multifaceted public health problem. Field Actions Sci Rep 21:6–7 http://journals.openedition.org/factsreports/
7. Bernardo LF, Oliveira LA, Nepomuceno MC, Andrade JM (2013) Use of refurbished shipping containers for the construction of housing buildings: details for the structural project. J Civ Eng Manag 19:628–646
8. Bluyssen P (2009) Towards an integrative approach of improving indoor air quality. Build Environ 44(9):1980–1989. https://doi.org/10.1016/j.buildenv.2009.01.012
9. Boyce PR, Wilkins A (2018) Visual discomfort indoors. Light Res Technol 50(1):98–114
10. Brink H, Loomans M, Mobach M, Kort H (2020) Classrooms indoor environmental conditions affecting the academic achievement of students and teachers in higher education: a systematic literature review. Int J Indoor Environ Air 31(2):405–425 https://doi.org/10.1111/ina.12745
11. Burge P (2004) Sick building syndrome. Occup Environ Med 61:185–190. https://doi.org/10.1136/oem.2003.008813
12. Catalina T, Iordache V (2012) IEQ assessment on schools in the design stage. Build Environ 49:129–140. https://doi.org/10.1016/j.buildenv.2011.09.014
13. De Carli M, De Giuli V (2009) Optimization of daylight in buildings to save energy and to improve visual comfort: analysis in different latitudes. In: 11th International IBPSA conference
14. Eke C, Aigbavboa C, Thwala W (2015) Common illness that affect the performance of residence: a case from South Africa. In: Shen L, Ye K, Mao C (eds) Proceedings of the 19th international symposium on advancement of construction management and real estate. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-46994-1_96
15. Elrayies G (2017) Thermal performance assessment of shipping container architecture in hot and humid climates. Int J Adv Sci Eng Inf Technol 7:1114. https://doi.org/10.18517/ijaseit.7.4.2235
16. Gopal N, van Niekerk C (2018) Safety in student residences matters! South Afr J High Educ 32. https://doi.org/10.20853/32-3-2524
17. Graham P, Hurtado S, Gonyea R (2018) The benefits of living on campus: do residence halls provide distinctive environments of engagement? J Student Aff Res Pract 55:1–15. https://doi.org/10.1080/19496591.2018.1474752
18. Grant EM (2013) Pack'em, rack'em and stack'em: the appropriateness of the use and reuse of shipping containers for prison accommodation. Constr Econ Build 13(2):35–44
19. Greenleaf C, Hinchman K (2009) Reimagining our inexperienced adolescent readers: from struggling, striving, marginalized, and reluctant to thriving. J Adolesc Health 53:4–13. https://doi.org/10.1598/JAAL.53.1.1
20. Heinzerling D, Webster T, Arens E (2013) Indoor environmental quality assessment models: a literature review and a proposed weighting and classification scheme. Build Environ 70:210–222. https://doi.org/10.1016/j.buildenv.2013.08.027

21. Ikuabe M, Oke A, Aigbavboa C (2020) Impact of contractors' opportunism on construction project transaction costs: construction professionals' perception. J Fin Manage Prop Constr 25(1):125–141. https://doi.org/10.1108/JFMPC-04-2019-0040
22. Ikuabe MO, Aigbavboa CO, Anumba C, Oke AE, Aghimien L (2022) Confirmatory factor analysis of performance measurement indicators determining the uptake of CPS for facilities management. Buildings 12(4):466. https://doi.org/10.3390/buildings12040466
23. Jansen L, Dube A (2013) R1bn for KZN student housing. The Mercury. Available from: http://www.iol.co.za/news/south-africa/kwazulu-natal/r1bn-for-kzn-student-housing-1.1469498. Accessed 22 Sept 2022
24. Kamaruzzaman SN, Egbu C, Mahyuddin N, Zawawi E, Chua S, Azmi N (2017) The impact of IEQ on occupants' satisfaction in Malaysian buildings. Indoor Built Environ 27:1420326X1668949. https://doi.org/10.1177/1420326X16689493
25. Khozaei F, Ramayah T, Hassan A (2012) A shorter version of student accommodation preferences index (SAPI). Am Trans Eng Appl Sci
26. Kumar R (2011) Research methodology. SAGE publications, London
27. Mustafa S, Kamaruddin S, Othman Z (2009) The effect of ergonomics applications in work system on mental health of visual display terminal workers. Eur J Sci Res 31
28. Pallant J (2007) SPSS survival manual: a step-by-step guide to data analysis using SPSS version 15. McGraw hill, Nova Jorque
29. Sarbu I, Sebarchievici C (2013) Aspects of indoor environmental quality assessment in buildings. Energy Build 60:410–419. https://doi.org/10.1016/j.enbuild.2013.02.005
30. Saunders MS, McCormick EJ (1993) Human factors in engineering and design, 7th edn. McGraw-Hill, New York, NY
31. Sawyerr PT, Yusof NA (2013) Student Satisfaction with hostel Facilities in Nigeria polytechnics. J Facil Manag 11(4):306–322. https://doi.org/10.1108/JFM-08-2012-0041
32. Sayuti N, Montana-Hoyos C, Bonollo E (2015) A study of furniture design incorporating living organisms with particular reference to biophilic and emotional design criteria. Acad J Sci 4(1):75–106
33. Silva JB (2013) Intermodal steel building units as an alternative for building low-income housing units in PuertoRico. PRAXIS@FAE, pp 17–24
34. Smardzewski J (2015) Furniture design. Springer, Berlin/Heidelberg, Germany
35. Tavakol M, Dennick R (2011) Making sense of Cronbach's Alpha. Int J Med Educ 2:53–55
36. Vijayalaxmi J (2010) Towards sustainable architecture—A case with Greentainer. Local Environ 15:245–259. https://doi.org/10.1080/13549830903575596

# A Review of Indoor Air Quality and Thermal Comfort Guidelines for New Zealand Primary School Classrooms: A Comparison of DQLS Document (Old Versus New)

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## 1 Introduction

Providing good indoor air quality in a classroom is essential for children. It offers an indoor space with fresh air, which is vital for their health and well-being. However, the Environmental Protection Agency of the United States of America (USEPA) has listed IAQ within an indoor environment as a top concern with context to respiratory and ill health-related issues [30, 50]. Studies in school premises examining IAQ have been a popular concern for years. The adverse effects of poor IAQ have been extensively studied in past works. For instance, Ivošević et al. [24] showed that the impact of poor IAQ is reaching far beyond children's health. Poor IAQ impacts children's health and lowers their learning abilities [24]. Korsavi et al. [28] noted that IAQ in school environments is considered one of the crucial factors which impact children's health and well-being, and further, it costs their academic results.

Children are found to spend approximately 10–12% of their time within the school classroom [35]. Henceforth, it becomes crucial for governing bodies and school authorities to ensure the IAQ prevalent in the classroom is well maintained for children [10, 11]. Monitoring IAQ in a school classroom is mainly done by assessing the concentration of carbon dioxide and ventilation rates. The physics shows that higher levels of carbon dioxide in the indoor environment are directly proportional to lower ventilation rates. Thus, both the concentration of carbon dioxide and ventilation rates are considered significant proxies or indicators for checking the quality of indoor air [5, 10, 11].

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The concentration of carbon dioxide above 1000 ppm indicates inadequate ventilation rates within the indoor environment. High carbon dioxide levels are associated with an unpleasant indoor atmosphere, which can negatively impact indoor air quality [4]. Inadequate ventilation hinders the proper exchange of fresh air, accumulating carbon dioxide and potentially other pollutants. This affects the comfort of the individuals present in the space and indicates a potential decline in the indoor air quality, which is associated with an unpleasant environment [4]. Poor IAQ creates an unhealthy indoor environment for children, which is also considered a significant cause of the development of chronic illnesses related to the respiratory tract in children [47].

The design requirement expressed in the DQLS document applies to all the school dwellings to be "Newly—Built" or " Existing".

The recently updated 2022 DQLS document aimed to address the problems with prevalent inadequate IAQ in school buildings. This paper critically examined these changes to highlight the specific changes and ascertain the appropriateness of these changes in providing the required IAQ in class rooms.

## 2 Literature Review

### *2.1 Indoor Air Quality (IAQ) and School Children's Performance*

Studies related to health have shown vast evidence of environmental agents like thermal discomfort (high temperatures) and air pollution impacting and challenging individuals' physical and mental health. Air pollution agents like fine particulate matter and ozone are directly associated with the development of cardio and respiratory illness in the human body [29]. A scientific study by Taylor et al. [48] shows that long-term exposure to air pollution can cause fatal damage to the human neurological system, leading to cognitive disability, stroke attacks, fatigue, and depression in the adult population. The abovementioned impacts are likely to cause more detrimental effects among young children due to not fully grown body parts and systems. Hence, children are accounted to be more vulnerable and susceptible to air pollution as their nervous system, immune system, and respiratory system are in the developing stage, also due to a higher percentage of breathing than adults [32].

IAQ in school is commonly found to be poor due to the higher number of occupants and inadequate ventilation rates, resulting in thermal discomfort. Similarly, classrooms are usually considered overcrowded and vary in temperature (high temperature) with lower airflow [28]. Poor IAQ in school buildings is a combined result of the building design, maintenance, and occupancy-related factors [45]. Studies conducted in epidemiology and neuroscience with context to cognitive ability and children have shown significant evidence that most schools do not maintain carbon dioxide concentration below 1000 ppm, impacting children's cognitive performance [17].

Coley and Beisteiner [13] state that a higher number of children in the classroom is directly associated with high carbon dioxide levels. Children aged between 5 and 9 years tend to produce around 14 L of carbon dioxide each hour in a regular breathing routine. Various international organizing bodies worldwide have made a tolerance limit for the maximum percentage of carbon dioxide in the classroom, which should be approximately 1500 ppm. Looking at the young children aged between 5 and 9 years, their tolerance limit is anticipated to be achieved sooner to 1000 ppm. Additionally, after a specific limit depending upon rates of ventilation and the number of occupancy, the movement of the air becomes stagnant, which can cause nausea, severe headache, concentration issues, a problem with vision, fatigue, and other severe problems in young children [42].

Numerous studies have shown a significant association between enhancing the quality of indoor air in classrooms and improving student performance in academic results and well-being [9, 12, 20, 41, 43]. A study conducted in the State of America involving the participation of 100 schools noted that by improving ventilation rates, significant results were observed in student academic records in mathematics and reading abilities [21]. In another study conducted in Austria, which involved the participation of around 400 children, the findings observed lower cognitive abilities due to a higher percentage of carbon dioxide and particulate matter [23]. Similarly, in a Scotland study, which involved the participation of 60 schools, the finding stated that a higher level of carbon dioxide presence was associated with absenteeism and lower academic results in reading, writing, and mathematics tests [19]. Additionally, in Portugal, a study involving 50 primary schools found that a higher percentage of carbon dioxide was associated with less concentration of attention in children within a classroom [49].

Previous studies have already shown enough robust evidence that good IAQ and TC supports children's learning outcomes and helps improve their health and well-being [1, 3, 6, 51]. Good indoor quality within educational facilities or spaces not only offers support to the teacher but also provides help to learners efficiently toward success. Poorly ventilated indoor areas can create undesired thermal discomfort and high level of carbon dioxide, which can further lead to tiredness and often feeling sleepy [2]. Pollution in the indoor environment is commonly found to be noxious and can create irritation within the eyes and nose leading to itchiness, which can interfere with learning tasks. Young children in school premises are considered more susceptible to indoor air contaminants than adults as they tend to breathe more air, and their body parts are actively developing. Due to such differences in body parts and higher metabolism rates, children are also considered to be quite sensitive to higher indoor temperatures. Children, compared to adults, tend to have more physical activities, making them sensitive to high temperatures. Thus, children are anticipated to stay more comfortable in a few lower temperatures within the indoor spaces.

Children in NZ are expected to spend the majority of their time within an indoor environment, i.e., a school classroom where they are considerably exposed to poor IAQ and pollutants. Severe respiratory conditions like asthma and high absenteeism rates are common in NZ [8]. Exposure to continuous poor IAQ is responsible for worsening these symptoms at a high rate [31]. Pollutants from indoors and outdoors impact the quality of the air in classrooms, as research has shown that indoor particulate matter (PM) concentrations in classrooms are closely connected with outside ones [44]. This is concerning since many schools and day-care centers are situated on major highways with high levels of traffic-related air pollution, which elevates during schooling hours [46]. Similar to other Western countries' studies, enhancing ventilation rates in NZ school classrooms has brought significant attention to improving the children's well-being and learning abilities and less the percentage of school absenteeism [14].

### 2.2 New Zealand School Buildings' Design and Maintenance and the Designing Quality Learning Spaces (DQLS) Documents

It is anticipated that more than two-thirds of students attend a state school in NZ. Approximately 11% attends integrated school and 4% attends privately owned schools. The Ministry of Education (MOE), NZ, is the governing body that proposes regulation and design requirements for school classrooms. MOE, NZ, owns a majority of state schools worth around NZD 30 billion [22]. MOE, NZ holds one of the largest real estate properties, with over 15,000 properties, over 35,000 educational spots, and around 2,100 teaching institutions.

Over the past 30 years, a majority of these school buildings have been in poor conditions, experiencing New Zealand's educational facilities. During these years, schools that underwent renovation projects also experienced problems such as leaky conditions related to poor design and maintenance. In response to these issues, MOE, NZ released a document—"The School Property Guide" [36]—to address the quality and aesthetics problems associated with school buildings.

The School Property Guide document provided recommendations for procedure, capacity or area, and budget for school buildings. Specifically, the document required all new and ongoing upgrading projects related to school dwellings to be certified by MOE and must undergo a design review procedure as per the document's requirements. Also, the "School Property Guide" document specified space criteria for classrooms as 78 $m^2$ for primary school classrooms and 70 $m^2$ for secondary school classrooms [39]. In 2016, the Ministry of Education noted that to achieve healthy indoor environmental quality in a better-quality learning classroom, the ideal area with a single teacher and 30 students should be around 90–120 $m^2$ instead of 70–78 $m^2$ [37]. This increase reduces the concentration of $CO_2$ levels in the classroom at a given time.

As an improvement, MOE released the Designing Quality Learning Spaces (DQLS) for IAQ and Thermal Comfort (TC) guideline in 2007. The DQLS document states the minimum standards and addressing suggestions while constructing or renovating school dwellings. In collaboration with the Building Research Association of New Zealand (BRANZ), the document was released in two different sections, i.e., Designing Quality Learning Spaces—Heating and Insulation, and Ventilation and IAQ.

The DQLS document has undergone a substantial upgrade since its first release. In 2017, the Ministry of Education New Zealand amalgamated the two sections into one document: Designing Quality Learning Spaces: IAQ and Thermal Comfort (Version 1.0). The significant changes incorporated in version 1.0, included a recommendation to present teaching practices and adaptable learning practices to the designed space. The upgraded document specified minimum criteria as "Mandatory" and "Recommendation" for architects, engineers and designers involved with educational construction practices to newly built or upgrade designs. In particular, the document established that the average and maximum threshold for the concentration of $CO_2$ should not go beyond 1500–3000 ppm during peak hours for newly built and existing schools in the state for upgrades [38].

The advent of COVID-19 in February 2020 in New Zealand has significantly impacted school children around the world. Thus, ensuring the critical emphasis on COVID-19, the MOE updated the latest version 2.0, 2022, focusing on good ventilation is crucial in spreading COVID-19 and other air-borne diseases. The document aims to create healthier and more comfortable school buildings by the following:

- Enhanced performance requirements for fresh air entry or distribution.
- Improved recommendations for heating and cooling with respect to different climatic conditions.
- Reliability with checking designs i.e., verification and compliance of design, followed by modeling for bigger buildings.
- A mandate for Indoor Environmental monitoring tools within each classroom will keep a continuous connection with ventilation system operations.

> The document also states, the Ministry will regularly review the latest public health findings and adjust its building design advice accordingly. However effective building design is just one aspect of providing safe learning environments. Proper operation and maintenance are also vital to keeping the building safer and healthier. This might involve, opening and closing windows to achieve healthier internal conditions, if mechanically ventilated adjusting its setting to reach healthier environments, and continuously checking for air filters to be kept clean.

As such, in 2022, MOE, New Zealand released the latest version, 2.0 for the DQLS document, adding further changes to the minimum criteria for "Mandatory" and "Recommendation" for designing quality learning spaces stronger and to better complying industry standards and recent construction reviews. This latest 2.0 version, strengthens the mandatory requirements to support MOE's School Property Strategy 2030 program. The program's objective is to provide quality educational spaces for learning and teaching practices and keep well-being in focus simultaneously for all individuals present on school premises. In addition, the design and upgrade of educational learning spaces are now commissioned through a variety of procedures by both national and regional governing levels [40].

The major purpose behind setting out requirements for IAQ and TC in the 2022 DQLS version recognized that approximately 90% of primary schools in New Zealand are designed to be reliable on natural sources of ventilation, which is by opening doors and windows [33]. These requirements ensure that indoor learning environments are thermally comfortable, supporting different learning and teaching techniques and traditions. They aimed to MOE [40]:

- Set out the compulsory minimum threshold limit to achieve quality indoor learning spaces.
- Set out the basic evaluation requirement for IAQ and TC with context to the project designing phase and Post Occupancy Evaluation (POEs).
- Assist in designing and modeling schools by emphasizing the cost-value model, with pressing attention toward enhancing academic results.

The New Zealand Ministry of Education aims to provide healthy classrooms by enhancing the IAQ and thermal comfort. Looking at the compounded nature of the classroom, the indoor environmental quality (IEQ) of such complex spaces requires greater detailed attention. The designers must ensure that during the design stage of the classroom, the requirement set out in the DQLS document is to be applied together for IAQ and TC along with acoustics and vision/lighting requirements in parallel. However, indoor environmental quality (IEQ) is considered a system in commissioning the entire building quality, which comprises different variables: IAQ, thermal comfort, acoustics, and lightning. These variables should be evaluated throughout the process of designing to ensure holistic comfort. A complete strategy is required, and every indoor environmental quality variable should be changed after first considering its impact on the others [40].

This study compares the requirements of IAQ and TC for designing quality learning spaces in two different versions of the DQLS document.

## 3 Methodology

The study opts a qualitative method using content analysis. The literature review related to schools, children, IAQ, ventilation, thermal comfort, academic result, and well-being were reviewed using online database resources like Google Scholar, Massey Library, and PubMed. Abstracts and titles were read thoroughly to understand the relativity of the available online source to the present study. Hence, after reviewing the abstract, titles and keywords, the relative journal articles and other resources opted to support the finding for this study. The steps undertaken to perform this study are stipulated below in Fig. 1.

Next, we compared measurable variables responsible for Indoor air quality, Ventilation and Thermal comfort evaluation within an indoor environment. The two versions of the Designing Quality Learning Spaces documents (Versions 1.0

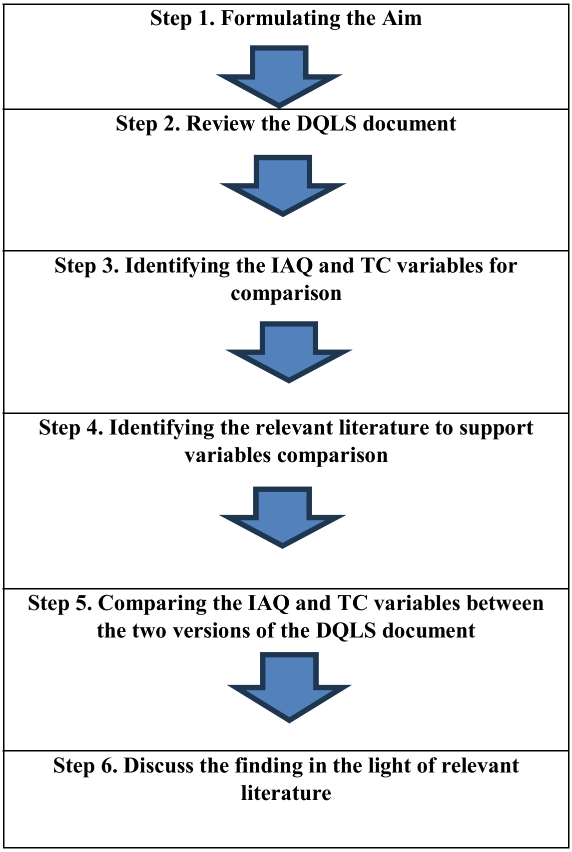


**Fig. 1** Research method flowchart

and 2.0) were analyzed, focusing on the Indoor Air Quality and Thermal Comfort requirements.

- **Designing Quality Learning Spaces, Version 1.0 (2017)**: Aims to ensure learning spaces in New Zealand support offering quality outcomes by improving IAQ and TC.
- **Designing Quality Learning Spaces, Version 2.0 (2022)**: The main objective is to ensure learning spaces in New Zealand support academic outcomes and improve the health and well-being of every individual present within the school premises.

These two versions of the DQLS: IAQ and TC document were critically reviewed based on the following measurable variables as these variables are closely interconnected [16]:

- Carbon dioxide ($CO_2$) concerntration
- Ventilation rates
- Indoor temperature

- Relative Humidity
- Widow-to-wall ratio

The findings are discussed in the section below.

## 4 Findings and Discussion

Tables 1 and 2 present the minimum to maximum requirements for IAQ, ventilation and Thermal Comfort between the two sets of DQLS documents published in 2017 and 2022 with individual upgrades to previous versions.

The mandatory minimum and maximum allowable criteria for IAQ, Ventilation and Thermal Comfort for New Zealand classrooms depicted in Tables 1 and 2 show significant changes between version 1.0 and 2.0. These changes are discussed below.

### 4.1 *Carbon Dioxide ($CO_2$) Concentration*

Looking at carbon dioxide concentration and ventilation range for DQLS, 2017, the minimum range lies between 1000 and 1500 ppm and the maximum permissible range to 3000 ppm, whereas in DQLS, 2022, the minimum range has been minimized to 800–1250 ppm and maximum permissible range to 2000 ppm. According to Wargocki et al. [52], around 12% improvement in performance and a 2% improvement in accuracy were observed in children when the average minimum concentration

**Table 1** IAQ, ventilation and thermal comfort—DQLS, 2017

| Season | Summer | Winter |
|---|---|---|
| | Minimum | Maximum |
| Carbon dioxide (ppm) | 1000–1500 (Average) | 3000 |
| Outdoor air supply (ACPH) | 2.5–5 | 0.5–2 |
| Outdoor air supply (l/s/p) | 6–8 | 1.5–5 |
| Ventilation effectiveness | Ideally achievable (average) | Poor ventilation |
| Subjective response | Light odor | Odors, stuffiness, headaches, and fatigue |
| Student performance (%) | Averagely close to 100 | Minimizes by 5–1 |
| Absenteeism (%) | Close to 5 | Increase to 15 |
| Indoor temperature (°C) | 18–28 | 18–25 |
| Relative humidity | – | |
| Window to wall (%) | 30–50 | |

**Table 2** IAQ, ventilation and thermal comfort—DQLS, 2022

| Season | Summer | | Winter |
|---|---|---|---|
| | Minimum | | Maximum |
| | On-Demand | Average | |
| Carbon dioxide | 800 ppmm | 1250 ppm | 2000 ppm |
| Outdoor air supply (ACPH) | 3 | 7.5 | 2 |
| Outdoor air supply (l/s/p) | 8 | 12 | 3.5–4 |
| Ventilation effectiveness | Well-ventilated to an ideal range | | Poor ventilation |
| Subjective response | Close to supply of fresh air | | Odor and stuffiness |
| Student performance (%) | 110–100 | | Slightly lower to 95 |
| Absenteeism (%) | Less than 5 | | Increase to 10 |
| Indoor temperature | 19–28 °C (No more than 40 Occupied hours) | | |
| Relative humidity | Should by 35–70% | | |
| Window-to-wall ratio | 25–35% | | |
| | (To reduce Overheating and allow more daylight) | | |

of carbon dioxide was decreased from 2000 to 900 ppm. Using attendance as a positive indicator for healthy IAQ in the classroom, a 2.5% improvement was observed when carbon dioxide ranges below 1000 ppm daily [54].

## *4.2 Ventilation Rates*

For the supply of outdoor air (l/s/p), DQLS, 2017 ranges between 6 and 8 l/s/p, whereas in DQLS, 2022, the supply of outdoor air is to 8–12 l/s/p. The 10 l/s/p air flow of outdoor air supply is closely associated with the range of carbon dioxide below 1000 ppm [52]. Research conducted in California found that increasing the ventilation rates by 1 l/s/p improved academic results in primary schools [34]. Another study stated that doubling the ventilation rates in primary school classrooms showed an improvement in children's performance by 14% [54]. Moreover, 10% less spread of illness is anticipated when the air supply is doubled in the classroom [18].

## *4.3 Indoor Temperature*

The indoor temperature (Classroom) range for DQLS 2017 is set between 18 and 28 °C. It is a mandatory requirement that during the occupied hours, the internal temperature should not go beyond two threshold limits, i.e., 25and 28 °C. In addition, the difference between indoor and outdoor temperatures during occupied hours should not exceed 5 °C. In contrast to DQLS 2022, the minimum requirement for indoor temperature should be 19 °C (±1 °C), while the maximum permissible indoor temperature should be 28 °C for no more than 40 occupied hours. Previous studies conducted in a classroom with context to thermal comfort and children's health, well- and academic performance have shown that every 1 °C fall (Minimum) within the indoor temperature resulted in a positive by 2–4% in children's academic results [27, 53–55].

## 4.4 Relative Humidity

The relative humidity in DQLS 2017 was not exactly mentioned, but in DQLS 2022, the RH range should be maintained within 35–70%. According to Jin et al. [25, 26], the percentage of RH does not directly impact thermal discomfort, but its effects get intense with higher differences between indoor and outdoor temperatures and higher metabolic rates.

## 4.5 Window–Wall Ratio

By improving the window–wall ratio requirement in school dwellings, can readily achieve better ventilation or aeration which can significantly help to reduce overheating. As, adequate ventilation can help with dissipating the heat stored, and also allows for better circulation of fresh air within confined spaces such as classrooms. Adding more, improved window wall ratio also allows for more natural light to enter and minimizes the need for artificial lights during the daytime. Natural light not only improves visible comfort ness but also the well-being of the occupants. Natural daylight can create a more pleasant and productive indoor environment [15]. However, it is important to balance the benefits of increased natural light and ventilation with potential drawbacks, such as increased heat gain during warmer seasons and potential glare issues. Proper shading, orientation, and the use of energy-efficient glazing can help mitigate these concerns while maximizing the advantages of an increased window–wall ratio.

Classrooms are supposed to be contemporary or adaptable learning spaces. Innovative learning surroundings, creative learning spaces, flexible learning, and quality learning environments have been used to describe newly constructed or upgraded classrooms [7].

Version 1.0 typically focuses on the usability of learning space and its impact on academic outcomes, whereas Version 2.0 includes enhancement with education results, maintaining health and well–being. Moreover, the minimum necessary requirement in Version 2.0 is established in response to best practices and in particular, to MOE's requirements. Still, it is also stated that the current Version 2.0 DQLS document design does not address each possible case. In addition, it provides the solution to the problem on behalf of recent research, technology, innovation, new methods, and feedback to address common issues.

Overall, both document has their advantage and disadvantage with context to published time. However, according to the study point of view, DQLS Version 1.0 solely focused on IAQ, Ventilation and Thermal Comfort, whereas DQLS Version 2.0 understand that strengthening standards will work. Still, it has to be a holistic approach which addresses overall performance. Additional new information or changes incorporated in Version 2.0 is an understanding of the importance of indoor environmental quality. However, IAQ, ventilation and thermal comfort are three sub-sections of IEQ as a holistic model for a dwelling. Furthermore, version 2.0 holds a sub-section in the document, which provides significant information about adequate ventilation rates and minimizing the aerial pathogen and COVID-19. In version 2.0, there has been a significant change with window-to-wall ratio to version 1.0, as DQLS, 2022 focuses on reducing overheating and allowing more daylight. Both version 1.0 and 2.0 stress following natural means of ventilation in New Zealand schools, although there is a requirement for adopting mechanical ventilation.

## 5 Conclusion

After a thorough review of both the DQLS documents and other relevant online data sources, including a comprehensive scientific literature review, the authors of the study have arrived at the following conclusion that the minimum requirements and recommendations stated in DQLS documents align with international guidelines followed by different countries to enhance the IAQ, ventilation and thermal comfort standards for school dwellings. The DQLS document developed used Thermal Comfort: ANSI/ASHRAE standard 2005 and CIBSE TM52 and Ventilation: UK Building Bulletin 101 (Ventilation for school building). The minimum airflow was developed from NZS 4303:1990 in mechanically ventilated school classrooms. The latest version, 2.0, released in 2022, has significantly enhanced the minimum mandatory requirement for the concentration of carbon dioxide, air flow rates, indoor temperature, and window-to-wall ratio. However, neither version 1.0 nor version 2.0 have provided specific criteria for occupant density and space. However, from a literature point of view, it is found that in New Zealand primary school classrooms, the maximum number of occupancy for children is 30 with a single teacher for a total space area of 70 to 78 $m^2$. Moreover, following the OECD country's guidelines for better holistically enhancing the IEQ within indoor educational spaces, the minimum occupant density should be around 3–4 $m^2$, ideally making a total classroom learning area around 90–120 $m^2$.

The novelty of this research includes critiquing the DQLS documents, which have never been done before. Also, the documents are an integral part of the governing entity of New Zealand, the Ministry of Education and the research conducted is an educational perspective to understand the importance of IAQ and Thermal Comfort standards, thus making the outcome with an unbiased point of view. However, the study compared the two DQLS documents with context to IAQ and TC standards for healthy indoor environments in New Zealand classrooms. The study is limited to the New Zealand context, which can be expanded when compared to other Western countries for IAQ and TC classroom standards. Another limitation is the methodology used in this study. Future studies can incorporate a mixed-method approach using both qualitative and quantitative analysis.

## References


1. Ackley A (2017) The influence of indoor environmental quality in schools a systematic literature review. Michael Donn and Geoff Thomas
2. Ackley A (2021) Classroom environments have more impacts than you think. Newsroom
3. Ackley AU (2021) Measuring indoor environmental quality (IEQ) in a national school property portfolio. Victoria University of Wellington. Open Access Victoria University of Wellington Te Herenga Waka. Published Doctoral Thesis
4. Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S, Sinphonie Group (2013) IAQ and sources in schools and related health effects. J Toxicol Environ Health, Part B 16(8):491–550
5. Bakó-Biró Z, Clements-Croome DJ, Kochhar N, Awbi HB, Williams MJ (2012) Ventilation rates in schools and pupils' performance. Build Environ 48:215–223
6. Barrett P, Davies F, Zhang Y, Barrett L (2015) The impact of classroom design on pupils' learning: final results of holistic, multi-level analysis. Build Environ 89:118–133
7. Benade L (2017) The evolution of policy: a critical examination of school property under the national-led government. Waikato J Educ 22(1)
8. Bennett J, Davy P, Trompetter B, Wang Y, Pierse N, Boulic M, Phipps R, Howden-Chapman P (2019) Sources of indoor air pollution at a New Zealand urban primary school; a case study. Atmos Pollut Res 10(2):435–444
9. Brabhukumr A, Malhi P, Ravindra K, Lakshmi PVM (2020) Exposure to household air pollution during first 3 years of life and IQ level among 6–8-year-old children in India–A cross-sectional study. Sci Total Environ 709:135110
10. Chatzidiakou L, Mumovic D, Summerfield A (2015) Is $CO_2$ a good proxy for IAQ in classrooms? Part 2: health outcomes and perceived IAQ about classroom exposure and building characteristics. Build Serv Eng Res Technol 36(2):162–181
11. Chatzidiakou L, Mumovic D, Summerfield A (2015) Is $CO_2$ a good proxy for IAQ in classrooms? Part 1: the interrelationships between thermal conditions, $CO_2$ levels, ventilation rates and selected indoor pollutants. Build Serv Eng Res Technol 36(2):129–161
12. Chiu YHM, Bellinger DC, Coull BA, Anderson S, Barber R, Wright RO, Wright RJ (2013) Associations between traffic-related black carbon exposure and attention in a prospective birth cohort of urban children. Environ Health Perspect 121(7):859–864
13. Coley DA, Beisteiner A (2002) Carbon dioxide levels and ventilation rates in schools. Int J Vent 1(1):45–52
14. de Gennaro G, Dambruoso PR, Loiotile AD, Di Gilio A, Giungato P, Tutino M, Marzocca A, Mazzone A, Palmisani J, Porcelli F (2014) IAQ in schools. Environ Chem Lett 12(4):467–482
15. De Luca F, Kiil M, Simson R, Kurnitski J, Murula R (2019) Evaluating daylight factor standard through climate based daylight simulations and overheating regulations in Estonia. In: Proceedings of the 16th IBPSA conference, vol 2, p 4
16. Designing Quality Learning Spaces (DQLS) (2022) Indoor air quality and thermal comfort. Ministry Edu, 2.0. https://assets.education.govt.nz/public/Documents/Primary-Secondary/Property/Design/Indoor-Air-Quality-and-Thermal-Comfort-V2-v2.0-2022.pdf
17. Fisk WJ (2017) The ventilation problem in schools: literature review. Indoor Air 27(6):1039–1051

18. Fisk WJ, Seppanen O, Faulkner D, Huang J (2003) Economizer system cost effectiveness: accounting for the influence of ventilation rate on sick leave (No. LBNL-53192). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States)
19. Gaihre S, Semple S, Miller J, Fielding S, Turner S (2014) Classroom carbon dioxide concentration, school attendance, and educational attainment. J Sch Health 84(9):569–574
20. Harris MH, Gold DR, Rifas-Shiman SL, Melly SJ, Zanobetti A, Coull BA, Schwartz JD, Gryparis A, Kloog I, Koutrakis P, Bellinger DC, Oken E (2015) Prenatal and childhood traffic-related pollution exposure and childhood cognition in the project viva cohort (Massachusetts, USA). Environ Health Perspect 123(10):1072–1078
21. Haverinen-Shaughnessy U, Moschandreas DJ, Shaughnessy RJ (2011) Association between substandard classroom ventilation rates and students' academic achievement. Indoor Air 21(2):121–131
22. Hipkins C (2020) Towards a comprehensive reform of school property. In: Cabinet Paper. Retrieved, 18. https://www.newsroom.co.nz/ideasroom/classroom-environments-have-more-impactsthan-you-think
23. Hutter HP, Haluza D, Piegler K, Hohenblum P, Fröhlich M, Scharf S, Uhl M, Damberger B, Tappler P, Kundi M, Wallner P, Moshammer H (2013) Semivolatile compounds in schools and their influence on cognitive performance of children. Int J Occup Med Environ Health 26(4):628–635
24. Ivošević T, Nikolaus P, Pranjić-Petrović T, Orlić I (2021) IAQ in a high school classroom in rijeka, croatia (sick classrooms caused by rising $CO_2$ levels). Environ Eng-Inženjerstvo okoliša 8(1–2):1–10
25. Jin L, Zhang Y, Zhang Z (2017) Human responses to high humidity in elevated temperatures for people in hot-humid climates. Build Environ 114:257–266
26. Jing S, Li B, Tan M, Liu H (2013) Impact of relative humidity on thermal comfort in a warm environment. Indoor Built Environ 22(4):598–607
27. Katafygiotou MC, Serghides DK (2014) Thermal comfort of a typical secondary school building in Cyprus. Sustain Cities Soc 13:303–312
28. Korsavi SS, Montazami A, Mumovic D (2020) IAQ (IAQ) in naturally ventilated primary schools in the UK: occupant-related factors. Build Environ 180:106992
29. Liu C, Chen R, Sera F, Vicedo-Cabrera AM, Guo Y, Tong S, Coelho MS, Saldiva PH, Lavigne E, Matus P, Valdes Ortega N, Kan H (2019) Ambient particulate air pollution and daily mortality in 652 cities. New England J Med 381(8):705–715
30. Loh JY, Andamon MM (2017) A review of IAQ standards and guidelines for Australian and New Zealand school classrooms. Back Future: Next 50
31. MacIntyre EA, Gehring U, Mölter A, Fuertes E, Klümper C, Krämer U, Quass U, Hoffmann B, Gascon M, Brunekreef B, Koppelman GH, Heinrich J (2014) Air pollution and respiratory infections during early childhood: an analysis of 10 European birth cohorts within the ESCAPE Project. Environ Health Perspect 122(1):107–113
32. Makri A, Goveia M, Balbus J, Parkin R (2004) Children's susceptibility to chemicals: a review by developmental stage. J Toxicol Environ Health, Part B 7(6):417–435
33. McIntosh J (2011) The IAQ in 35 Wellington primary schools. Master. Victoria University of Wellington, Wellington, New Zealand
34. Mendell MJ, Eliseeva EA, Davies MM, Spears M, Lobscheid A, Fisk WJ, Apte MG (2013) Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools. Indoor Air 23(6):515–528
35. Mendell MJ, Heath GA (2005) Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air 15(1):27–52
36. Ministry of Education (2015) Designing schools in New Zealand. Requirements and guidelines. https://www.education.govt.nz/assets/Documents/Primary/Secondary/Property/Design/Design-guidance/DSNZ-version-1-0-20151014.pdf
37. Ministry of Education (2016) Flexible learning spaces: how the design of spaces can help student achievement. Factsheet. https://www.education.govt.nz/assets/Documents/Primary/Secodary/Property/Design/Flexible-learning-spaces/FLS-How-the-design-of-spaces-can-help-student-achievement.pdf

38. Ministry of Education (2017) Designing quality learning spaces: IAQ and thermal comfort, (Version 1.0.). Education Infrastructure Service
39. Ministry of Education (2019) Plan and build a new teaching space. www.education.govt.nz/school/funding-and-financials/funding/teaching-space-funding/plan-and-build-a-new-teaching-space/
40. Ministry of Education (2022) Designing quality learning spaces (DQLS): IAQ and thermal comfort, (Version 2.0.). Education Infrastructure Service. https://assets.education.govt.nz/public/Documents/Primary-Secondary/Property/Design/Indoor-Air-Quality-and-Thermal-Comfort-V2-v2.0-2022.pdf
41. Porta D, Narduzzi S, Badaloni C, Bucci S, Cesaroni G, Colelli V, Davoli M, Sunyer J, Zirro E, Schwartz J, Forastiere F (2016) In a prospective Italian birth cohort, air pollution and cognitive development at age 7. Epidemiology 27(2):228–236
42. Poscia A, Burali A, Calzoni J, Colaiacomo E, Csobod E, De Maio F, Kocic A, La Milia D, Ponzo V, Ricciardi W, Romano S, Moscato U (2014) How good is my classroom? Italian results from the international SEARCH II project on energy, IAQ and comfort at school: Andrea Poscia. Euro J Public Health 24(suppl_2), cku162–073
43. Pujol J, Martínez-Vilavella G, Macià D, Fenoll R, Alvarez-Pedrerol M, Rivas I, Forns J, Blanco-Hinojo L, Capellades J, Querol X, Deus J, Sunyer J (2016) Traffic pollution exposure is associated with altered brain connectivity in school children. Neuroimage 129:175–184
44. Raysoni AU, Sarnat JA, Sarnat SE, Garcia JH, Holguin F, Luèvano SF, Li WW (2011) Binational school-based monitoring of traffic-related air pollutants in El Paso, Texas (USA) and Ciudad Juárez, Chihuahua (México). Environ Pollut 159(10):2476–2486
45. Spengler JD, Chen Q (2000) IAQ factors in designing a healthy building. Annu Rev Energy Env 25(1):567–600
46. Sunyer J, Esnaola M, Alvarez-Pedrerol M, Forns J, Rivas I, López-Vicente M, Suades-González E, Foraster M, Garcia-Esteban R, Basagaña X, Viana M, Querol X (2015) Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study. PLoS medicine 12(3):e1001792
47. Taptiklis P, Phipps R (2017) IAQ in New Zealand homes and schools. In: A literature review of healthy homes and schools with emphasis on the issues pertinent to New Zealand
48. Taylor L, Watkins SL, Marshall H, Dascombe BJ, Foster J (2016) The impact of different environmental conditions on cognitive function: a focused review. Front Physiol 6:372
49. Twardella D, Matzen W, Lahrz T, Burghardt R, Spegel H, Hendrowarsito L, Frenzel AC, Fromme H (2012) Effect of classroom air quality on students' concentration: results of a cluster-randomized cross-over experimental study. Indoor Air 22(5):378–387
50. US EPA (1993) Targeting indoor air pollution, EPA's approach and progress, United States Environmental Protection Agency
51. Wall G (2016) The impact of physical design on student outcomes. Available from: Ministry of Education, New Zealand http://educationcounts.edcentre.govt.nz. Accessed 20 May 2017
52. Wargocki P, Porras-Salazar JA, Contreras-Espinoza S, Bahnfleth W (2020) The relationships between classroom air quality and children's performance in school. Build Environ 173:106749
53. Wargocki P, Wyon DP (2007) The effects of outdoor air supply rate and supply air filter condition in classrooms on the performance of schoolwork by children (RP-1257). Hvac&r Res 13(2):165–191
54. Wargocki P, Wyon DP (2013) Providing better thermal and air quality conditions in school classrooms would be cost-effective. Build Environ 59:581–589
55. Zhang F, de Dear R, Hancock P (2019) Effects of moderate thermal environments on cognitive performance: a multidisciplinary review. Appl Energy 236:760–777

# Sustainability of Post-disaster Temporary Houses: A Review of Principles and Assessment Methods

**Alireza Shamloo, Suzanne Wilkinson, Mohamed Elkharboutly, and Niluka Domingo**

## 1 Introduction

The growing population of the world, global climate change, and the mounting number of climate-related disasters have increased the number of displaced people and the need for post-disaster housing [44]. According to the latest report by the United Nations High Commissioner for Refugees (UNHCR), the overall number of people forcibly displaced worldwide has grown to 108.4 million in 2022, which is more than twice the number of forcibly displaced people a decade ago [55]. As the "Global Report on Internal Displacement (GRID) 2023" report by the Internal Displacement Monitoring Centre (IDMC) shows, over 32 million displacements in 2022 have been related to disasters, which indicates the extent of the need for reconstruction of houses and settlements around the world [30]. According to the building back better concept, to prevent the recreation of the vulnerabilities in the built environment, the resilience and sustainability factors should be considered carefully in reconstruction projects [38].

Global challenges like climate change have shown that sustainable development is an inevitable roadmap for saving future generations. It has been proved that embracing sustainable development principles in the construction sector is crucial to safeguarding the environment, improving quality of life, promoting economic growth, and addressing climate change challenges. It aligns with the broader goal of creating a balanced and resilient society that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable reconstruction is becoming an essential need, and temporary housing needs to meet sustainability standards as a part of the reconstruction process. Despite this,

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temporary housing solutions such as prefabricated units are often criticized for weak sustainability performance [1, 27].

### 1.1 Research Method

The research method employed for this review paper is a critical and comprehensive approach to gathering and synthesizing existing scholarly works related to sustainability in reconstruction and temporary houses. This method involves a thorough search of reputable academic databases to identify relevant articles, books, and other sources. After the initial selection, a secondary screening process is conducted to ensure the inclusion of high-quality and pertinent literature. To classify the state of knowledge on the subject, the findings are classified into three subsections: sustainable housing, sustainable reconstruction, and sustainable temporary housing. The main goal of this study is to review sustainability principles and assessment tools in the post-disaster context. For this purpose, the paper starts with general sustainable housing attributes and assessment systems and then studies the post-disaster construction characteristics and related sustainability guidelines and assessment tools.

## 2 Post-disaster Construction

Post-disaster housing processes start with emergency sheltering and finish after the permanent housing stage. Quarantelli [48] defines four main stages for housing recovery: emergency sheltering, temporary sheltering, temporary housing, and permanent housing. The first stage includes finding a safe place to stay for the first nights. Other references, for instance [13], summarized post-disaster housing into a three-stage model of temporary sheltering, temporary or transitional housing, and permanent housing. Post-disaster temporary housing strategy is not necessarily the best solution after a disaster. Temporary housing units (ready-made units) have several problems, including high expenditures that may lead to delays in permanent housing, being undesirable or unacceptable in meeting displaced people's needs, limiting their participation capabilities in the reconstruction process, and also adverse effects on the environment [2, 27]. An alternative solution is a two-stage recovery in which the transitional housing can be omitted. This model of housing recovery is based on extending the emergency shelter usage or using alternative available settlement options and accelerating the permanent housing process. It requires preplans for reconstruction and the use of rapid construction technologies for permanent housing [13].

However, temporary housing is considered to have a critical role in the recovery process. Providing a temporary "home" as a safe place for survivors to live in (until the permanent houses are built) is among the first essential steps in the recovery process. This is rooted in the fact that losing a house is more than just a physical loss and affects all aspects of the survivors' lives, from privacy and mental health to security and safety against illnesses and pollution [3]. The experiences of previous disasters have shown that extensive usage of temporary housing facilities is inevitable in some cases, which is mostly a function of the disaster scale, resourcing shortages, and the weather conditions [18, 33, 36, 43].

### *2.1 Temporary Housing*

The temporary housing phase begins after the emergency and temporary sheltering stage and usually lasts for six months to 3 years [43]. Temporary housing has two major options. The first option is using existing facilities, such as available rental accommodations, collective living spaces, re-purposed public buildings, and so on, and the second option is providing temporary houses by building them in place or assembling kit structures or delivering prefabricated units [36].

According to Hosseini et al. [28], an appropriate strategy in selecting a suitable temporary housing type is derived from the capability of that system to match the local circumstances and the lack of coordination between the selected temporary housing system's specifications and the local stakeholders' needs will result in failure of the recovery project. Temporary houses have a wide variety and are built using a wide range of structural systems and materials. Some of the most commonly used temporary housing solutions are listed in Table 1.

## 3 Sustainability

Since 1990, numerous sustainability guidelines and principles have been proposed worldwide [51]. According to one of the first definitions by the World Commission on Environment and Development report in 1987, "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. UNESCO considers four dimensions for sustainable development: society, environment, culture, and economy. The United Nations Department of Economic and Social Affairs, in the "Transforming our World: 2030 Agenda for Sustainable Development" [54], has defined 17 sustainable development goals (SDGs). In this guideline, the sustainability of human settlements is the 11th goal, and it is emphasized that sustainable housing and urban development are among the essential SDGs crucial to the quality of life of people. Sustainable housing is considered one of the most important individual elements of sustainable development [15].

Among the 17 SDGs, sustainable construction firstly contributes to SDG 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Sustainable construction practices reduce urban sprawl, promote energy efficiency,

**Table 1** Temporary housing structures and materials retrieved from sources: [7, 8, 12, 13, 19, 57, 58]

| Temporary housing structural systems | Main materials |
|---|---|
| Sandwich panel units | EPS, steel/aluminum sheet, plywood/fiberboard/PVC wall covering |
| Shipping containers | Corrugated steel sheets and profiles |
| Bamboo/reed structures | Bamboo, reeds, straw, or metal or plastic sheet roofing |
| Paper tube structures | Paper tube, fiberboard floor, metal or plastic sheet roofing |
| Reinforced masonry structures | Stone, brick, concrete, steel rebar, corrugated metal roofs |
| Steel framed structures | Steel profile, different wall options (brick/concrete, clay, or AAC blocks) |
| Timber-framed/wooden structures | Sawn timber, wooden walls, corrugated sheet or straw roofing |
| Concrete structures (cast-in-place, 3D panel) | Concrete (cement, water, aggregates), steel mesh/rebar, EPS |
| Earthen structures | Rammed earth, Superadobe, compressed earth blocks |
| Hybrid and composite structures | Different options (wood/plastic/metal/fiberglass and …) |
| 3D-printed structures/3D-printed components | Concrete, soil, corrugated sheet roofing |
| Modular structures/kit structures | Different options (wood/plastic/metal/fiberglass and …) |
| Tensile structures/long-term tents | Polyester, fabric, ETFE, and … |

and enhance infrastructure, thereby fostering more livable and eco-friendly cities. Furthermore, sustainable construction aligns with SDG 9 by developing innovation and building resilient infrastructure, essential for economic growth and industrial development. By prioritizing sustainable materials, efficient energy use, and waste reduction, it directly supports SDG 12, which targets responsible consumption and production patterns. Lastly, sustainable construction also advances SDG 13 on climate action, as it reduces carbon emissions and helps mitigate the impacts of climate change. In essence, sustainable construction emerges as a linchpin in the global pursuit of the SDGs, providing the foundation for a more equitable, prosperous, and sustainable future for all [42, 50].

Sustainable reconstruction has gained more notice in recent years because of the increasing number of climate-related disasters and awareness of the unsustainable development consequences. According to Goubran [25], the building industry is the most significant sector in terms of emissions, and the construction and real estate sectors can contribute to achieving 44% of all targets in all 17 SDGs. In this regard, sustainable reconstruction as an opportunity to build-back-better and a significant part of the construction industry plays an important role in achieving the SDGs.

### 3.1 Sustainable Housing

Sustainable housing is not a new concept; numerous studies and practices have been done in this field in the last three decades, and there are clear guidelines, principles, and assessment systems for sustainable development and sustainable housing [15, 39]. The built environment and construction industry account for a large portion of the global energy consumption and greenhouse gasses (GHGs) emissions. Buildings are responsible for half of the global energy use and over 30% of CO2 emissions [31, 35, 41]. In this sector, considering the overgrowing population of the world, the housing industry and residential buildings play an important role, as they form the largest part of the built environment. Housing has the potential to contribute to sustainability by being built of local materials and with less carbon footprint [40, 56].

Sustainable housing, as a cornerstone of sustainable construction, focuses on energy-efficient design, renewable energy integration, and environmentally friendly building materials. By reducing energy consumption and carbon emissions, sustainable housing plays a vital role in mitigating climate change. Sustainable housing not only minimize the carbon footprint of individual dwellings but also sets a precedent for sustainable urban development. Moreover, sustainable housing fosters healthier and more comfortable living environments, promoting well-being while addressing social and economic aspects of sustainability. In essence, sustainable housing serves as a critical component of the broader effort to curb climate change and promote a more resilient and environmentally conscious future [24, 32].

Robichaud and Anantatmula [49] believe that the main goals of sustainable housing can be summarized as minimizing the environmental footprint, improving the health of occupants, returning the investments to local communities, meeting sociocultural requirements, and enhancing the lifecycle considerations.

Having examined the literature, sustainable housing attributes can be sorted based on three pillars: environmental, economic, and sociocultural indexes. Figure 1 shows the most common attributes and indicators of sustainable housing retrieved from the literature. Greenhouse gas (GHGs) emissions and carbon footprint and their impacts on climate change have gained more attention among the extensive characteristics and indicators of sustainable housing, and most of the sustainability attributes of Table 1 have direct or indirect impacts on GHG emissions.

### 3.2 Sustainable Reconstruction

Disasters can easily disrupt the usual functions of a society [22]. From another point of view, disasters are also valuable opportunities for addressing the deficiencies and vulnerabilities of the built environment and, moreover, implementing sustainability and resilience principles to create a more resistant and greener community [53]. Sustainable housing (temporary and permanent) in a post-disaster context has a distinctive difference from sustainable housing in general terms, it is mixed with

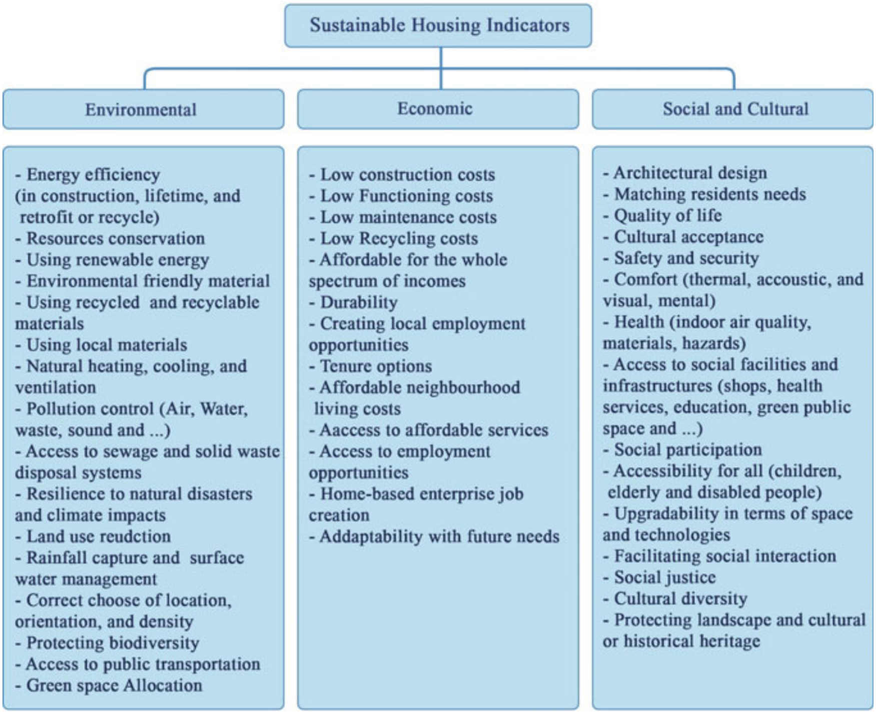


**Fig. 1** List of sustainable housing factors retrieved from the literature [15, 39, 49, 52]

necessity and urgency. The need for immediate decisions and restoring services while considering the long-term requirements of sustainable development is the main challenge in sustainable reconstruction, which can mean housing recovery projects have conflicting objectives [33, 37].

Sustainability principles encompass a holistic approach that considers environmental, social, and economic dimensions, advocating for efficient resource utilization, reduced carbon footprint, equitable access to resources, and community engagement. By prioritizing sustainable infrastructure, renewable energy sources, disaster-resistant designs, and inclusive decision-making processes, post-disaster reconstruction can mitigate future risks, foster adaptive capacities, and promote equitable development trajectories. The imperative for sustainability in post-disaster reconstruction resonates with global commitments to sustainable development and climate action, underscoring the pivotal role it plays in shaping the trajectories of disaster-affected regions and fostering a more resilient and harmonious coexistence between human societies and the natural world [14].

Meeting post-disaster housing requirements through sustainable and resilient reconstruction methods should be a goal for strategic decision-makers and people. According to research by Charlesworth and Ahmed [9] and Mannakkara et al. [38], the experiences of the practitioners in the field show that sustainable reconstruction success depends on the appropriate implementation of several factors, including integration of housing with infrastructures, supporting livelihoods and local economy, sustained engagement of organizations, ensuring multi-stakeholders engagement, using local built environment professionals help, and having an owner-driven approach.

## 3.3 Temporary Housing Sustainability

Although sustainability is a key factor in urban development and housing, it is often neglected in post-disaster sheltering or temporary housing [45]. Temporary housing solutions are normally considered to be used for several months or a few years, but experiences across the world show that, in practice, they may be in use for several years [59].

Research by [3, 29, 33, 57] show that the most important factors for achieving a successful and sustainable temporary housing are:

- Meeting the displaced people’s needs and cultural properties.
- Low costs and availability.
- Meeting climatic and geographic specifications.
- Short building/provision/delivery time and ease of construction or transportation.
- Safety and Security.
- Privacy and comfort.
- Suitable location and communication.
- Supporting livelihoods.
- The ability to be reused or recycled.
- Minimizing environmental impacts.

With an increasingly developing climate crisis, providing sustainable temporary houses will remain one of the most important and influential objectives. Changing material types and a need to provide reduced resource usage means that new mechanisms for sustainable temporary houses are required. The most frequently observed problems with temporary housing projects within the literature include the following: incompatibility with the survivors’ needs; high expenditure; wrong location; and environmental impacts [16, 21]. These incompatibilities have led to rejection of the survivors to use temporary houses or using them with dissatisfaction in several cases. For instance, after the 2003 earthquake in Bam (Iran), parts of the temporary facilities remained useless due to their inappropriate location; or after the 2004 tsunami of Aceh (Indonesia) the changes in the recovery approach led to late delivery and poor quality of temporary housing [11, 13, 20].

According to the mentioned sustainability principles, to have a sustainable shelter, not only the materials should be from reusable, recyclable, or biodegradable sources, but also, the reasonable costs, compatibility with climate and social requirements, and availability are some of the most important factors. Figure 2 shows two shelter

**Fig. 2** Temporary housing solutions designed by Shigeru Ban [5]

concepts designed by the humanitarian architect, Shigeru Ban. One of them is mostly based on reeds and plants and the other one is built using the paper tubes.

## 4 Assessment Systems and Methods

Building sustainability assessment systems are designed and used in order to find out to what extent a building meets the requirements of sustainability. According to Beardsley et al. [4], the main purposes of assessments include the following: improving the designing and building process of new buildings, evaluating the sustainability of existing buildings, verifying compliance with national and international regulations, and raising general awareness and educational purposes.

The assessments are based on weighting and aggregating sustainability indices and their components [23]. The literature shows that in the past 30 years, the number and complexity of environmental assessment tools designed for buildings have increased, and now, there are over 150 tools for the assessment and benchmarking of buildings [4]. Among these assessment tools, some of the internationally recognized systems are LEED, BREEAM, CASBEE, SBTool, SBAT, HQE, GBND, GBI, and so on [4, 10]. Most of these assessment systems have a set of tools developed for various categories, such as sustainability assessment of houses, neighborhoods, urban infrastructures, and so on. Despite the availability of a wide variety of assessment tools, researchers and organizations are constantly developing new sustainability assessment tools, which are mostly customized tools for special locations and types of buildings.

A recent study by Lazar and Chithra [35] shows that the majority of building sustainability assessment tools are designed based on environmental sustainability, and this is because of the important role of environmental considerations in sustainable development.

### 4.1 Reconstruction Sustainability Assessment

Sustainability assessments of post-disaster or post-crisis reconstruction programs are done to show how much the processes are compatible with long-term goals of sustainability. This can help planners and decision-makers improve future reconstruction efforts and decrease the harmful consequences of inappropriate environmental choices [57].

There are tools especially developed for the assessment of post-disaster reconstruction processes. One of these tools is QSAND (Quantifying Sustainability in the Aftermath of Natural Disasters). QSAND is an open-source shelter and settlement sustainability and resilience self-assessment tool. It has been developed on behalf of The International Federation of Red Cross and Red Crescent Societies (IFRC) and follows the standards developed by the BREEAM assessment system. It covers eight categories of sustainability factors that are as follows:

- Shelter and community.
- Settlement.
- Material and waste.
- Energy.
- Water and sanitation.
- Natural environment.
- Communications.
- Cross-cutting [47].

The other tools include PASSA (Participatory Approach for Safe Shelter Awareness), and T3B (Talk to the Buildings) which is more based on achieving sustainability qualities through design and architectural patterns. In this method, ten essential patterns of creating a "Home" are the basis for sustainability assessment of post-disaster shelters and houses [46].

### 4.2 Sustainability Assessment of Temporary Houses

Temporary housing sustainability assessment is a part of the whole post-disaster recovery assessment. Regarding the long period of survivors' settlement in post-disaster temporary houses (which lasts for several months to a few years), their sustainability as a part of residential buildings needs to be assessed. This can contribute to minimizing the negative environmental impacts of human settlements [1].

Temporary housing sustainability assessment includes the assessment of the whole process and the life-cycle assessment of temporary houses/units. Post-disaster temporary housing as a process, needs several decision-makings; including the location of temporary houses, type and technology, building method, materials etc. [34]. Hosseini et al. [27] believe that the appropriate decision over the selection of an optimal temporary housing strategy is a result of considering the natural hazard characteristics, the local characteristics and the temporary house characteristics; and experts from different disciplines should be involved in the temporary housing processes.

Examining the literature shows that sustainability assessment and decision-making over temporary houses and shelters has a shorter history compared to permanent houses. One of the first researches was done by El-Anwar et al. [17], in which they developed a model by quantifying the qualitative specification of temporary houses and their impacts on the users. During the last decade, several other pieces of research have been done on temporary housing sustainability assessments. Hosseini et al. [26] developed a selection model based on sustainability indicators of temporary houses, including provision cost, maintenance cost, health, well-being, resource consumption, pollution, solid waste, and reusability.

Reviewing the literature reveals that because of the limited number of tools in reconstruction sustainability assessment, and especially in temporary housing assessment, researchers have tried to develop new methods and tools for the assessment of temporary housing sustainability. The most used method for developing a sustainability assessment is Multi-Criteria Decision-Making (MCDM), which is a technique that combines each parameter's performance over numerous qualitative and/or quantitative criteria (sometimes contradicting each other) and results in a solution that needs a consensus. In this method, each assessment parameter is evaluated by considering its weight and impact [35].

## 5 Discussion and Conclusion

Sustainability assessment in post-disaster construction plays a vital role in ensuring that rebuilding efforts not only restore communities but also contribute to long-term environmental and societal resilience. This process involves evaluating the environmental impact, resource efficiency, and social considerations of construction projects in the aftermath of natural or man-made disasters. By prioritizing sustainable building materials, energy-efficient designs, and community engagement, these assessments help minimize the ecological footprint, enhance disaster resilience, and promote the well-being of affected populations.

In this study, the main characteristics of sustainable housing and sustainable reconstruction have been collected and classified. Post-disaster housing processes and post-disaster temporary housing characteristics are explained. Finally, sustainability assessment methods in general and post-disaster fields are reviewed. According to the literature, despite the difficulties of considering the long-term requirements of sustainable construction in the emergency circumstances of post-disaster recovery, moving toward sustainable reconstruction (temporary and permanent) is inevitable. The reason is climate change and the increasing number of natural disasters. Sustainable housing reconstruction should prevent future vulnerabilities and contribute to the reduction of climate change effects.

The findings of this study show that despite the numerous sustainability assessment systems in the world and in the built environment sector, there are limited resources and principles for the sustainability assessment of temporary houses, and one of the most used techniques is MCDM.

Although temporary housing sustainability assessment tools may have limitations and deficiencies in results, they can support post-disaster decision-makers in choosing the most appropriate solutions. Future research needs to provide a method for optimizing and advancing the sustainable features of temporary houses. Also, further research needs to be done on whether sustainability assessments of the most used temporary housing solutions in each country/region against the prevalent disasters actually reduce climate change impacts or not.

## References

1. Atmaca N (2017) Life-cycle assessment of post-disaster temporary housing. Build Res Inf 45(5):524–538. https://doi.org/10.1080/09613218.2015.1127116
2. Barakat S (2003) Housing reconstruction after conflict and disaster. In: Humanitarian Policy Group, Network Papers, vol 43
3. Bashawri A, Garrity S, Moodley K (2014) An overview of the design of disaster relief shelters
4. Beardsley E, Burroughs S, Crowhurst D, Yates MA, Ward C, Dari K, Ilomäki A, Gibberd J, Gupta PR, Jansen F (2017) Building sustainability assessment and benchmarking-an introduction. United Nations Settlements Programme (UN-Habitat)
5. Boardman B (2017) Shigeru Ban architects. The inventive work of Shigeru Ban
6. Brundtland GH (1987) Our common future: report of the world commission on environment and development. Geneva, Switzerland. Available at: http://www.un-documents.net/ocf-ov.htm
7. Casagrande D, Sinito E, Izzi M, Pasetto G, Polastri A (2021) Structural performance of a hybrid timber wall system for emergency housing facilities. J Build Eng 33:101566. https://doi.org/10.1016/j.jobe.2020.101566
8. Celentano G, Hischier V, Habert G, Zea Escamilla E, Göswein V (2016) Re-thinking material selection for large scale post-disaster reconstruction
9. Charlesworth E, Ahmed I (2015) Sustainable housing reconstruction: designing resilient housing after natural disasters. Routledge
10. Charoenkit S, Kumar S (2014) Environmental sustainability assessment tools for low carbon and climate resilient low income housing settlements. Renew Sustain Energy Rev 38:509–525. https://doi.org/10.1016/j.rser.2014.06.012
11. Da Silva J, Lubkowski Z, Maynard V (2010) Lessons from Aceh: key considerations in post-disaster reconstruction
12. Das S, Mukhopadhyay P (2018) Multi-hazard disaster resilient housing with bamboo-based system. Procedia Eng 212:937–945. https://doi.org/10.1016/j.proeng.2018.01.121
13. Davis I, Alexander D (2016) Recovery from disaster. Routledge is an imprint of the Taylor & Francis Group, an Informa business
14. Dube E (2020) The build-back-better concept as a disaster risk reduction strategy for positive reconstruction and sustainable development in Zimbabwe: a literature study. Int J Disaster Risk Reduct 43:101401. https://doi.org/10.1016/j.ijdrr.2019.101401
15. Edwards B, Turrent D (2000) Sustainable housing: principles and practice. Taylor & Francis Group
16. El-Anwar O, Asce S, El-Rayes K, Asce M, Elnashai A, Asce F (2009) Optimizing large-scale temporary housing arrangements after natural disasters. J Comput Civil Eng 23:110–118. https://doi.org/10.1061/(ASCE)0887-3801(2009)23:2(110)

17. El-Anwar O, El-Rayes K, Elnashai A (2008) Multi-objective optimization of temporary housing for the 1994 Northridge earthquake. J Earthq Eng 12:81–91. https://doi.org/10.1080/13632460802013602
18. Fallahi A, Arabpour F (2005) A review of reconstruction plan of the Dahuiyeh village following the 2005 earthquke. In: Third international conference on natural disaster management. Tehran
19. Faragallah RN (2021) Fundamentals of temporary dwelling solutions: a proposed sustainable model for design and construction. Ain Shams Eng J 12(3):3305–3316. https://doi.org/10.1016/j.asej.2020.11.016
20. Fayazi M (2012) Temporary housing experience after bam earthquake 2003
21. Fayazi M, Lizarralde G (2013) Temporary housing: an obstacle or an opportunity for enhancing community resilience in bam, Iran?
22. Frimpong A (2011) Sheltering and housing recovery after disasters: dissecting the problems of policy implementation and possible solutions
23. Gan X, Fernandez IC, Guo J, Wilson M, Zhao Y, Zhou B, Wu J (2017) When to use what: methods for weighting and aggregating sustainability indicators. Ecol Ind 81:491–502. https://doi.org/10.1016/j.ecolind.2017.05.068
24. Geropanta V, Karagianni A, Mavroudi S, Parthenios P (2021) Chapter 10—Exploring the relationship between the smart-sustainable city, well-being, and urban planning: an analysis of current approaches in Europe. In: Visvizi A, Pérez del Hoyo R (eds) Smart Cities and the un SDGs: Elsevier, pp 143–161
25. Goubran S (2019) On the role of construction in achieving the SDGs. J Sustain Res 1(2):e190020. https://doi.org/10.20900/jsr20190020
26. Hosseini SMA, de la Fuente A, Pons O (2016) Multi-criteria decision-making method for assessing the sustainability of post-disaster temporary housing units technologies: a case study in Bam, 2003. Sustain Cities Soc 20:38–51. https://doi.org/10.1016/j.scs.2015.09.012
27. Hosseini SMA, Farahzadi L, Pons O (2021) Assessing the sustainability index of different post-disaster temporary housing unit configuration types. J Build Eng 42:102806. https://doi.org/10.1016/j.jobe.2021.102806
28. Hosseini SMA, Pons O, De la Fuente A (2019) A sustainability-based model for dealing with the uncertainties of post-disaster temporary housing. https://doi.org/10.1080/23789689.2019.1583487
29. Hosseini SMA, Pons O, De la Fuente A (2019) Sustainable building technologies for post-disaster temporary housing: integrated sustainability assessment and life cycle assessment
30. IDMC (2023) Global report on internal displacement. Available at: https://reliefweb.int/attachments/6b08a77a-b68c-498b-a519-069c5bee713e/IDMC_GRID_2023_Global_Report_on_Internal_Displacement_LR.pdf
31. IPCC (2015) Climate change 2014: synthesis report. IPCC, Geneva, Switzerland
32. Jacobs DE (2023) Chapter 9—Reframing health, environment, and housing. In: Jacobs DE (ed) Fifty years of peeling away the lead paint problem. Academic Press, pp 351–371
33. Johnson C, Lizarralde G, Davidson C (2006) A systems view of temporary housing projects in post-disaster reconstruction. Constr Manag Econ 24:367–378. https://doi.org/10.1080/01446190600567977
34. Kapucu N, Garayev V (2011) Collaborative decision-making in emergency and disaster management. Int J Public Adm 34(6):366–375. https://doi.org/10.1080/01900692.2011.561477
35. Lazar N, Chithra K (2020) A comprehensive literature review on development of building sustainability assessment systems. J Build Eng 32:101450. https://doi.org/10.1016/j.jobe.2020.101450
36. Lizarralde G, Johnson C, Davidson C (2010) Rebuilding after disasters: from emergency to sustainability
37. MacAskill K, Guthrie P (2014) Application of sustainability principles in post-disaster reconstruction. In: Proceedings 30th annual association of researchers in construction management conference, ARCOM, pp 43–52

38. Mannakkara S, Wilkinson S, Potangaroa R (2018) Resilient post disaster recovery through building back better
39. Ming Yip N, Mohamad J (2017) Indicators of sustainable housing development (SHD): a review and conceptual framework
40. Murtagh N, Scott L, Fan J (2020) Sustainable and resilient construction: current status and future challenges. J Clean Prod 268:122264. https://doi.org/10.1016/j.jclepro.2020.122264
41. Olu-Ajayi R, Alaka H, Sulaimon I, Sunmola F, Ajayi S (2022) Building energy consumption prediction for residential buildings using deep learning and other machine learning techniques. J Build Eng 45:103406. https://doi.org/10.1016/j.jobe.2021.103406
42. Opoku A, Ahmed V, Ofori G (2022) Realising the sustainable development goals through organisational learning and efficient resource management in construction. Resour Conserv Recycl 184:106427. https://doi.org/10.1016/j.resconrec.2022.106427
43. Perrucci D, Baroud H (2020) A review of temporary housing management modeling: trends in design strategies, optimization models, and decision-making methods. Sustainability 12:10388. https://doi.org/10.3390/su122410388
44. Perrucci D, Vazquez B, Aktas C (2016) Sustainable temporary housing: global trends and outlook. Procedia Eng 145:327–332. https://doi.org/10.1016/j.proeng.2016.04.082
45. Pomponi F, Moghayedi A, Alshawawreh L, D'Amico B, Windapo A (2019) Sustainability of post-disaster and post-conflict sheltering in Africa: what matters? Sustain Prod Consump 20:140–150. https://doi.org/10.1016/j.spc.2019.06.007
46. Potangaroa R (2015) Sustainability by design: the challenge of shelter in post disaster reconstruction. Procedia Soc Behav Sci 179:212–221. https://doi.org/10.1016/j.sbspro.2015.02.424
47. QSAND (2022) About QSAND. Available at: https://www.qsand.org/about-qsand/
48. Quarantelli EL (1995) Patterns of sheltering and housing in US disasters. Disaster Preven Manag Int J 4(3):43–53. https://doi.org/10.1108/09653569510088069
49. Robichaud L, Anantatmula V (2010) Greening project management practices for sustainable construction. J Manage Eng 27:48–57. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000030
50. Scrucca F, Ingrao C, Barberio G, Matarazzo A, Lagioia G (2023) On the role of sustainable buildings in achieving the 2030 UN sustainable development goals. Environ Impact Assess Rev 100:107069. https://doi.org/10.1016/j.eiar.2023.107069
51. Shrivastava P, Berger S (2010) Sustainability principles: a review and directions. Organ Manag J 7(4):246–261. https://doi.org/10.1057/omj.2010.35
52. Tayefi Nasrabadi M, Hataminejad H (2019) Assessing sustainable housing indicators: a structural equation modeling analysis. Smart Sustain Built Environ 8:457–472. https://doi.org/10.1108/SASBE-01-2019-0008
53. Tomkinson C (2013) Amaratunga D, Haigh R (eds) Post-disaster reconstruction of the built environment: rebuilding for resilience. Wiley-Blackwell, London, 2011 336 pp, ISBN 978 1 4443 3356 5, £75.00 (hb); Construct Manag Econ 31. https://doi.org/10.1080/01446193.2012.729847
54. UN (2015) Transforming our world: the 2030 agenda for sustainable development. Available at: https://doi.org/10.1007/s13398-014-0173-7.2
55. UNHCR (2022) Global report, Geneva, Switzerland. Available at: https://reporting.unhcr.org/global-report-2022
56. Winston N, Pareja-Eastaway M (2008) Sustainable housing in the urban context: international sustainable development indicator sets and housing. Soc Indic Res 87:211–221. https://doi.org/10.1007/s11205-007-9165-8
57. Zea Escamilla E, Habert G (2015) Global or local construction materials for post-disaster reconstruction? Sustainability assessment of twenty post-disaster shelter designs. Build Environ 92:692–702. https://doi.org/10.1016/j.buildenv.2015.05.036

58. Zhang G, Setunge S, Elmpt S (2014) Using shipping containers to provide temporary housing in post-disaster recovery: social case studies. Procedia Econ Financ 18:618–625. https://doi.org/10.1016/S2212-5671(14)00983-6
59. Zhang G, Setunge S, van Elmpt S (2014) Using shipping containers to provide temporary housing in post-disaster recovery: social case studies. Procedia Econ Financ 18:618–625. https://doi.org/10.1016/S2212-5671(14)00983-6

# Construction and Demolition Waste Management in Affluent Economies in Transition: Implementing the 3R Strategy

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## 1 Introduction

The construction industry plays a significant role in modifying the natural environment, but it also gives rise to significant environmental impacts such as resource depletion, pollution, and waste generation. Recently, there has been a growing recognition of the importance of sustainability and effective waste management in the construction sector. Sustainability within this sector covers a variety of initiatives aimed at mitigating adverse effects, promoting societal well-being, and ensuring economic viability throughout the whole construction lifecycle. These concepts comprise the promotion of energy efficiency, resource preservation, waste minimization, and the utilization of ecologically sustainable products [25]. Economic

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development, coupled with the swift pace of urbanization, caused the global proliferation of CDW generation, which is recognized as a significant concern within the construction industry, primarily because of its adverse effects on the environment and the overall efficiency of the construction sector [24].

Waste generation creates a widespread challenge that impacts communities at a global scale. Construction waste refers to unwanted materials generated directly or indirectly from construction activities. This encompasses various construction components, including insulation, nails, electrical wiring, and rebar, alongside waste materials generated during site preparation, such as dredging materials, tree stumps, and rubble. On the other hand, demolition waste refers to the debris generated from demolishing a building, including insulation, electrical wiring, rebar, wood, concrete, and bricks. Both construction and demolition wastes may contain lead, asbestos, or other potentially harmful materials [32, 47]. However, it is important to note that data on CDW is not consistently collected, resulting in most published Figures being estimated and requiring careful interpretation. Estimates indicate that in 2012, the European Union generated over 8,200 million tons of CDW. In the same year, Japan produced 77 million tons, China 33 million tons, and India 17 million tons. Additionally, the fast-developing cities of Dubai and Abu Dhabi each generated nearly 7 million tons of CDW in 2011 and 2013, respectively [48]. At a global level, a significant fraction of CDW, ~ 35%, is disposed of in landfills [23]. Effective CDW management is imperative in preserving the environment, conserving natural resources, sustaining the economy, and benefiting society as a whole. Numerous studies have been conducted in the field of CDW management, with a specific focus on the hierarchical approach of reduce, reuse, and recycle techniques that are widely recognized as the core principle in CDW management with well-documented implementation efforts individually or in combination [23, 24].

Governments and communities acknowledged the importance of handling CDW by implementing regulations and policies targeting effective management techniques. Policies about sustainability in the construction industry usually prioritize waste reduction, promotion of recycling, and adherence to responsible disposal requirements. Prioritizing sustainability and efficient management of CDW is crucial as it reduces negative impacts and improves social well-being and economic viability. The appropriate management of construction waste contributes to the mitigation of resource depletion and the alleviation of the industry's associated burdens [26, 49].

In recent years, a growing global interest in the concept of circular economy (CE) is evident as a potential solution to address the prevailing production and consumption paradigm, which relies on perpetual growth and escalating resource utilization. Implementing closing-the-loop production patterns involves integrating sustainable practices throughout the product lifecycle, from design and production to consumption and disposal. This approach aims to minimize resource consumption, waste generation, and environmental impacts by maximizing the reuse, recycling, and recovery of materials. By adopting closing-the-loop production patterns, organizations can reduce their reliance on raw resources and decrease waste sent to land [18].

Several studies examined the five fundamental stages of the waste management hierarchy (WMH) [13], including waste reduction, reuse, recycling (3Rs), treatment, and disposal. While treatment or recovery options are typically categorized within general waste management practices, disposal is not considered an efficient approach to proper management. The management hierarchy of CDW prioritizes options based on their preference, with waste avoidance being the most desirable outcome and disposal being the least desirable end. The waste management hierarchy encompasses five distinct levels. However, from the academic perspective, the primary parts of CDW management techniques are the 3R's principle of waste minimization [27]. Historically, the hierarchical approach to CDW management, which encompasses the 3Rs principles, has been perceived as a viable strategy for exploring CDW management [23, 24].

This study examines the legislative and management practices related to CDW in the UAE, with a specific emphasis on implementing effective methods based on the 3R principle. The study focuses on the crucial factors that influence the management of CDW in response to its escalating quantity resulting from fast urban expansion. The significance of minimizing waste generation, advocating for material reuse, and establishing recycling infrastructure is underscored, with a focus on strategies to improve CDW management practices. These approaches encompass public awareness campaigns, incentivization strategies, penalties for non-compliance, investments in recycling infrastructure, regulatory enhancements, and capacity-building initiatives within the construction sector. The primary objective is to make a valuable contribution toward the sustainable management of CDW in light of the increasing construction activities in the UAE.

### *1.1 The UAE Context*

The UAE is a constitutional federation comprising seven emirates. Over the last five decades, the UAE has successfully transitioned its economy from primarily reliant on fishing and agriculture to a technologically advanced and highly competitive one [39]. This transformation has positioned the UAE as a global leader in terms of economic performance, boasting one of the highest per capita incomes globally. While the economy continues to rely on the oil sector, its contribution to the gross domestic product (GDP) is gradually diminishing [7, 34]. Figure 1 shows the economic growth in terms of GDP from the year 2010–2022 for various economic activities. The economic sectors of mining and quarrying, including the extraction of crude oil and natural gas, contribute to around 27% of the GDP. The construction and manufacturing sectors collectively account for 20% of the GDP [16]. The construction industry and related activities are widely acknowledged as substantial economic growth and development contributors. The two main emirates of Dubai and Abu Dhabi emerged as prominent leaders in the construction and real estate of megaprojects, assuming a crucial role in the attraction of foreign investment, promotion

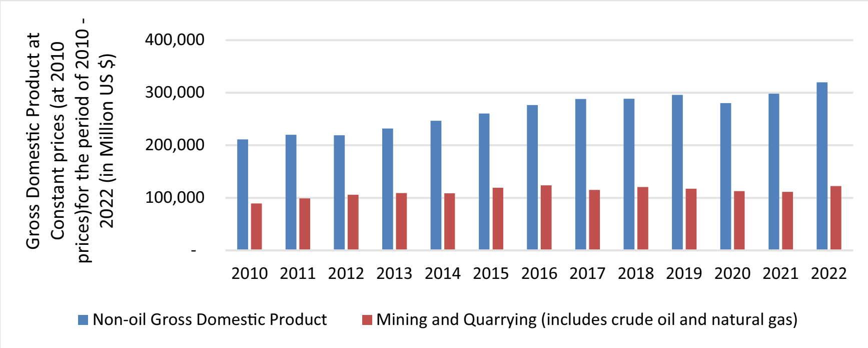


**Fig. 1** Economic growth in terms of GDP (*Data from Federal Competitiveness and Statistics Centre, 2022a*)

of tourism, and elevating the international standing of the country. The sector facilitates generating employment opportunities and job prospects for a diverse range of individuals possessing different skill levels, encompassing unskilled, semi-skilled, and skilled laborers. Furthermore, it is crucial in generating income in both the formal and informal sectors. It functions as an additional source of foreign exchange earnings, supplementing those derived from the trade of construction materials and engineering services [11, 34].

Despite positive contributions made through the construction industry, it is essential to acknowledge and address its adverse environmental effects. The built environment accounts for approximately 40% of global carbon emissions [21]. This encompasses both operational carbon emissions, which occur during the regular use of a building, and embodied carbon emissions originating from the inherent carbon content of the building materials [14]. The construction sector is also responsible for contributing to the environmental impacts of increased CDW. In the context of the UAE, CDW contributes to the exacerbation of environmental challenges, including air pollution, habitat disruption, resource depletion, and heightened energy consumption. The UAE is witnessing an increase in urbanization that exacerbates urban challenges, emphasizing the need for sustainable management of CDW under an affluent economy in transition [22, 29, 37]. Figure 2 illustrates the CDW produced in the UAE from 2016 to 2021. A significant portion of non-hazardous waste attributable to CDW reached 82% of the total waste produced in 2021, an increase of 50% from 2020 [17].

The quantity of waste produced by construction projects has the potential to increase due to the need to accommodate the growing population and expanding industrial sector with a need to implement strategies to minimize waste generation [30]. As such, the government adopted legislative measures and developed comprehensive strategies and policies to support the implementation of integrated waste management practices. Hence, the primary objective of this study is to examine the

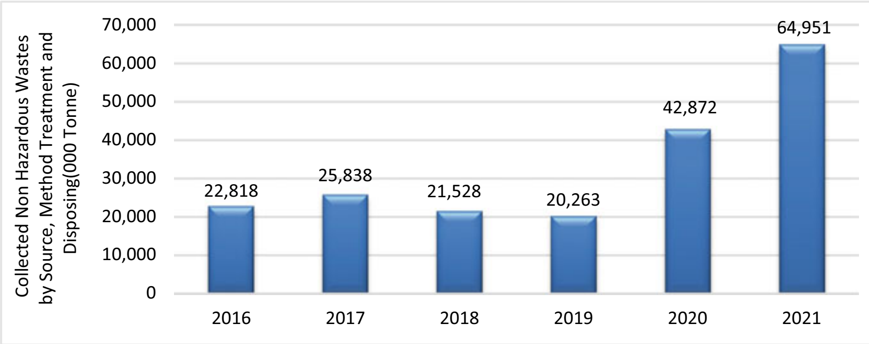


**Fig. 2** Quantity of collected non-hazardous wastes *(Data from Federal Competitiveness and Statistics Centre, 2021a)*

legislative and policy measures set by the UAE government for the purpose of integrated CDW management and identify factors that can constrain or facilitate CDW management in the UAE within the framework of the 3R (reduce, reuse, and recycle) principle.

## 2 Methodology

To achieve our study goals, we have implemented a comprehensive desk based research approach with the purpose of acquiring a profound comprehension of the practices involved in the treatment and management of CDW in the UAE. In order to attain the overarching objective, our main sources of information consisted of the official websites of the government, particularly those that are managed by the Ministry and pertinent government entities. A comprehensive and rigorous analysis was undertaken to derive significant information about the existing policies and treatment procedures pertaining to CDW management from these online sites.

A comprehensive review of academic literature sourced from credible sources, such as Google Scholar and Scopus, in order to investigate the obstacles and facilitators associated with CDW management in the UAE was carried out for this study with the aim of optimizing the discovery of relevant research resources. The search keywords were modified and improved by integrating new informatics approaches and employing Boolean operators to enhance accuracy and inclusiveness. The systematic strategy was implemented in the following manner: Systematic searches were conducted inside the Scopus database, employing strategic utilization of key terms such as "Construction and Demolition Waste Management," "United Arab Emirates," "Circular Economy," and "Construction." The selected keywords were strategically utilized throughout several sections, such as the topic, article title, abstract, and keywords, to ensure a thorough and comprehensive exploration of the subject matter. It is important to highlight that over the duration of our study, we met a significant dearth of pertinent material pertaining to the management of CDW in the UAE, particularly in relation to the legal framework and regulations governing this field.

Our investigation is predicated on an in-depth grasp of the challenges that are experienced as well as the suggested solutions that are intended to enhance the productiveness of the management of CDW. This provides the basis for our investigation. The fundamental ideas underlying the circular economy are the primary focus of our investigation, with a particular concentration placed on the "3R" model.

## 3 Existing Conditions: CDW Policies, Legislative and Treatment Modes in the UAE

The scarcity of relevant literature concerning the UAE's CDW management is noteworthy, particularly concerning the laws and legislation governing this domain. As such, the analysis is guided by the challenges faced and proposed solutions aimed at enhancing the effectiveness of CDW management, with a specific focus on the principles of the Circular Economy, notably the "3R" framework.

### *3.1 National and Regional Policies and Legislation*

The UAE Federal Environmental Agency was formed in 1993 by Federal Law No. (7) with a mandate to develop policies, assess environmental impacts, enforce laws, and promote sustainability. Federal Law No. 24 of 1999—Protection and Development of the Environment covers the primary legislation for environmental protection and CDWM regulations in the UAE [20], which aims to establish guidelines for the appropriate management, treatment, and disposal of waste materials. The legislation endeavors to advance the principles of recycling, waste minimization, and pollution mitigation to safeguard the environment and cultivate sustainable development throughout the nation.

Federal Law No. 12 of 2018 by the Ministry of Climate Change and Environment on integrated waste management has put forth 35 articles to establish a systematic approach to waste management and standardize the tools utilized for proper disposal by implementing effective and advanced procedures and methodologies. The legal framework encompasses all stages of waste management, including production, sorting, transportation, storage, recycling, treatment, and disposal, except radioactive waste [43]. The legislation also defines the penalties for illegal dumping of waste at undesignated sites.

Ministerial Resolution No. 21 of 2019 was also issued by the Ministry of Climate Change and Environment to increase the recycling rate toward fulfilling the country's zero waste target. It pertains to using recycled aggregates derived from CDW in constructing roads and other infrastructure projects undertaken by the UAE's public and private sectors. The resolution outlines environmental prerequisites for recycling cement, concrete, steel, bricks, gravel, sand, asphalt, timber, and gypsum waste into new high-value materials. The decree mandates concerned local departments to have contractors collect and sort waste generated at construction and demolition sites. Depending on their size, the recycled materials can be used for paving roads, grading dirt roads and parking areas, or earth filling at construction sites. The aggregates must undergo quality testing in laboratories to verify compliance with UAE standards and LEED and BREEAM certification requirements [44]. The local authorities oversee waste management responsibilities in different emirates of the UAE. The National Waste Management Database was implemented by the UAE government in 2018. This database is a platform for facilitating the connection and collaboration among waste management authorities across all emirates within the country. Several other national-related policies and legislation are presented in Table 1.

### 3.2 CWD Treatment and Recycling Centers in the UAE

The successful enforcement of legislative measures led to a significant enhancement in the recycling rate of CDW by 2021, reaching an impressive 85% and aligning with the increasing global interest in enhancing waste management [17]. The management of waste concerns is addressed by implementing recycling practices, converting waste into energy and valuable resources, using innovative technology, and enhancing waste separation and collection systems. The UAE is committed to mitigating the adverse environmental effects in urban areas, improving air quality, and enhancing waste management practices at the municipal and beyond [40].

Recycling CDW has proven to be an efficient method for minimizing the overall waste generated by construction and demolition activities. The recycling process of this waste is facilitated by establishing facilities in various parts of the country dedicated to this specific purpose [24]. More specifically, the *Centre of Waste Management Tadweer,* which was created by the Government of Abu Dhabi in 2008, oversees the Emirate's policy, Strategy, and contractual waste management mechanisms. The initial facility is located in Abu Dhabi, followed by a second in Al Ain and a third in the Al Dhafra region. Collectively, these facilities possess a combined annual capacity of 10,000 tons per day. The recycling activities associated with CDW yield four distinct sizes of gravel with applications in infrastructure projects. Additionally, sand generated from treatment procedures is utilized to cover waste materials that are subsequently deposited in landfills [2]. *The Integrated Waste Management Master Plan of Dubai Municipality* was formulated by its Waste Management Department in 2012 with the primary objective of eliminating waste disposal in landfills within 20 years, using an integrated and pioneering methodology. The Dubai Municipality has recently made public its plans to construct the most extensive Middle East facility dedicated to converting solid waste into electricity [19]. *The Bee'ah CDW recycling facility of Sharjah* handles a large quantity of waste, consisting of

**Table 1** Key construction and demolition waste management laws and regulations

| Year | Description | Source |
|---|---|---|
| 1999 | Federal Law No. (24) of 1999, modified by Federal Law No. 11 for 2006 for the protection and development of the environment, includes provisions for waste management, focusing on pollution control, waste reduction, recycling, and proper disposal to protect the environment | MOCCE |
| 2001 | Cabinet Order No.37 of 2001 for Executive Order of Federal Law No. 24 of 1999 for regulation of handling hazardous materials, hazardous waste, and medical waste | MOCCE |
| 2018 | The 2018 Federal Law No. 12 on integrated waste management. The law regulates every aspect of waste management: production to classification, transport, storage, recycling, treatment, and disposal | MOCCE |
| 2019 | Ministerial Decision No.21 of 2019 on the use of recycled materials from construction and demolition waste in road and infrastructure projects | MOCCE |
| 2021 | Cabinet Resolution No.39 of 2021 regarding the Executive Regulations of Federal Law No.12 of 2018 regarding integrated waste management | MOCCE |
| 2003 | Local Order No. (5) of 2003 Amending Local Order (7) of 2002 concerning waste disposal sites in the Emirate of Dubai | DM |
| 2015 | Technical guidelines No.7 mandatory waste segregation enforces waste generators to segregate inert aggregates, metals, timber, dry recyclables, and hazardous materials | DM |
| 2015 | Technical guidelines No. 5 waste classification defines the types of materials that could be available in CD waste | DM |
| 2017 | Executive Council Resolution No. (58) of 2017 on approving fees and fines for waste disposal in the Emirate of Dubai | DM |
| 2021 | Technical Guideline No. 9 recyclable waste materials promotes the utilization of recyclable materials in order to reduce environmental impact and promote a circular economy | DM |
| 2005 | Law No. (21) Of 2005 for waste management in The Emirate Of Abu Dhabi to promote the reduction of generated waste, recycling, and reuse | EA–AD |
| 2009 | Abu Dhabi Decree No.2 G24 of 2009 for the tariff system | EA–AD |
| 2022 | Environmental management policy to empower optimized waste management and encourage circular economy principles | EA–AD |
| 2019 | Waste collection—segregation—transfer and tracking policy | EA–AD |
| 2019 | Waste classification policy | EA–AD |
| 2019 | Waste planning policy | EA–AD |
| 2019 | Waste reuse-recycling-resource recovery—treatment and disposal policy | EA–AD |
| 2019 | Licensing and enforcement policy for the waste sector | EA–AD |
| 2008 | Centre for waste management technical guidelines | Tadweer–AD |
| 2011 | Law No. 4 of 2011 On Amending Law No. 2 of 2007 of Environment protection and development | Ras al Khaima |
| 2022 | Recycling quality policy, Bee'ah recycling provide zero waste strategies | Sharjah |

AD: Abu Dhabi; DM: Dubai municipality; EA: Environment agency; MOCCE: Ministry of climate change and environment concrete, bricks, wood, insulation, and asphalt, enabling the diversion of CDW from landfills. Bee'ah utilizes reclaimed CDW to manufacture various sustainable products, including concrete eco-curbstones, aggregates for road-base construction, recycled concrete eco-interlocks, and recycled concrete eco-blocks. Additional materials were retrieved, including stainless steel, rebar steel, aluminum, and copper. The by-products from this process comprise five distinct grades of aggregate frequently used to construct roads, pavements, and industry-certified recyclable products like curb stones and interlocks. The recycled aggregate is also commonly employed as a base or sub-base material for roads and other construction applications [8]. Concurrently, there has been a discernible rise in the country's production of CDW, invariably leading to environmental impacts. While increased awareness levels in this context are evident at a national scale, the construction industry still lacks expertise or adequate incentives for the successful implementation of efficient waste management practices.

## 4 Challenges and Enablers Based on the 3R Principles

The management of waste poses a significant challenge within the construction sector in the UAE and beyond. Inadequate planning, insufficient skills, and non-equitable contracts collectively impede the attainment of optimal performance within this critical industry. Consequently, the country incurs financial losses due to the inadequate execution of projects [30]. The construction industry is commonly perceived as prioritizing project delivery with limited concern for environmental protection, albeit the recognition of adverse impacts on the local ecosystem with broader effects beyond the immediate area. Such impacts are not limited to waste generation during the construction phase but also encompass waste generation during the decommissioning and demolition of constructed structures [15].

The causes and sources of construction waste generation are influenced by various factors, such as procurement processes, material handling procedures, construction practices, and the attitudes and behavior of the construction team. Inefficient practices contribute significantly to waste generation. Such practices encompass inadequate waste management strategies, inaccuracies in material procurement, substandard quality of procured materials, improper storage practices, reliance on conventional construction techniques, insufficient segregation, inadequate coordination of documents, and the need for rework resulting from errors. Also, the lack of awareness of the negative impact of waste on the environment, the absence of adequate training in environmental and waste management practices, the absence of managerial backing for waste management initiatives, and lack of absence of a construction waste management plan are some of the factors that lead to waste generation in the UAE.

This section examines the primary problems encountered by the management of CDW, as well as the factors that facilitate its success. The analysis of waste management practices in the UAE is approached from a comprehensive standpoint

**Table 2** Key challenges and enablers in the management of CDW

| 3Rs | Challenges | Enablers |
|---|---|---|
| Reduce | • Design change effect on CDW increase<br>• Supply chain and material handling<br>• Planning and methods for building construction<br>• Work culture and lack of environmental awareness | • Building information modeling (BIM)<br>• Lean construction practices<br>• Sustainability assessment tools |
| Reuse | • Guidance for effective CDW collection and sorting<br>• Knowledge and standards for reused CDW | • Cost saving |
| Recycle | • Under-developed market for recycled CDW<br>• Material contamination | • National and regional legislation<br>• On-site segregation mandates by green building regulations |

that incorporates the principles of reduce, reuse, and recycle, which are fundamental to the notion of circular economy. Table 2 highlights challenges and enablers in the management of CDW in the UAE based on the core tenets of the Circular Economy, namely the 3Rs principle, further detailed below.

Embracing this perspective allows the uncovering of the diverse obstacles that CDW management faces within a fast-moving economy such as the UAE and the concomitant analysis of potential solutions. The perspective enables exploring the complex dynamics of waste management with beneficial solutions consistent with the principles of circularity, making a valuable contribution to a more sustainable and ecologically conscious framework for managing CDW.

## *4.1 Reduce*

Waste reduction is considered the most effective and efficient approach since it allows for minimizing costs associated with waste management (transport, recycling, and disposal). Among the 3Rs, waste reduction is the most favorable owing to its minimal adverse effects on the environment, and hence, it is commonly prioritized in developing CDW management plans [23]. While the recycling rate in the UAE is high, the continuously increasing rate and volume of CDW generation remains a challenge and can be minimized through active stakeholders' participation in the construction sector.

#### 4.1.1 Reduction Challenges

- *Design Change Effect on CDW Increase* has the highest impact in generating construction waste due to frequent occurrence of design revisions, particularly after the startup of construction activities due mainly to lack of effective communication among contractors, designers, and clients during the design phase when stakeholders must convene to reach a final decision before the commencement of construction projects [33]. Design changes after construction commencement, mistakes in project documents, incomplete information, and lack of contractors' influence on contract documentation are common challenges causing increased CDW in the UAE construction industry [10]. The absence of awareness by the design team on the effect of CDW on the environment can equally influence waste generation [22].
- *Supply Chain and Material Handling* is another common cause of waste generation associated with errors in the quantity of ordered products that can manifest themselves in two ways: ordering a considerable amount or ordering an insufficiently small quantity of products. In addition, the procurement of goods that fail to meet the necessary technical specifications, material damage during transport/transfer from one location to another, and improper storage at the site are critical factors in increased waste generation [5, 10].
- *Planning and Methods for Building Construction* are characterized by a complicated and multifaceted nature, with several factors contributing to the complexity (Luangcharoenrat et al. 2019), including the divergent goals and interests among stakeholders (i.e., owners, architects, engineers, contractors, and subcontractors) which affects building project progression. The potential outcome of this divergence invariably involves modifications to the contract, alterations to the scope of work, and an increase in waste generation, particularly when the preordering of long lead items occurs. Furthermore, subtle planning considerations such as inadequate site inspection and harsh weather conditions can contribute significantly to increased CDW at construction sites [10] (El-Sayegh et al. 2020).
- *Work Culture and Lack of Environmental Awareness* are often associated with professionals in the construction industry since their primary focus and dedication are directed toward expediting project completion [28]. Poor waste management and environmental education, insufficient management commitment to waste reduction, and no building waste management strategy in place led to increased CDW in the construction sector [10, 22, 37].

#### 4.1.2 Reduction Enablers

- *Building Information Modeling (BIM) in Construction Design* has transformed the Architecture, Engineering, and Construction (AEC) sector by enhancing collaboration and coordination among various parties involved in a project, leading to more efficient data and information management. Additionally, it contributes to improved decision-making capabilities throughout the construction process, aiding in the identification and resolution of possible difficulties that may arise throughout this phase benefiting all stakeholders [36]. The UAE has allocated substantial funds to develop building and infrastructure sectors with an increasing trend toward adopting BIM to enhance the effectiveness and sustainability of these endeavors. The UAE has emerged as a prominent frontrunner in the Middle East region regarding its adoption and implementation of BIM, with Dubai Municipality pioneering the adoption of BIM across the region [1]. Using BIM in construction has been reported to reduce construction waste due to design changes and reworks [31].

- *Lean Construction Practices* are advocated to design production systems to minimize the waste of materials, time, and effort to generate the maximum possible amount of value [46]. The construction process in the UAE exhibits distinct characteristics leading to potential variations in waste generation and the use of lean construction methodologies. In a manner akin to lean manufacturing and services principles, six sigma can serve as a synergistic component within the context of lean construction. Enhancing quality within the construction domain aligns with lean methodology principles, prioritizing efficient project completion and cost efficiency. This is achieved by minimizing the need for rework, delays, and repetitions in completed jobs and assuring the quality of materials delivered to the building site. However, one of the primary obstacles to implementing lean techniques in the UAE is the limited awareness and interest in the concept and value of lean construction. Additionally, there is a notable hesitancy among construction professionals to disclose information about the types of waste in their projects [4, 46].
- *Sustainability Assessment Tools* have exhibited a growing trend since 2006, including international green building standards like LEED (Leadership in Energy and Environmental Design) certification by the USA and BREEAM (Building Research Establishment Environmental Assessment Method) certification by the UK. These certifications are globally acknowledged as a standard for evaluating and recognizing environmentally sustainable construction (Emirates Green Building Council 2020) and have been implemented in various projects within the UAE, catalyzing the formulation and enforcement of customized regulations and rating systems for sustainable construction practices. Abu Dhabi, for instance, took the initiative of implementing a requirement for the Estidama Pearl Rating System (Abu Dhabi Urban Planning Council 2010a). Similarly, Dubai formulated the Dubai Green Building Regulations and Specifications, which were replaced by the Al Safat Rating System. Implementing these regulations has facilitated the establishment of a regional marketplace for environmentally friendly building materials and technologies. Additionally, it has enhanced the knowledge and understanding among professionals in the industry about energy efficiency, water conservation, waste management, indoor environmental quality, and other sustainable building attributes (Yas and Jaafer 2020). In 2019, the Emirate of Ras Al Khaimah introduced its set of regulations, the Barjeel Green Building Regulations. In the same year, the Ministry of Infrastructure Development implemented the Green Building Guidelines for Federal Buildings in the UAE [35]. Furthermore,

the Sharjah Municipality has recently introduced its inaugural green building guidelines, which are currently being tested in the Emirate. The directive mandates that all newly constructed structures must meet predetermined benchmarks to effectively limit energy and water consumption while mitigating construction waste by recycling building materials.

## *4.2 Reuse*

The reuse of CDW holds significant importance in the context of sustainable waste management. The utilization of CDW materials, including reclaimed wood, concrete, and metals, holds substantial potential for mitigating the environmental impacts associated with construction endeavors by preserving natural resources and minimizing energy use and waste disposal. It is, however, imperative to acknowledge the constraints of quality control and adhering to regulatory compliance. Nevertheless, incorporating reuse into construction practices is expected to advance the principles of the circular economy while simultaneously yielding economic advantages and addressing the environmental consequences linked to resource extraction and waste generation within the building industry [24].

### 4.2.1 Reuse Challenges

- *Guidance for Effective CDW Collection and Sorting* remains lacking, albeit it is critical in waste minimization and management [29], but it is exclusively addressed during internal site progress meetings. Despite the potential cost savings and greater profitability associated with waste minimization, various stakeholders (consultants, contractors, client's representatives) prioritize monitoring the progress and quality of work, emphasizing mainly site cleanliness as a component of site safety measures, albeit acknowledging that waste minimization is a component of their cost control and value management practices. Furthermore, it is imperative to enhance the efficiency of waste measurement and segregation techniques in construction sites [6].
- *Knowledge and Standards for Reused CDW* remain equally lacking, with the complete absence of established criteria governing the utilization of recycled CDW materials leading customers to question the inherent characteristics of such materials. The utilization of CDW is not common due to concerns regarding the uncertain quality of these materials. Furthermore, it is frequently observed that materials are insufficient to be derived from recycled CDW [3, 9].

#### 4.2.2 Reuse Enablers

- *Cost Saving*: Is invariably the primary advantage and motivating factor for minimizing material waste in building projects, as perceived by most stakeholders. Reducing expenses associated with waste disposal and transportation and utilization of on-site or off-cut materials within construction sites offers a cost-saving advantage and enhances profitability [5, 28].

### *4.3 Recycling*

In the context of sustainable development, the recycling of CDW holds significant importance. The implementation of CDW recycling in the region has become more important due to the significant expansion of construction projects. This practice can alleviate the burden on landfills and effectively preserve valuable resources. The recycling facilities in the UAE utilize sophisticated technologies to categorize and treat various materials such as concrete, steel, and gypsum, thereby fostering a culture of environmental protection and accountability. This practice is in accordance with the UAE's dedication to environmentally friendly efforts aimed at mitigating carbon emissions and minimizing resource depletion. Moreover, it plays a significant role in promoting the development of a circular economy that stimulates economic growth and protects the environment. The recycling of CDW plays a crucial role in ensuring a sustainable trajectory [2, 42].

#### 4.3.1 Recycling Challenges

- *Under-Developed Market for Recycled CDW* limits the acceptance and utilization of building materials derived from recycled CDW. In the UAE, a standardized market for reused building materials remains lacking, impeding the efficient circulation of such resources throughout the construction sector. The system still does not facilitate the involvement of contractors in the process of material selection and the establishment of circular procurement criteria [3]. As a result, conventional procurement dominates in the country.
- *Material Contamination* by the waste producer remains a concern. In this context, source segregation is the most significant factor in ensuring proper recycling of CDW, which may contain small amounts of hazardous materials such as solvents and asbestos, causing specific hazards to the environment and hindering the process of recycling [38]. While concrete masonry blocks are the predominant building products that generate CDW, the latter is a heterogeneous mixture of several constituents, including concrete, mortar, and cement. When maintenance or demolition is necessary, it becomes exceedingly challenging to dismantle the structure in its original form, hence impeding its ability to be recycled back to its

initial state. Consequently, CDW is disposed of after the building reaches the end of its lifespan [9].

### 4.3.2 Recycling Enablers

- *National and Regional Legislation* (Table 1), coupled with policies for sustainable infrastructure and development, drive CDW away from landfills. Notable policies include the UAE Vision 2021, the UAE-UN sustainable development goals, the National Sustainable Production and Consumption Plan (2019–2030), the UAE Net Zero 2050, and the UAE Circular Economy Policy. Collectively, they aim to reduce GHG emissions and limit the rise in global temperature to 1.5 °C compared to pre-industrial levels, as well as to facilitate the shift toward a circular economy to attain sustainable resource management and optimize resource utilization. In this context, the participation of the private sector is imperative in advocating for the adoption of more environmentally friendly manufacturing practices and the increased utilization of cleaner production techniques within the industry. Advocate for adopting production and consumption practices that mitigate environmental strain and effectively provide essential human needs [41, 42, 45].
- *On-site Segregation Mandates by Green Building Regulations* have encouraged the 3R principle and the diversion of CWD from landfills. For instance, the Al Safat Green Building Regulation in Dubai requires buildings outside the CBD area a 50% diversion of CDW from landfills (by volume or weight of waste material generated during the construction and/or demolition of buildings) to be recycled or reused [12]. Similarly, the Barjeel Green Building Regulation (Ras Al Khaimah) stipulates the segregation of construction waste to facilitate recycling [35]. In Abu Dhabi, the Estidama Pearl Building Rating System calls for identifying site clearance, demolition, and construction materials and demonstrating that waste materials will be separated into several categories or according to material type with the aim to also achieve a minimum recycling rate of 50% (by weight or volume) (Abu Dhabi Urban Planning Council 2010b)

## 5 Conclusion

The increase in CDW generation presents significant environmental and economic difficulties, necessitating an effective control and management strategy. We examined the current CDW management policies and operational circumstances in the UAE, with emphasis on the 3R (Reduce, Reuse, and Recycle) principle to improve the Circular Economy framework. Recently, the UAE adopted several strategic measures toward sustainable CDW management consistent with the more ambitious objective of attaining net-zero waste by 2050. While relying on recycled CDW aggregates in the construction sector represents a circular framework, the escalating demand for building material highlights the importance of government participation in monitoring and providing incentives for recycling CWD to reduce raw material extraction, along with the efficient management of CDW, mostly by promoting the 3R principle of the Circular Economy. The analysis identified obstacles impeding the effective management of CDW, including the lack of standardized design methodologies, excessive ordering processes, inadequate planning, and a limited understanding of environmental considerations. Reusing CDW is challenged by the collection, sorting, and implementation of standardized procedures with various constraints, including an underdeveloped market and material contamination, hindering the recycling process. Nevertheless, viable opportunities can be considered through implementing BIM, Lean Practices, and sustainability assessment tools. In addition, recycling initiatives are supported by national and regional laws, legislations, and on-site segregation mandates.

The study recommends that it is crucial for the United Arab Emirates (UAE) to prioritize the implementation of efficient and innovative strategies and frameworks in order to enhance circular practices within the construction industry. This involves not just the reduction of waste but also the optimization of resource consumption throughout the entirety of building projects' lifecycle. It is imperative to highlight the significance of the potential knowledge that can be acquired through such attempts, as they have the capacity to provide valuable information and direction for the broad implementation of sustainable CDW management systems. These insights may encompass the identification of optimal methodologies, the evaluation of the economic feasibility of circular strategies, and the comprehension of the environmental advantages associated with reducing the formation of CDW while optimizing its reuse and recycling. The use of circularity principles within the building sector has the potential to yield both environmental and economic advantages, hence fostering the development of a sustainable and resilient built environment.

Future research endeavors will investigate business models that aim to improve the preservation of high residual values of materials within a framework that recognizes the circular nature of CDW management, while avoiding methods that involve the disposal of resources in landfills. In this particular context, it is crucial to involve several stakeholders in the construction sector in order to promote the implementation of waste circularity practices and tackle the prevalent tendencies of neglect and avoidance that are frequently found in building and demolition activities. The efficacy of CDW management is contingent upon the substantiation provided by relevant case studies, which serve as a catalyst for the establishment of a durable and cyclical trajectory toward the future. Additional study can delve into the perspectives of stakeholders on the circular economy, providing recommendations for policy improvement and examining different tactics and models related to the circular economy.

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## References


1. Abdalla SB, Rashid M, Yahia MW, Mushtaha E, Opoku A, Sukkar A, Maksoud A, Hamad R (2023) Comparative analysis of building information modeling (BIM) patterns and trends in the United Arab Emirates (UAE) with developed countries. Buildings, 13(3). https://doi.org/10.3390/buildings13030695
2. Abudhabi Waste Management Company (n.d.) Recycling construction and demolition waste Tadweer. Retrieved 27 Jul 2023, from https://www.tadweer.ae/en/Pages/RecyclingWaste.aspx
3. Ahmed S, Majava J, Aaltonen K (2023) Implementation of circular economy in construction projects: a procurement strategy approach. Constr Innov. https://doi.org/10.1108/ci-12-2022-0327
4. Al-Aomar R (2012) Analysis of lean construction practices at Abu Dhabi construction industry. Lean Construct J. http://creativecommons.org/licenses/by-nc-nd/3.0/page105www.leanconstructionjournal.orgwww.leanconstructionjournal.org
5. Al-Hajj A, Hamani K (2011) Material waste in the UAE construction industry: main causes and minimization practices. Architect Eng Des Manag 7(4):221–235. https://doi.org/10.1080/17452007.2011.594576
6. Al-Hajj, Iskandarani (n.d.) Reducing waste generation on the UAE construction sites
7. Asif M (2016) Growth and sustainability trends in the buildings sector in the GCC region with particular reference to the KSA and UAE. Renew Sustain Energy Rev 55:1267–1273. https://doi.org/10.1016/j.rser.2015.05.042
8. BEEAH Group Sharjah (n.d.) BEEAH recycling. Retrieved 26 Jul 2023, from https://www.beeahgroup.com/services/beeah-recycling/
9. Belpoliti V, Abbas HS, Ali MAA, Al Khulaifi AM (2018) Design from waste: review of the UAE waste management sector and experimentation on recycled materials to support the development of a sustainable and energy-efficient building market. In: 2018 advances in science and engineering technology international conferences, ASET 2018, pp 1–6. https://doi.org/10.1109/ICASET.2018.8376765
10. Bialko M (2023) Ranking factors influencing construction and demolition waste generation in companies of defined size based on surveys: the case from the United Arab Emirates. NanoWorld J 9(2):43–54. https://doi.org/10.17756/nwj.2023-116
11. Cherian A (2008) The construction industry in the perspective of an economic boost of The United Arab Emirates (UAE). Int Res J Eng Technol 9001. www.irjet.net
12. Dubai Municipality (2010) Al Sa'fat—Dubai green building system. https://www.dm.gov.ae/municipality-business/al-safat-dubai-green-building-system/
13. El Haggar S (2010) Sustainable industrial design and waste management: cradle-to-cradle for sustainable development. Academic Press
14. Ellen McArthur Foundation (2021) Building a world free from waste and pollution. https://ellenmacarthurfoundation.org/articles/building-a-world-free-from-waste-and-pollution
15. Faridi AS, El-Sayegh SM (2006) Significant factors causing delay in the UAE construction industry. Constr Manag Econ 24(11):1167–1176. https://doi.org/10.1080/01446190600827033
16. Federal competitiveness and statistics centre, the U (2022) National accounts-quarterly constant GDP. https://fcsc.gov.ae/en-us/Pages/Statistics/Statistics-by-Subject.aspx#/%3Ffolder=Economy/National%20Account/National%20Account&subject=Economy
17. Federal Competitiveness and Centre S (2021) Waste statistics. https://fcsc.gov.ae/en-us/Pages/Statistics/Statistics-by-Subject.aspx
18. Ghisellini P, Cialani C, Ulgiati S (2016) A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J Clean Prod 114:11–32. https://doi.org/10.1016/j.jclepro.2015.09.007
19. Government of Dubai (2022) Dubai integrated waste management strategy 2021–2041
20. Government of United Arab Emirates (1999) Federal Law No. 24 of 1999—Protection and development of the environment

21. Griffiths S, Sovacool BK (2020) Rethinking the future low-carbon city: carbon neutrality, green design, and sustainability tensions in the making of Masdar City. In: Energy research and social science, vol 62. Elsevier Ltd. https://doi.org/10.1016/j.erss.2019.101368
22. Hittini BY, Shibeika AI (2019) Construction waste management in UAE: an exploratory study. WIT Trans Ecol Environ 238:679–686. https://doi.org/10.2495/SC190581
23. Huang B, Wang X, Kua H, Geng Y, Bleischwitz R, Ren J (2018) Construction and demolition waste management in China through the 3R principle. Resour Conserv Recycl 129:36–44. https://doi.org/10.1016/j.resconrec.2017.09.029
24. Kabirifar K, Mojtahedi M, Wang C, Tam VWY (2020) Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: a review. J Clean Prod 263. https://doi.org/10.1016/j.jclepro.2020.121265
25. Lawrence M (2015) Reducing the environmental impact of construction by using renewable materials. J Renew Mater
26. Lu W, Tam VWY (2013) Construction waste management policies and their effectiveness in Hong Kong: a longitudinal review. Renew Sustain Energy Rev 23:214–223. https://doi.org/10.1016/j.rser.2013.03.007
27. Lu W, Yuan H (2011) A framework for understanding waste management studies in construction. Waste Manage 31(6):1252–1260. https://doi.org/10.1016/j.wasman.2011.01.018
28. Mawed M, Nuaimi MSA, Kashawni G (2020) Construction and demolition waste management in the uae: application and obstacles. GEOMATE J18(70):235–245
29. Mawed M, Al Nuaimi MS, Kashawni G (2020). Construction and demolition waste management in the UAE: application and obstacles. Int J GEOMATE 18(70):235–245. https://doi.org/10.21660/2020.70.45101
30. MEED (2020) Removing waste from construction: insights on reducing waste and improving efficiency in construction in the UAE
31. Mehran D (2016) Exploring the adoption of BIM in the UAE construction industry for AEC firms. Procedia Eng 145:1110–1118. https://doi.org/10.1016/j.proeng.2016.04.144
32. Municipality of Dubai (2015) Technical guideline No.5-waste classification
33. Nagapan S, Rahman IA, Asmi A (2011) A review of construction waste cause factors. In: Asian conference on real estate: sustainable growth managing challenges (ACRE), pp 967–987
34. Rahman M, Al-Azm Editors A (n.d.) Gulf studies 8 social change in the gulf region multidisciplinary perspectives
35. Ras Al Khaimah Municipality (2019) Barjeel green building regulation in RasAl Khaimah
36. Sacks R, Eastman C, Lee G, Teicholz P, Handbook BIM (2018) A guide to building information modeling for owners, designers, engineers, contractors, and facility managers. In: Sacks R (eds), vol 688
37. Rogers S (2011) Battling construction waste and winning: lessons from UAE. Proc Instit Civ Eng-Civ Eng 164:41–48
38. Tadweer- Abudhabi Waste Management Company (n.d.) Standard operating procedure for management of construction and demolition waste in Abu Dhabi Emirate
39. Telci IN (2022) United Arab Emirates. Handb Near Middle East States: Geogr-Hist-Cult-Polit-Econ 9:405
40. UAE Ministry of Cabinet Affairs (n.d.) Waste management. Retrieved 11 Aug 2023, from https://u.ae/en/information-and-services/environment-and-energy/waste-management
41. UAE Ministry of Cabinet Affairs (2021) UAE net zero 2050
42. United Arab Emirates Ministry of Cabinet Affairs (2021) UAE circular economy policy
43. United Arab Emirates Ministry of Climate change, and environment (2018) Federal law No. 12 of 2018 issued on 18/12/2018 corresponding to 10 Rabi' Al-Akhir 1440 H. On the integrated waste management
44. United Arab Emirates Ministry of Climate Change and Environment (2019) Ministerial resolution No. 21 of 2019 on recycled aggregates from construction, demolition waste
45. United Arab Emirates Ministry of Climate Change and Environment (2021) The United Arab Emirates general environmental policy 2021

46. Warid O, Hamani K (2003) Lean construction in the UAE: implementation of last planner system®. Lean Construct J 2023. www.leanconstructionjournal.orgLCJReview
47. Waste and Environment 2019 Report (n.d.)
48. Wilson DC (David C., United Nations Environment Programme, and International Solid Waste Association (2015) Global waste management outlook
49. Zhao X, Webber R, Kalutara P, Browne W, Pienaar J (2022) Construction and demolition waste management in Australia: a mini-review. In: Waste management and research, vol 40, no 1. SAGE Publications Ltd, , pp. 34–46. https://doi.org/10.1177/0734242X211029446