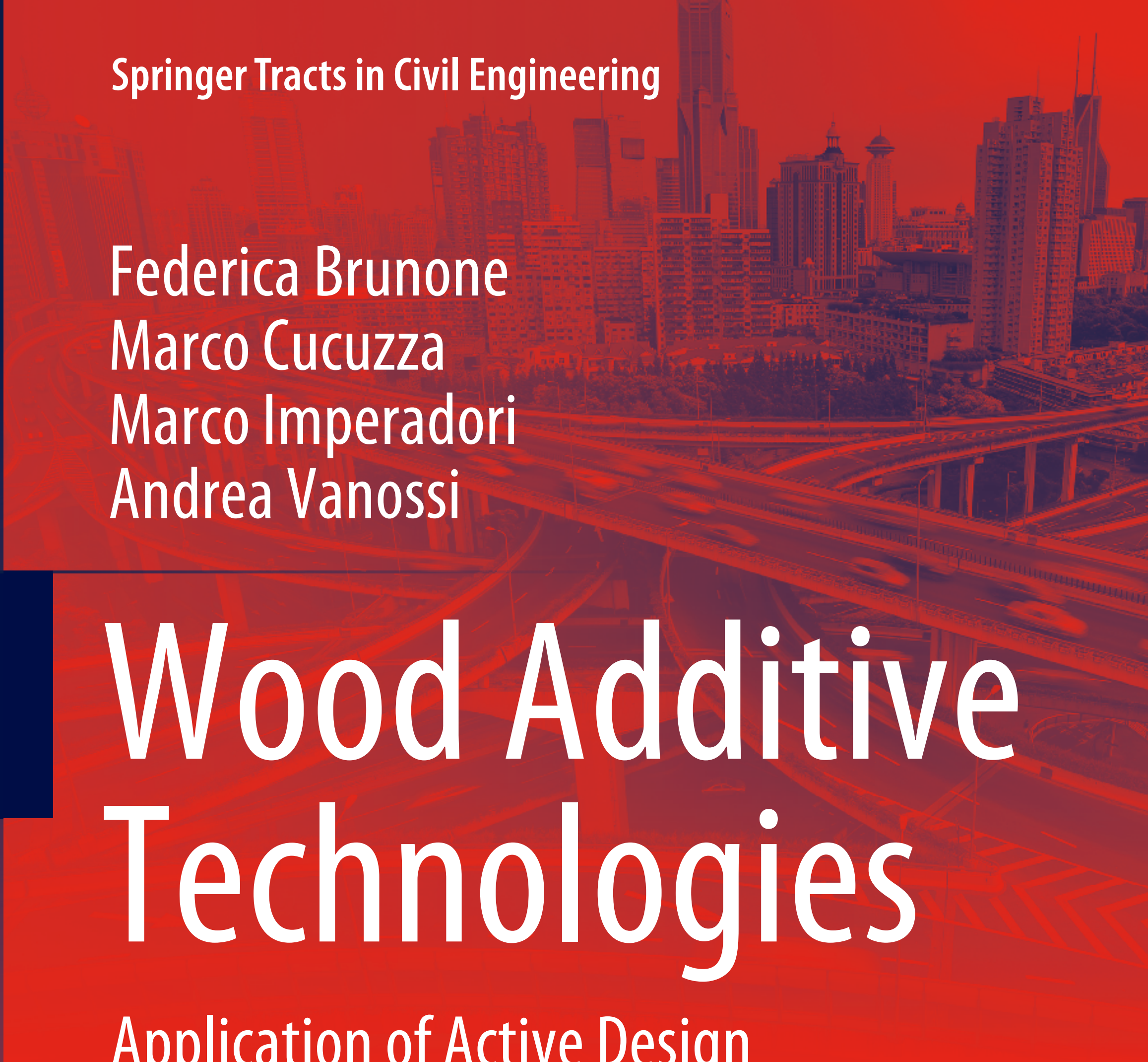

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Wood Additive Technologies

Application of Active Design Optioneering

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Preface

After some years of research, supported by Federlegno Arredo (FLA) and jointly with the Active House Alliance (AH), I decided to propose this book, which mainly results from the Ph.D. studies of Federica Brunone (supported by FLA Scholarship), in order to show a vision towards the metamorphic possibilities embedded in our existing building stock. This has been done using a methodology which is always based on real and built cases, thus a kind of milestone which can help to see the future evolutions on buildings transformation in the framework of AH.

Federica Brunone, currently working for CMB on the UN Headquarters in Geneva, has done a huge job of analysis and collection of information worldwide and then focusing on Italian case studies, which are the expression of one of the most advanced and innovative industries internationally.

Therefore the book shows what means to "implement" the existing stock by using wood-based systems in order to get them to an upgrade level on many different targets. This matches perfectly the actual Next Generation EU and New European Bauhaus targets which are the core of the incoming operative European Agenda.

This is a possible philosophical approach where buildings renovated can be the chance to avoid demolitions and wastes with the multiple "R" strategies; Reuse, Reduce, Recycle, but also Repair, and all this using wood as structure, envelope, claddings, etc., as a core material or even in hybrid situations.

Will this be the goal of a better future for all of us to "act" to avoid global warming after "strike" for climate change, as correctly done by Greta Thunberg?

The case studies, shown in this book, give a clear answer, real, and with different typological/aesthetical outputs which are a possible turning point, a change for our cities on their own existing architectures. All this is also guaranteed by Industry 4.0 in wood construction sector which has innovative processes and lean construction. Thanks to Marco Cucuzza, currently Ph.D. Scholar at Politecnico di Milano, to have studied this topic in the book.

All this cannot be possible today without Building Information Modelling (BIM) and multi-purpose performance analysis. Andrea Vanossi, one of the great experts of BIM in Italy (Ph.D. at Politecnico di Milano and currently BIM Manager at CMB), has curated all the aspects of this procedures applied to Active House approach.

Our cities and our future will be better if we will be able to adapt them (and transform them) with new and multiple values, because they are no more sustainable and the only chance we have is to change them, with new building systems, additive, and new strategies.

"...the only constant is change..."
Heraclitus

Milan, Italy
May 2021

Marco Imperadori

Acknowledgments

This work would have not been possible without the support and the cooperation of researchers, experts, and stakeholders of Federlegno Arredo and its industrial partners—Marlegno, WoodBeton, Galloppini Legnami, XLAM Dolomiti, Rilegno, Rubner—together with all the institutions, partners, and companies—CMB-Cooperativa Muratori e Braccianti di Carpi—at a global scale, which have welcome since the beginning the challenge of this vision: Active House Alliance, VELUX Group, VELUX Italia, Great Gulf Group, and Atsushi Kitagawara Architects Japan.

Finally and foremost, our deep thank goes to the research team at Politecnico di Milano, to the professors, and to past and present colleagues, which have all contributed in different ways to this outcome, whose purpose is to continue to witness the intense work and activities inspired by a vision for the sustainable development of our future.

Contents

About the Authors

Federica Brunone completed M.Sc. in Building Engineering and Architecture and Ph.D. in Building Production at Politecnico di Milano (Italy); Federica Brunone is Construction Engineer, interested in building technologies and innovations, towards the sustainable development for constructions, through BIM-based processes for data-management.

During her graduation, she was a guest researcher in I.LAB, the R&D department of Italcementi Group (Italy), where she developed and tested prototypes of new and experimental cement-based materials. Since 2015, she has taken part in several research activities at VELUXlab laboratory of Politecnico di Milano, in the field of integrated building design, focusing on comfort, environmental impact, and energy saving.

In 2017, she was awarded the first prize at the 3rd ANPE National Conference of Foamed Polyurethane, submitting an innovative project based on energy efficiency. In the same year, she joined the project of Maison Verte by Vanoncini, which was awarded the BIM&DIGITAL AWARD 2017. Between 2017 and 2019—besides the doctoral activities—she took part into several exhibitions and workshops, dealing with temporary design structures, between FARM Cultural Park (Favara), Arte Sella (Trento), La Triennale di Milano (Milano), PIDA (Italy), and Mori Art Museum (Tokyo), as a fellow of Prof. Marco Imperadori's team, and worked on several publications between the academic field and the technical dissemination. Since 2018, she cooperates with the Active House Alliance in the promotion of more sustainable and healthier buildings, as a member of Politecnico di Milano.

Finally, today, Federica Brunone works for CMB—Cooperativa Muratori Braccianti di Carpi, in the field of BIM applications for Asset Information Management (AIM), on the project for the renovation of the United Nations headquarters in Geneva, as Archibus expert and Junior Engineer, while working with the R&D division that follows several European calls for projects on digitalization for constructions.

Marco Cucuzza is Ph.D. Student and Assistant Professor at Politecnico di Milano working on Industry 4.0 and building industrialization, Modern Methods of Construction, and prefabrication. He is an M.Sc. graduate in Building Engineering and Architecture at Politecnico di Milano (Italy) with a thesis about the reuse of the EXPO 2015 Cluster timber structures and a height panoramic tower. Marco Cucuzza is a Construction Engineer who worked for two years as façade designer and 3D models responsible for engineering society. He collaborates with Prof. Imperadori since 2015 working at VeluxLab and as a member of international competitions (such as Lixil architectural competition). He won the Active House contest in 2016 about NZEB (Net Zero Energy Building), ventilation and lighting design.

He appreciates technical detail, innovation, and technology. He is skilled in CAD, BIM, and parametrical design software. He is working on BIM4EEB European Project for retrofitting residential buildings with prefabricated façade panels in a BIM environment. He is Assistant professor at Politecnico di Milano in Technical Architecture, Timber System Design Construction and Sustainability and Design of Complex Construction Sub-Systems. He teaches also at UNISOM - Università degli Studi di Palermo - 2nd level Master in "Materiali e Tecniche innovative per l'edilizia sostenibile". He is the author of scientific articles and he writes also for national magazines.

Marco Imperadori is University Full Professor, Researcher, and Designer, Marco Imperadori, and focuses his interests in high energy-efficient buildings, structure/envelope building systems, and in general sustainability. He is M.Sc. and Ph.D. in Building Engineering, but he likes to act as Architect, as his background results of a mixture of both these complementary aspects of building design. He was Lecturer and Visiting Professor in many universities and institutions worldwide. Since 2015, he is Visiting Professor at USJ Macau (China). He is Author of scientific publications and essays; his work was published in many books and international magazines.

Imperadori founded in 1998, with Valentina Gallotti, Atelier 2, design studio placed in Milan, where he applied experimental and academic research projects in practice, winning national and international awards and prizes. He directed the studio until 2016.

He is currently Rector's Delegate for the Far East representing Politecnico di Milano in Asia. He is a funder, with José Luis de Sales Marques and Carlos Marreiros, of ACE—Architecture Culture Environment seminars in Macau.

He was responsible for Politecnico di Milano in the building Resilience Network Android (EU-LLP). He is a member of Fondazione Pesenti board, Promozione Acciaio sustainability committee, and scientific consultant of FederlegnoArredo; a member of ISTeA (Italian Society of Science, Technology, and Engineering of Architecture) board and former member of CasaClima scientific committee. He represents Politecnico di Milano in the Active House Alliance, being Member of the Scientific Board and President of the Jury for the Active House Awards.

He has been awarded The Beautiful Mind 2016 by FARM Cultural Park and is a member of the Scientific Committee of the School of Architecture for Children SOU in Favara. With Ginette Caron, he was awarded the GRAND PRIX DU DESIGN

2018 in Canada, and in 2019, the project "Il Viaggio della Parola" has been selected for ADI Index, being among the finalist projects for Compasso D'Oro. He is the scientific consultant for Arte Sella in relation to the architectural installations and Honorary Consultant of CAC—Círculo dos Amigos da Cultura de Macau (since 2019).

Andrea Vanossi was born in Erba (Como), Italy, in 1974. He received his Ph.D. degree cum laude in Building Engineering from Politecnico di Milano University in 2014. In the same period of time, he studied BIM at the University of Salford/Manchester, parametric design in the Kengo Kuma Office in Tokyo. He studied architecture in the Glenn Murcutt Class in Australia in 2013. He received his master's science degree in building engineering in 2005 and architecture in 2001. He teaches and works on BIM and parametric design in different universities, Politecnico di Milano, the University Of Saint Joseph in Macao, University of Applied Sciences and Arts of Southern Switzerland. He has been responsible for the digitization of Design and Construction in different design and construction companies. From 2005 to 2006, he has been chef de projet at the Atelier Dubosc&Landowski in Paris. From 2007 to 2010, he held the same role in the engineering company AIACE Ltd. (Professor Ettore Zambelli) in Milan. From 2013, he is BIM Manager of CMB construction company (in charge of the construction of the new Zaha Hadid and Daniel Libeskind Tower in Milan)

Chapter 1
Existing Building Transformation: Current Drivers, Issues, and Possibilities

Abstract Constructions account for a huge amount of energy and resources consumptions, affecting our indoor and outdoor living environment with pollutant emissions, for our planet and ourselves. Besides the climate change, the constant development of urban areas leads to an increasing demand for building spaces (most of all, with residential functions), and, therefore, to the urban densification phenomenon. All those different needs require to be addressed by a set of integrated and valuable design strategies for the sustainable transformation—versus demolition—of the built environment, by combining the energy retrofit of existing buildings and the definition of newer and healthier constructions, with the choice of the most proper technologies and materials to interact with existing structures and envelopes. The chapter introduces the concept of additive building transformation and proposes a different taxonomic approach to the construction layering, foreseeing a new possible paradigm of action towards a sustainable "palinsesto".

1.1 Additive Strategies for the Transformation of the Existing Building Stock

Demolition or "evolution" of existing stock? This may seem a question for Shakespeare but it is the real, and actual, question mark that we can approach with clearly different strategies. The first means that we can for sure re-build with new and more efficient technologies but we will have to get rid of the waste and not always it is allowed (in heritage and listed cities, especially in Italy, impossible). The second is well known in historical cities which have always "evoluted" from their previous physical essence into something new by "addictions" and transformations (of surfaces or volumes).

The insights of the problem statement have enhanced the need to challenge the future development of the built environment, to activate a virtuous effect of circular economy (Fig. 1.1).

This chapter is authored by Marco Imperadori.

Palimpsest

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Fig. 1.1 Green solution house lateral extension by 3XN-GXN architects (Ph. Adam Mørk)

The minimization of the environmental impact, in terms of land occupation, energy use, and GHG emissions, and the improvement of the quality of indoor conditions—comfort, health, and wellbeing—are, indeed, new and additive motions to the already known demands of urban regeneration and densification, spatial re-functioning, architectural renewal, and structural retrofit. In order to reply to this variety of needs, with multiple levels of interpretation, the choice to act on the existing built environment seems to be the most logical (and almost unique) solution, in order to improve its overall quality and performances, as boosted at all levels of the decision-making chain [1–4].

The vision towards the sustainable management and development of the built environment, indeed, takes form within the multi-purposes improvement and transformation of existing buildings, as additive solutions for their spatial and functional integration. Addition—and/or (partial) substitution—has an inner positive approach, with infinite potentials for continuous regeneration. On the other side, the idea of demolition for new construction—with higher costs in terms of energy and environmental impact—drives instead towards an unsustainable direction [5].

The additive strategies are, actually, spontaneous mechanisms of Nature, such as the gradual and continuous layering of trees' growth-rings or the infinite expansion of the coral reef (Fig. 1.2).

From these spontaneous mechanisms of the natural world, several applications testify the success of the additive approach. The "talea" (scion) technique in

Fig. 1.2 The Poorters van Montfort vertical extension (Ph. Adam Mørk)

gardening is, exactly, a graft towards a new life, as a starting point for new possibilities. The same faith and hope have moved other sciences towards this direction, with, e.g., the transplant and prosthetics techniques of Medicine, and fields such as sports competitions, where these techniques have given power and regained possibilities to extraordinary champions. Or else, in the IT sector, the continuous development of new and multiple applications adds functions and new operations to existing devices.

Going back to the building sector, the concept could be translated into the additive strategy of construction layering, which is not an uncharted approach, but the leading principle of the historical development of our cities and buildings. This strategy has a clear target: to enhance the performances of the existing as a multipurpose approach for structural, physical, durability and aesthetical issues.

1.2 Acting on the Built Environment

Within an autogenous process, cities have become entities under a constant movement of changes, continuously replacing, adding, and overlapping functions, towards the densification of their forms. In this regard, the Marcello Theater in Rome (which later became Palazzo Orsini with the additive design of Antonio da Sangallo), the amphitheaters of Pollenzo and Lucca (actually inhabitated and which became a square), Ponte Vecchio in Florence (with its additions of workshops), the cathedral of Syracuse, and many more represent all the historical traces of the evolutionary essence of the existing building stock.

Similar examples can be tracked also in our times, among the literature review of new urban and architectural phenomena: urban regeneration, parasite, and ready-made architecture are widespread themes that seek to reply the need to interact with an ever-growing built environment [6]. High-density urban systems are an example of the social, economical, and political changes that are constantly outlining a range of functional and spatial needs. In these realities the growing housing demand and the high costs of lands have led to new forms of architecture: in Caracas the ready-made operations on existing constructions has transformed a stadium into a residential block [6]; in Tokyo, the combination of those drivers with the local culture has generated the phenomena of capsule hotels, till the deviation of the additional small spaces for shared housing of the co-dividuality experience [7].

These phenomena come up beside the technological, energetic, and environmental evaluation of the existing buildings, due to the imminent issues of oldness, conservation, and compliance with the actual high-performance standards.

In addition, the recent trends of the real estate market testify that 79% of the AEC sector production involves renovation and renewal projects on existing buildings [8], outlining a never-ending direction (Fig. 1.3).

Fig. 1.3 Private residence in Pisogne (BR) vertical extension. *Source* WoodBeton

1.2.1 A Complex Framework: Domain, Standards, and Virtuous Examples

Many of the examples quoted before are about historical/monumental value but it is clear that the process of transformation instead of demolition has occurred also to many simple buildings due to their structural solidity which allowed to add instead of destroy.

The defining framework of the architectural and technological strategies of the intervention on the built environment is wide, and a correct and complete analysis needs to take into account all the items involved.

At first, the domain of research has to be set. The environmental analysis of the major European researcher centers [9, 10] and the statistical surveys on the Italian territory [8, 9] have progressively enhanced the importance to focus also on that portion of the built environment populated by the so-called "common" buildings, without any specific and/or acknowledged architectural or cultural value (Fig. 1.4). In fact, only by referring to the Italian context—which is one of the world's most culturally enriched—just one hundred thousand over a population of 14 million buildings are considered with a particular value [12].

Towards this direction, the legislative organisms have started to promote several redevelopment actions focused on existing buildings, both with an indirect approach through the limitations on the energy and soil consumptions [11, 13] and directly

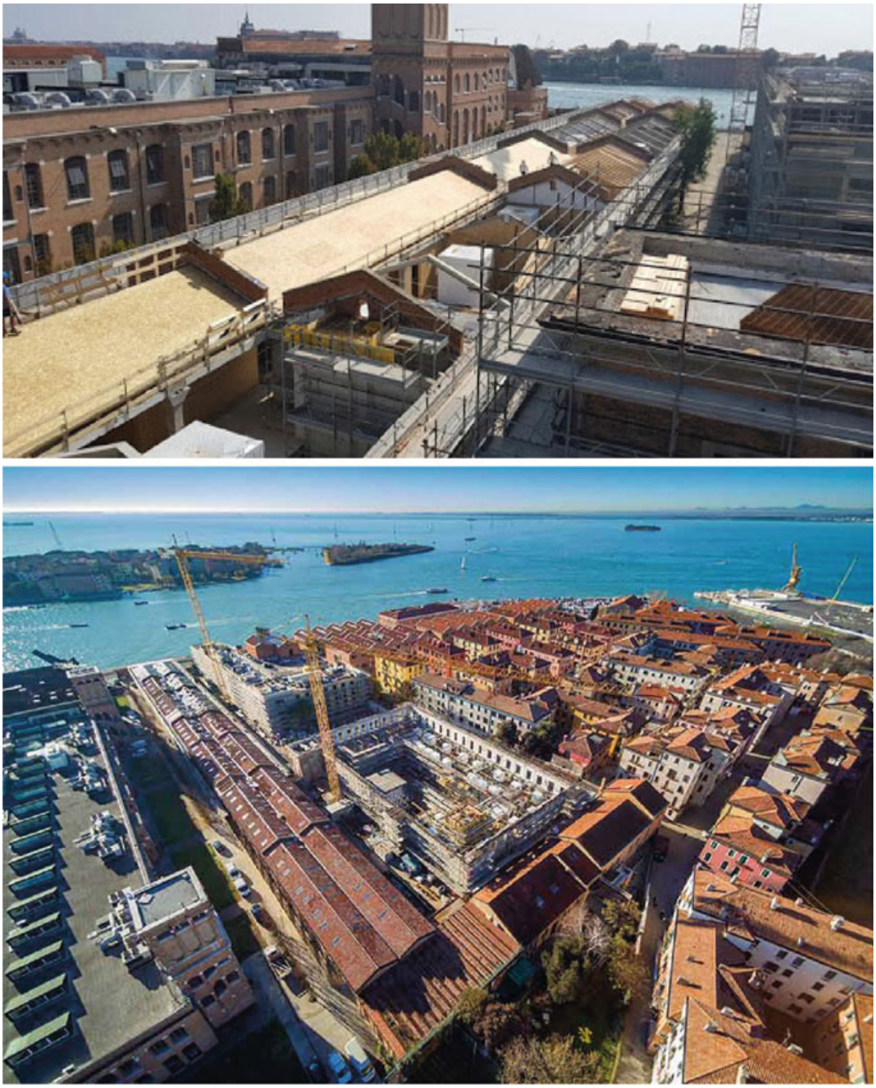

Fig. 1.4 Santa Marta students residences in Venice (VE): the cube and the longer extensions; building Above + Inside + Under. *Source* CMB—Cooperativa Muratori e Braccianti di Carpi

through national, regional, and local incentives to promote existing buildings renovation and expansion. Among the Italian examples of these approaches, the urban and building renewal policies of the so-called "Piano Casa" (Housing plan) has defined a set of legislative measures and economic subsidies aimed at the simplification of the procedures for additive constructions, mainly focused on the residential sector. As a part of this experience, since 2006, e.g., the so-called "Bonus cubature" project of the Autonomous Province of Bolzano has promoted the energy upgrading of the local existing building stock, by allowing a further addition of 20% of volume over the limit prescribed by the urban standards in face of a corresponding upgrade of the energy profile for the existing building, In particular, the requirement was to reach the appositely defined standards of CasaClima R protocol [14]. More recently, another example of the translation of European directives into practical local policies resulted from the joined interpretation of the Regional Law 7/2017 and the “Tourism and Attraction Notice” in Lombardy [15]: the first document allows recovering part of the new building area within the local planning tool limits; the second provides an economic facility for renovation works (Fig. 1.5).

However, if the regulations scenario is bringing the actors of the AEC sector to undertake paths of transformations of the built environment through additive solutions, the binding technical standards of construction are also moving towards increasingly restrictive criteria. The revised text of the NTC 2016 [16], indeed, imposes a new limit for the structural validation of works that deal with the addition of extra-loads to the existing structure. In these cases, the rule requires a structural adjustment both for volumetric expansion works and for loads increased more than 10%.

The fields of potential work, therefore, range from urban and architectural renewal (in its spatial, aesthetic, and functional dimensions) to the energy-technological

Fig. 1.5 Verdello (BG) vertical elevation. *Source* Marlegno

upgrading, to seismic adaptation and post-disaster reconstruction, with an important focus on structural aspects.

1.3 A Taxonomic Approach on Building Transformation and the Definition of "BAEIOU" Strategies

The technical literature generally distinguishes the retrofit building strategies, according to various taxonomic analyses that follow different criteria, mainly intended to describe the interaction between the existing item and the transformation action, as the result of a designed strategy driven by specific requirements, and acknowledged by following the same perspective. Therefore, architectural renovations are read in the context of refurbishment, technological improvements are encoded only into the retrofit of building performances, ect.

On a higher level of review, the most common interpretation divides the transformation practices into substitution and/or modification, and addition through two-dimensional layering or volumetric expansion [17]. The latter term could be conceived both as the overlapping of architectural elements to the existing ones, as well as the insertion and/or integration [18].

The construction layering is, therefore, represented by the juxtaposition of layers as bi-dimensional stratus, or by the volume addition, as a three-dimensional extension, where the construction of new spaces starts from the upgrade of the existing ones, as a further variation of the additive transformation (Fig. 1.6).

1.3.1 Additional Strategies Taxionomies: Top-Down and Bottom-Up Approaches

Further researches that in recent years have been interested in these strategies follow two systemic methodologies in order to analyze the heritage and rearrange the information: the top-down and the bottom-up approach. The first proposes an aggregate description, starting from the statistical observation of reality, while the second

Fig. 1.6 BAEIOU strategies of retrofit on existing buildings. *Source* Author's proceeding

analyzes the characteristics of a set of samples, to extrapolate valuable results and describe the phenomena [18].

In detail, the analyzed studies have identified the reading criteria, starting from the investigation of real case studies: re-elaboration and systematization of the experiences spread-up in the building market define the codification criteria, as urban, architectural or technological point of view (bottom-up approach).

The first investigated aspect concerns the architectural dialogue between pre-existence and addition: from the exhaustive debates of restoration theories, it is possible to outline a ranking of re-modelling, according to progressive stages of intensity: erasure, mimesis, integration, and contrast [17]. At this juncture, comments on parasite architectures are assimilated. Despite the term evokes a negative judgment, recent studies have shown that this type of architectural approach, which was born as a spontaneous phenomenon and is currently an increasingly widespread practice, could be considered as a shared pattern of urban growth, according to a recycling view of urban realities [6]. From the urban point of view, indeed, the additive construction practices often coincide with the phenomenon of urban densification. Recent researches propose a qualitative assessment of existing case studies, in terms of perceivable urban influence, through the system repeatability and the energy efficiency criteria. On the other hand, the technological literature identifies the stratified dry solutions as the response to the need for building renewal, especially about the performance retrofit of the existing constructions (Fig. 1.7). Thermal and acoustic

Fig. 1.7 Cameri (NO) vertical extension. *Source* Galloppini Legnami

behaviour and fire resistance are all envelope features, which have to be compared with additive strategies.

1.3.2 A Different Taxonomic Approach: Building Above, bEside, Inside, Outside, and Under (BAEIOU)

The technical proposed taxonomy emphasizes the possible interactions between new interventions and existing building, structuring the possible retrofit solutions into in-contact systems, dynamic systems, and active systems [5] (Fig. 1.8).

The proposed strategies classification parameter is spatial—the addition by two-dimensional layering differs from the volumetric addition, in the three space directions—and identify five additive practices:

- Building ABOVE (BA), volumetric extensions, in a vertical direction,
- Building BESIDE (BE), volumetric extensions, in a horizontal direction,
- Building INSIDE (BI), two-dimensional layering, toward an inner direction (inveloping),
- Building OUTSIDE (BO) two-dimensional stratification, toward an outer direction (enveloping),
- Building UNDER (BU), volumetric filling.

The analysis draws an identifying profile of the additive strategies, which highlights:

- initial and boundaries conditions which cause the need for intervention;
- constraints due to interferences with pre-existence and the solutions adopted for the realization of the works;
- the achieved results over the satisfaction of the initial needs;
- diffusion and potential interest in different market shares, in relation to the application contexts (suburbs, urban centre), functional areas (residential, industrial, school, receptive), building typologies (multi-storey building, single house, ruin), with a special focus on wood-based technologies applications.

In conclusion, this book, and mainly the researches of Federica Brunone and finally the help of Marco Cucuzza in their Phd path, show the great potential actually present in the existing stock (90% of it will still be in function in 2050 as estimated) and its transformation. Active House strategies, multicriteria approach, Building Information Modelling and Lean construction (Wood and CNC processing is normal) are currently already shaping our cities into something new and more appropriate.

The Industry 4.0 of Wood Technologies is very active and propositive (especially in Italy) with real solutions (visible in this book) which will solve many problems of obsolescence of actual built stock to make it ready for the actual challenges of Climate change, Sustainability and therefore totally responding to UN—SDG (Sustainable Development Goals) which are the core of our future cities and societies. The actual

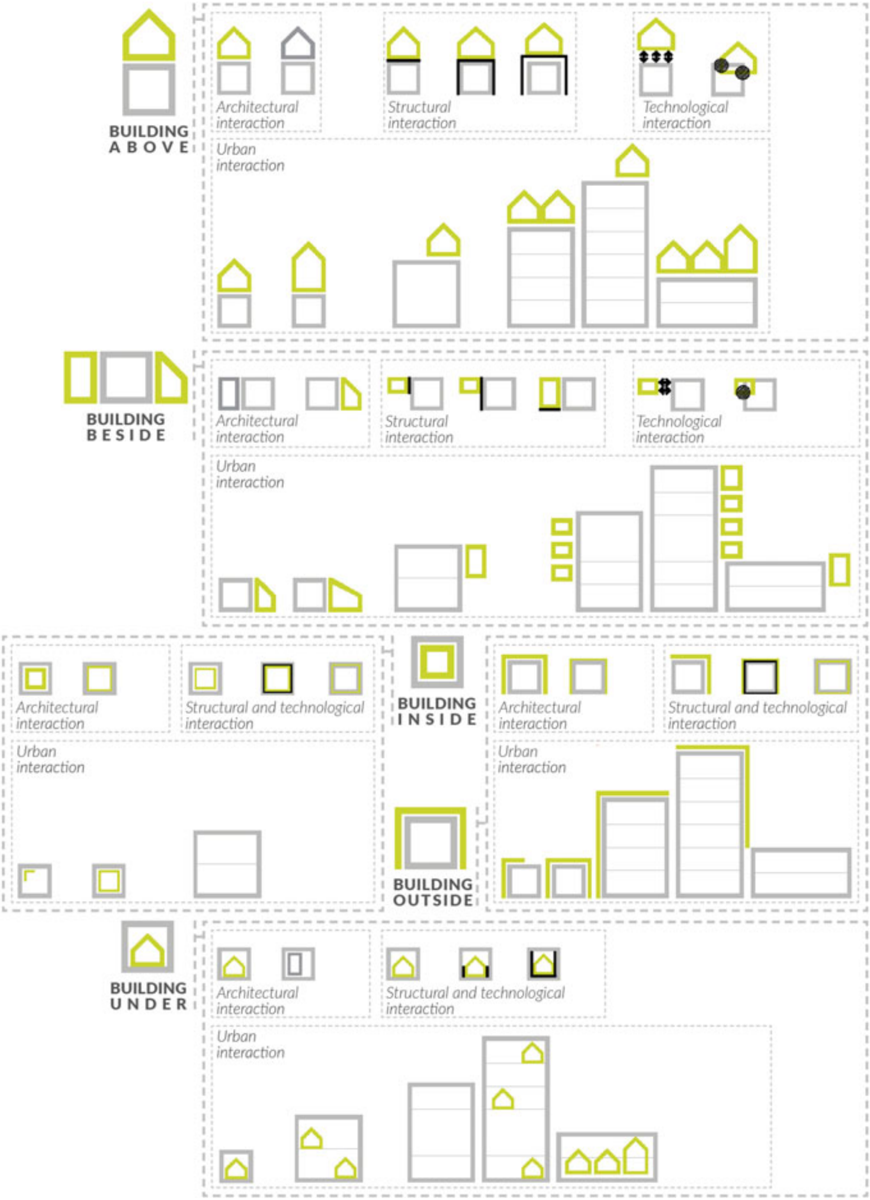

Fig. 1.8 BAEIOU strategies: the scheme reports the taxonomy for the retrofit design strategies of the Building Above, Beside, Inside, Outside, Under analyses. *Source* Author's elaboration

2020/2021 pandemic and the incoming Next Generation EU and New European Bauhaus (in Italy also connected to the so called 110% SuperBonus which has boosted the construction industry even in a critical time) will be for sure the leverage tools for the next decade in order to achieve better buildings in terms of Comfort, Energy and Environmental impact.

References

1. UN (United Nations) (2015) The 2030 agenda for sustainable development, A/ RES/70/1, vol 16301
2. European Parliament (2018) Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/ EU on energy efficiency. Official Journal of the European Union, 2018(May 2010), pp 75–91. Retrieved online from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN
3. European Commission (2017) Next-generation of energy performance assessment and certification. Retrieved 1 July 2019, from https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-sc3-ee-5–2018–2019–2020
4. Agenzia delle Entrate (2019) Le agevolazioni fiscali per il risparmio energetico. Retrieved from https://www.agenziaentrate.gov.it/
5. Imperadori M (2001) Costruire sul costruito Tecnologie leggere nel recupero edilizio. In: Carocci E (ed). Roma
6. Marini S (2015) Architettura Parassita Strategie di reciclaggio per la città. In: Quodli- bet (ed). Terza ediz
7. Liotta S-J A (2018) Temporary architecture for sharing. AGATHÒN 04 Int J Archit, Art and Des 29–36
8. Symbola-Cresme (2017) Una nuova edilizia contro la crisi. Retrieved from http://www.symbola.net/html/press/pressrelease/Nuo-vaedilizia
9. United Nations Environment Programmes Sustainable Building and Climate Initiative (UNEP-SBCI). Last consulted: December 2016. URL http://www.unep.org/sbci/AboutSBCI/Background.asp
10. Eurostat database of the statistical office of the European Union. Available at http://ec.europa.eu/eurostat/data/database
11. ISPRA—Istituto Superiore per la Protezione e la Ricerca Ambientale (2014) Il consumo di suolo in Italia. Roma. Retrieved from http://www.isprambiente.gov.it/files/pubblicazioni/rapporti/Rapporto_Consumo_di_Suoo_in_Italia_2014.pdf
12. ISTAT Database of the Italian statistical in- stitute. Available at https://www.istat.it/en/analysis-and-products/a-z-statistics
13. European Parliament (2010) Directive 2010/31/EUof the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (EPBD). Official J Eur Union 13–35. Retrieved from https://eur-lex.europa.u/legal-ontent/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN
14. Verones S, Rinaldi A, Rebecchi S (2014) Retrofit e rigenerazione urbana Il progetto EPOurban. In: Edizioni E (ed)
15. Regional Law 10 marzo 2017—n. 7 "Re- cupero dei vani e locali seminterrati esis- tenti". BURL, Supplemento n. 11 del 13 marzo 2017. http://mailing.ordinearchitetticomo.it/mailing-manager/files/BURL_%20 SUP11_13–03–2017.pdf
16. Ministero delle Infrastrutture e dei Trasporti (2017) Costruzioni esistenti. In NTC 2016—Norme tecniche per le Costruzioni 2016

17. Zambelli E (2004) Ristrutturazione e trasformazione del costruito Tecnologie per la rifunzionalizzazione e la riorganizzazione architettonica degli spazi. (Il Sole 24 Ore, ed), Milano
18. Mastrucci A, Marvuglia A, Leopold U, Benetto E (2017) Life cycle assessment of building stocks from urban to transnational scales: a review. Renew Sustain Energy Rev 74:316–332. https://doi.org/10.1016/j.rser.2017.02.060

Chapter 2
A New Taxonomic Perspective on Wood-Based Technologies for the Transformation of the AEC Sector

Abstract The transformation of the built environment requests specific considerations in the definition of construction strategies. Under the technological perspective, the major requirements are lightness and efficiency, intended as the minimization of the impact over the existing building, along with the maximization of the building performances and overall value. To find suitable solutions, this chapter investigates wood as a construction material. At first, it defines the domain of the timber construction industry, by addressing the state of the art on wood innovations, between processes and products, according to the literature review and the outcomes from the interviews with international stakeholders. Afterward, it describes the taxonomic approach as a method to characterize building systems, proposing a revision of the current classification approach and the introduction of a creative taxonomy of timber-based construction systems. Finally, this taxonomy review is used to structure the final case-history survey upon timber construction strategies for building transformation, whose methodology and results are presented accordingly.

Keywords Wood-based construction materials · Wood-based construction technologies · Timber construction systems taxonomy · Wood innovation

2.1 Wood as a Construction Material: Innovations Within Processes and Products

Wood is one of the oldest materials for constructions [1, 2]. Its availability and the ease of processing in manufacturing have allowed over time the diffusion of a multitude of varied construction techniques on a global scale: from the northern European *Blockbau* and *Fachwerkbau*—respectively the fathers of the Canadian log system and the American Balloon Frame—to the Japanese joinery crafts, which—e.g.—still marvelously define the solid structure of the Horyu-Ji five-stories pagoda, the oldest wooden building of the world [3].

Today, the continuous innovations of the research in material sciences [4, 5], prefabricated products and technological solutions, and automated production

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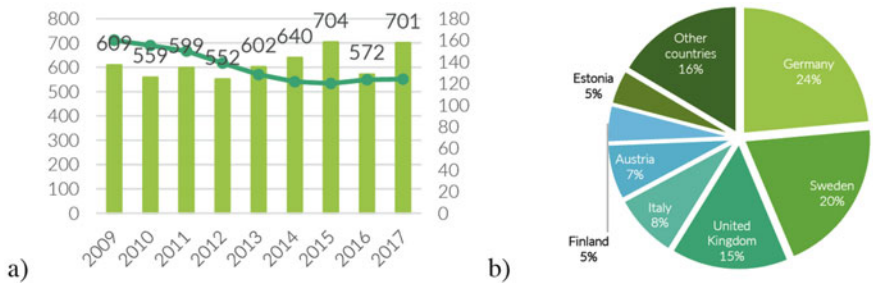

Fig. 2.1 **a** Historical thread of the Italian building production: comparison between the investments in the construction sector (dark line) and the annual production trends of timber buildings (bar chart); values in millions [€]. **b** Timber building production by 2017. *Source* Author's elaboration based on statistical data by Prodcom, Ance, Eurostat, and Istat, as retrieved from [7, 8]

processes [6] let the wood construction industry experience a strong growth. It is attested by the values of the market trends: Italian data showed a production stability until 2014 despite the overall contraction of the construction sector [7], and a progressive increasing from 2016 accordingly to the economic recovery of the market [8] (Fig. 1a). On a European level (Fig. 1b), timber buildings registered + 5.9% of production [8] by 2017, following the positive trends of the recent past years.

Timber is fascinating the decision-makers of the building process, especially since sustainability has become one of the major drivers crossing multiple aspects of our lives: wood as a construction material has been already attested to have a positive impact on the environment, thanks to the low embodied energy and carbon storage (Table 2.1) [9, 10], and considering the increasing adoption of the certification systems that attest a sustainable forestry management [11–13].

Wood has just become once again a total material for constructions, with applications in structures and envelopes, even in those areas where other materials had prevailed since the end of the XVIII century.

2.1.1 *Wood Dimensions*

Wood a hard substance that forms the branches and trunks of trees and can be used as a building material [14].

Timber trees that are grown so that the wood from them can be used for building; wood used for building [15]; uncut trees or logs that are suitable for conversion to lumber; wood sawn into balks, battens, boards, etc., suitable for use in carpentry, joinery and general construction [16].

Lumber Timber sawed or split in the forms of beams, boards, joists, planks, etc. [17].

Table 2.1 Embodied energy and carbon storage inventory data of the most common construction materials.

Construction material	Embodied energy (MJ/kg)	Carbon storage (kgC/kg)
Steel	24.40	0.482
Concrete	0.95	0.035
Portland cement	4.60	0.226
Bricks	3.00	0.060
Timber	8.50	0.125
Glue-laminated timber	12.00	–
Hardboard	16.00	0.234
MDF	11.00	0.161
Particleboards	9.50	0.139
Plywood	15.00	0.221
Sawn hardwood	7.80	0.128
Sawn softwood	7.40	0.123
Veneer particleboard	23.00	0.338

Source Data extracted from [9]

"Wood", "timber", and "lumber" are the first three keywords to enter the multi-dimensional world of this material, even if just limited to construction applications. Only by their definitions, these terms introduce already a set of other tags, that go beyond a pure semantic matter. Wood, per se or within the expressions "wooden buildings", "wood-based technologies", "timber products", etc., actually implies a complexity that is identifiable already in the material essence.

2.1.1.1 Wood Materials

Despite a similar constitutive structure which outlines the main physical and mechanical features of this material (both already widely analyzed in the technical literature [2, 18–21]), wood is represented by a diversified spectrum of different species, commonly divided into soft (gymnosperm) and hard (angiosperm and monocotyledons) wood, whose specific characteristics and properties define their applications within the building sector, by addressing specific requirements. Different species mean, indeed, different features in terms of natural durability and treatability, such as gluing and manufacturing and implying, therefore, different uses.

Cedar, Cypress, Douglas-fir, Inoki, Larch, Pine, Spruce, Sugi, and Yew; Birch, Cherry, Chestnut, Iroko, Locust, Mahogany Maple, Oak, Teak, Walnut, and Bamboo are only a few of the numerous existing essences used nowadays in the building sector, from the most common practices in constructions and furniture, to the advanced

Fig. 2.2 Wood species for construction uses. *Source* Author's elaboration on illustrations retrieved from [19]

experimentations of design, technology, and research. In particular, for structural and construction purposes [19], the main wood species (Fig. 2.2) are:

- Spruce (density [u = 15%] = 450 –470 kg/m^3), mainly applied as solid wood in framed structures or within glued-laminated products for big slender constructions or massive planar products;
- Pine (density [u = 15%] = 520 kg/m^3), used for structural elements, carpentry, and derived products (engineered timber);
- Larch (density [u = 15%] = 600 kg/m^3), thanks to its natural durability and varying texture that progressively change color according to the outdoor exposition, is used frequently for finishing layers of structural elements as well as envelopes;
- Douglas-fir (density [u = 15%] = 510 kg/m^3), for indoor and outdoor finishing and fixtures;
- Beech (density [u = 15%] = 720 kg/m^3), mainly used for engineered timber (layered or cross-layered of veneers, strands, or fibers);
- Oak or Durmast (density [u = 15%] = 690 kg/m^3), used for structural elements installed on-site with high levels of exposition class for durability.
- Ash (density [u = 15%] = 690 kg/m^3), Locus (density [u = 15%] = 770 kg/m^3), and Chestnut (density [u = 15%] = 630 kg/m^3), used for indoor or outdoor finishing layers, thanks to its high natural durability and resistance to fungal attacks.

2.1.1.2 Wood Innovation

Besides a complexity of multiple essences within the same construction material, another taxonomic dimension derives from the innovation of the industrial manufacturing processes and the resulting definition of multiple derived materials and products [22–25]—such as the engineered or the recycled wood—defined to overcome most of the limitations of traditional solid wood: bound dimensions, defects, sensitivity to biologic attacks, anisotropic mechanical behavior, and waste management.

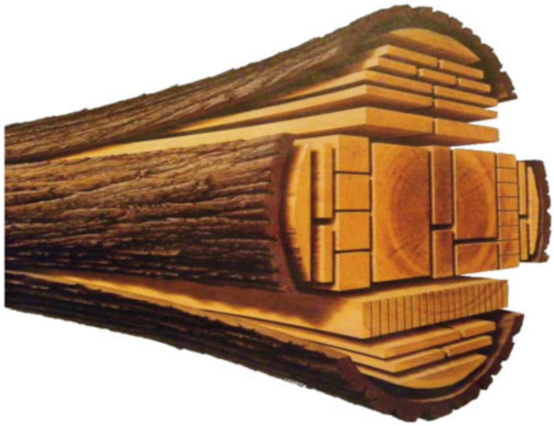

Fig. 2.3 The processing of logs into sawn timber, whose elements present different sections to optimize the use of wood and minimize wasting. *Source* Author's elaboration from [26]

From the '70s, indeed, the introduction of the finger-joints [22] realized through CNC—based machines [24] has given the possibility to work with different sizes of timber sections derived from the parceling of the trunk (Fig. 2.3), by connecting them to recreate bigger and/or stratified elements.

This has allowed the innovation of the industrial production in multiple directions:

- The log parceling optimizes material use, by processing also those marginal parts of the trunk previously discharged because of quality lack;
- The following selection of wood elements allows both avoiding macroscopic defects by the cut-off of localized faulty parts, and choosing different essence to optimize mechanical and/or durability properties;
- The connection of elements lets to overcome the geometrical limitations of solid wood, due to the restricted dimensions of logs;
- And, finally, the definition of a wide range of products which populate the construction market nowadays (Fig. 2.4).

Indeed, the finger-joint has been applied, at first, to solid square wood, planned to size, dried, and recombined with similar pieces, in order to obtain the so-called KVH (*KonstructionsVollHolz*) or Finger-jointed solid timber, long beams with standardized sections [29].

Furthermore, the use of finger-joints together with the lamination and gluing processes has led to the production of glue-laminated timber elements, winning the challenge of building big-spans structures with wood-based products, still unfeasible with traditional solid wood beams. Moreover, by curving the laminates before the layering and gluing processes, almost all the geometrical boundaries of wood have been removed and the material has gained the possibility to be applied for the shapes of contemporary architectures, previously reserved only to concrete (by forms pouring) or steel (by forms extrusion) [24]. Glue-laminated timber is actually acknowledged as a specific wood-based construction material, with its own physical and mechanical properties [30].

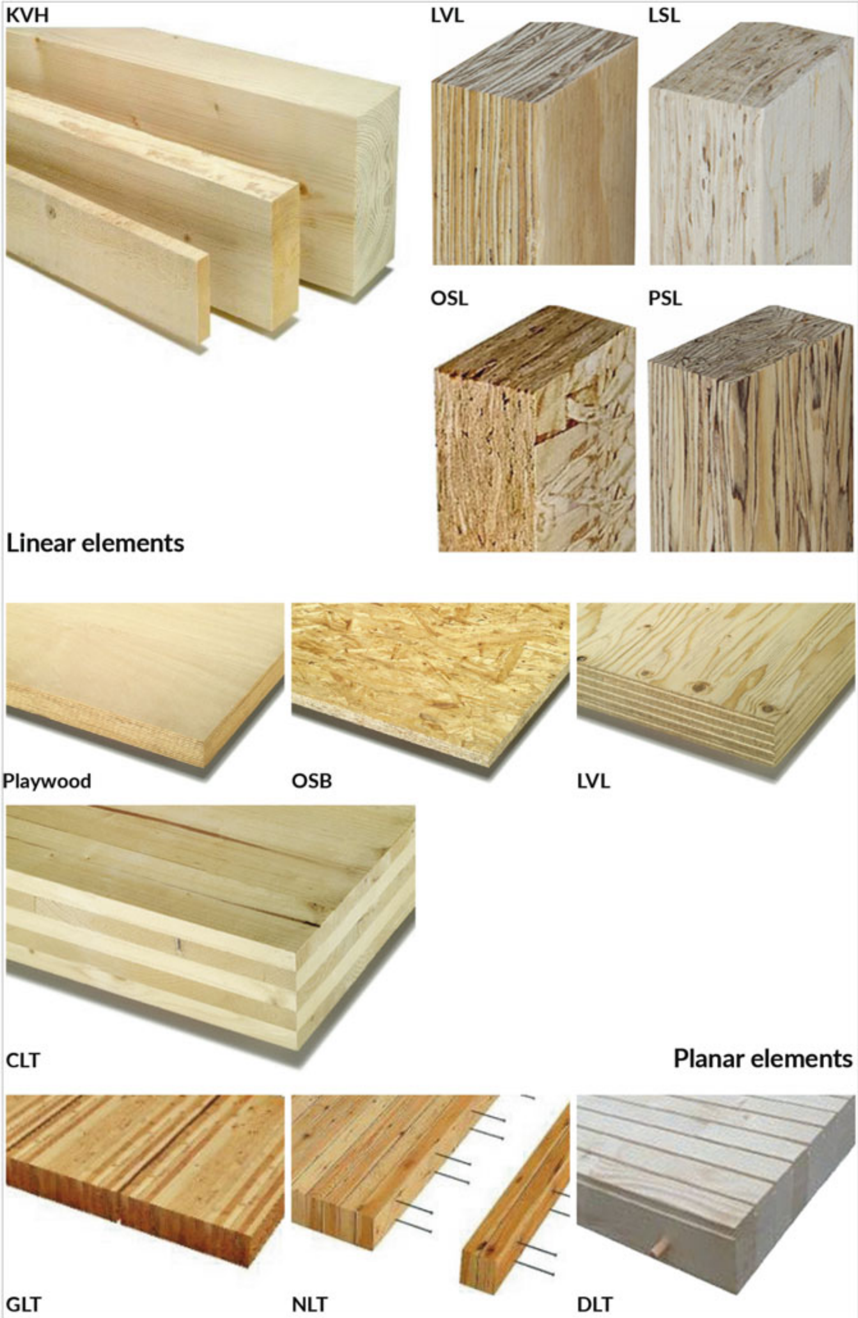

Fig. 2.4 Wood products. *Source* Author's elaboration on illustrations retrieved from [27, 28]

More recently, the sharpening of these laminating and gluing processes has found further improvements and applications within the LVL (Laminated Veneer Lumber) processes [31], whose outcomes are mainly beams and structural panels of layered and glued thin sheets of lumber. Very similar to this new wood-based material, the LSL (Laminated Strand Lumber), OSL (Oriented Strand Lumber), and PSL (Parallel Strand Lumber) are made from flaked wood strands that have a length-to-thickness ratio of approximately 75–150, and—combined with an adhesive—are oriented and formed into a large mat or billet and pressed.

By following the history of innovation, it's easy to notice how the same production processes have been adopted to overcome the limitations of plain solid wood and define, as well, the wide panorama of the timber-based panels.

As per the veneers-based and wood chips-based beams, the production of OSB (Oriented Strands Board), LVL panels, and plywood panels proposes the use of waste particles from the prime sawing process, then glued and pressed. Besides the optimization of the productive cycle and the recycling aim, the adoption of stratified and glued thinner layer helps, indeed, to overcome the dimensional limitation of solid wood to reach considerable spans of the planar dimension only by prime sawing processes.

The main difference between OSB and plywood panels lies in the size of the primary elements that enter the second step of the production chain, and—above all—in the mutual position of single layers. The crosswise joining of plywood allows, indeed, to overcome the issues of the typical anisotropic mechanical behavior of wood, defining a more homogeneous load-bearing material.

This last consideration was the spark to take another innovative leap in the thread of the timber industry: the definition of CLT (Cross Laminated Timber) panels (Fig. 2.4). The CLT consists of (at least) three layers of softwood-glued planks, where the direction of the grain in adjacent layers is perpendicular to each other, and the planks may be joined by edge-gluing and finger-jointed in the longitudinal direction. CLT represents, therefore, the gradual transition from multi-layered solid wood panels and/or laminates-bases panels (LVL or plywood), as presenting a larger dimension of individual elements [32]. Moreover, the layering allows to detail the functional performance of each stratum, and thereof chose the best wood essence that could satisfy the specific local requirement.

Besides the CLT, other production processes could define massive, load-bearing, timber panels, such as the GLT (Glue-Laminated Timber), based on glue connection similar to glulam and/or LVL, where layers are oriented primarily in the same direction. A mechanical connection system, instead, is used for NLT (Nailed Laminated Timber), with metal-based connectors, and DLT (Dowel Laminated Timber), with inner wood joinery (Fig. 2.4).

In particular, these two last solutions aim to cut off the negative environmental impact of the high glue-content of CLT and GLT panels. Nevertheless, the CLT design and production chain could be, sometimes, smother than the NLT or DLT ones. The latter, e.g., have to include the specific design of the connections' placement, as related to the eventual voids defined for the specific project.

In conclusion, processes and products' innovation, in a virtuous mechanism of continuous implementation, has led to a first taxonomy of elements, which renews the collective imagination of *wood*: from a rough material linked to traditional constructions and practices, to a modern high-tech product [25], always suitable for further implementations.

2.1.1.3 From Products to Systems

The assembly of different products allows the definition of components and technological solutions for the envelope, where timber-based materials could be used for both the structural elements, insulations (fiber panels, e.g.), and indoor/outdoor cladding layers.

This part of the design process is linked to the definition of those features, typical of the building components, able to meet the needs required to the envelope: thermal insulation, airtightness, durability, acoustics, etc [27, 33].

In particular, timber-based constructions belong to dry, layered, and light technological systems, which are able to specifically satisfy each requirement by the layering of the most proper materials, properly analyzed within their features as single elements and part of a more complex solution [28].

Regarding the thermal properties, wood-based insulating materials, such as cork or wood-fiber panels, are capable of good levels of both thermal transmittance, and thermal capacity, thanks to the high density (Table 2.2).

On the wider and more complex perspective of technological solutions, the framed walls (Fig. 5a), i-e., offer the maximum levels of thermal performances with a very reduced overall thickness (if compared to cement-based or brick-based constructions), adding also a proper thermal delay—for summer seasons—when equipped with insulations layers of variable density.

Besides the thermal requirements, the choice of the most proper insulating product is often affected by the evaluation of the ease of installation, since any insulation discontinuity could cause humidity fluxes and mold.

The hygroscopic balance is, indeed, another important aspect for the design of an optimal technical solution, since wood is very sensitive to variations in its humidity content, especially for low-frequencies (seasonal) variations [34]. Indeed, the application of vapor barriers (inside) and wind-barriers (outside) grants the airtightness of

Table 2.2 Comparison among the thermal properties of the most diffused insulation material and vegetable-derived material

Construction material	Density (kg/m^3)	Thermal conductivity (W/mK)	Thermal capacity (J/kgK)
Rock wool	30	0.040	830
Polyurethane	30	0.030	1480
Wood-fiber	150	0.038	2100
Cork	110	0.045	1700

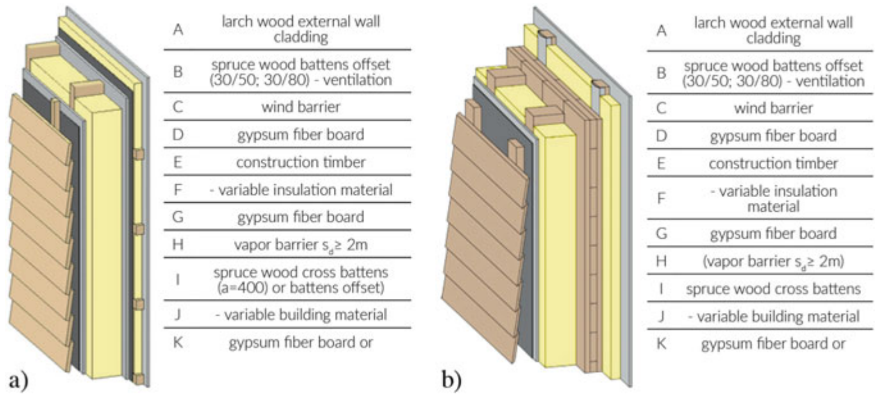

Fig. 2.5 **a** Framed technological solution. **b** Massive timber technological solution. *Source* Author's elaboration on image and technical details retrieved from the dataholz catalog [32]

the envelope and the durability of all the materials, by balancing the fluxes of water vapor between the building components and the outdoor and indoor environment. In particular, the technological design needs to focus on the *sd* (the equivalent thickness to air) [m], which represents the resistance to vapor diffusion. According to the approach that the designer rather follow:

- To manage the vapor fluxes, by adopting a permeable technological solution, made of consecutive layers with a decreasing *sd* value from inside to outside;
- To avoid any vapor or air permeability, completely blocking any flux from the outdoor or indoor environment.

A special remark has to be given to massive timber solutions (Fig. 5b), where the continuity of the structural layer grants a high value for the resistance to vapor transmittance ($sd = 3.4$– 6.8 m).

Great support in the control of the humidity content and the quality of realization for timber-based building components is given by the great prefabrication potential that timber-based constructions have, thanks to the enormous advancement of the 4.0 approach within the timber industry (Fig. 2.6). Lightness and ease of manufacturing allow, indeed, the introduction of different levels of prefabrication, shifting the amount of assembling processes that are performed between the factory and the work-site, according to the most suitable solution for each project (transport issues, accessibility limitations, need to build in a hygroscopic controlled environment…). In particular, different levels of prefabricated wood components are:

- Single Structural Elements—structural elements: i.e. parts of beams, lattice beams, etc. that are produced from the first sawing process and deliver directly to the construction site;
- Two Dimensional Elements—wall and floor elements commonly prefabricated (usually supplied as already equipped with insulation and waterproof layers, or even already with mechanical and electrical installations);

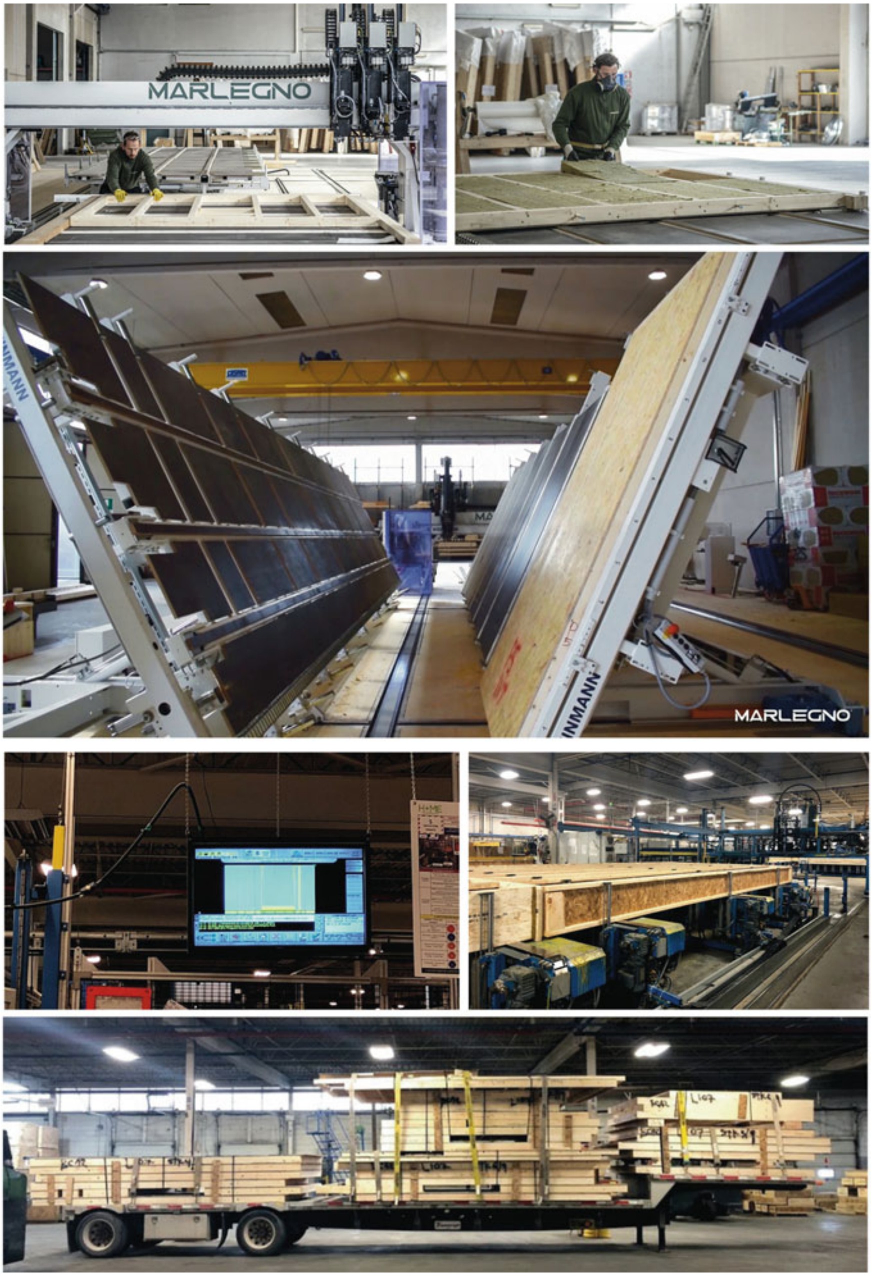

Fig. 2.6 Above, the prefabrication plants of Marlegno near Bergamo, Italy. *Source* Marlegno photo courtesy. Below of Great Gulf in Toronto, Canada. *Source* Author's photo credit

- Three Dimensional Elements—complete spatial units, also available with mechanical and electrical installations, or even completely finished and including furniture;
- On-Site Prefabricated Elements—assembly great prefab modules, otherwise not transportable.

2.2 Timber Construction Systems: A Taxonomic Perspective

2.2.1 The Taxonomic Approach to Building Systems

The technical literature and the national and international guidelines and standards have since always tried to explain the complex and articulated panorama of building systems, according to a multitude of different approaches.

By analyzing the technological thread, the first criterion is the construction material [35]—concrete, masonry, steel, wood, glass, or textile membranes… [36].

Besides, the continuous innovation of these practices has led to other approaches, i.e. based on the contrast between the so-called traditional construction systems and the newer ones of dried construction technologies [37, 38].

As specifically related to timber construction, an additional criterion is represented by the concept of *wall-systems* [39], which considers for a taxonomic evaluation only the technological solutions that are currently used for the vertical enclosures. Besides, other studies propose a taxonomic review based on the variety of wood-based products and components available on the market, and thereof categorizes systems as framed or panel-based ones [20].

Finally, other possible taxonomies concern the application [35], within new constructions or building retrofit, and thereof the impact those systems have on building performances, or the different building typology—i.e. the Canadian taxonomy of timber construction systems of mid-rise and high-rise wooden buildings [40].

2.2.2 Timber Construction Systems

Moving from the literature review, the author proposes a new creative taxonomy of timber-based construction systems, starting with the analysis of the triad:

- *Products*, as solid, engineered, or recycled wood-based;
- *Processes*, as the assembly of timber-based devices, within the different levels of industrial productions and prefabrication;

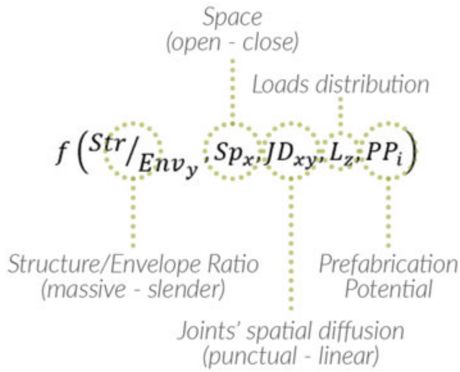

Fig. 2.7 The function to outline the criteria of the proposed taxonomy for timber construction systems. *Source* Author's elaboration

- *Projects*, embedding the designing processes that result in the best application practices.

  And which follows a set of criteria, i.e.:

- *Construction typology*, which considers the ratio between Structure and Envelope (S/E) and results in the duality of the massive and slender system;
- *Spatiality*, which accounts for the relation and possible fluxes between the outer space and the open or close construction volume;
- *Joints' spatial diffusion*, resulting as a tendency from the integration of the previous two criteria, from punctual to linear connections;
- The mechanical behavior of the system under the *Loads distribution*.

The taxonomy has been resumed throughout the function of Fig. 2.7 and resulting in the diagram of Fig. 2.8.

2.2.2.1 The Creative Taxonomy of Timber Construction Systems

Structural Frame System. It represents a punctual framed system, with customized linear products (beams and columns), derived from solid wood, KHV, and/or glue-laminated timber processes. It is considered as a slender construction type, with an open spatiality, and punctual mechanical connections between vertical and horizontal elements.

The system could be structurally realized through Posts and Beams solutions, usually realized on-site, or as pre-assembled Portal Frames (Fig. 9a).

Timber Framed System. It is mainly considered as a lightweight framed wall system, based on the traditional North-European *Fachwerkbau* and the North-American *balloon frame* and *platform frame* techniques. It is, indeed, the results of the assembly of standardized linear products (timber studs), derived from solid (finger-joint or glued-squared) KVH and glulam processes. The construction type is slender, with an open spatiality bounded to the standardized span between the

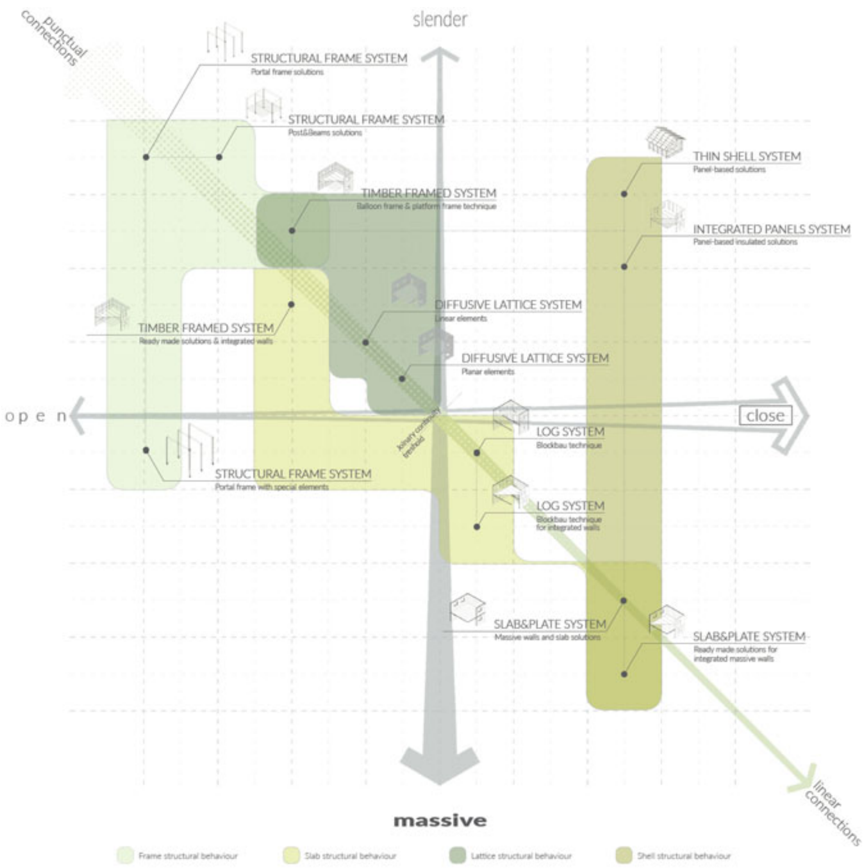

Fig. 2.8 The proposed taxonomy for wood-based construction technologies started from the basic distinction between slender and massive systems, furthermore, classified into open and close structures. The intersection of these four parameters enhanced a trend about the joints' spatial diffusion. *Source* Author's elaboration

elements—usually 600 –650 mm, as related to the application of timber panels as wind-bracing elements. The mechanical behavior is, indeed, considered as a framing response, when claded by solid wood boards, or as a braced frame system if reinforced by timber-based panels—OSB, plywood, etc.

The level of prefabrication of this system is flexible: from the assembly of singular elements on the construction site to the realization of the reinforced frame, then equipped by insulation layers, as *ready-made* solutions, till the integrated walls with mechanical and electrical systems, or even windows, further assembled as three-dimensional modules and shipped (Fig. 9b–c).

Diffusive Lattice System. From the Japanese traditional crafts of wooden joinery, this wall system is represented by scattered structural nodes, along the planar, or even the third dimension (Fig. 9d–e). A set of customized linear or planar products,

Fig. 2.9 Architectural examples of the application of timber-based construction systems. *Source* Author's elaboration

derived from solid wood, glulam, or massive timber processes, are mechanically assembled through wooden connections in structures, whose slenderness could be varied according to the parametric variation of the structural spans.

The defined rhythm of the enclosures is, indeed, the place where the contemporary and innovative interpretation of the Asian craft, today realized through CNC-based processes, meets the Easter philosophy of Void and Emptiness, embedded in the porosity of the system. Its spatiality results, therefore, as semi-closed and ephemeral, where the Joints' spatial diffusion presents an upgrading intensity on bi-dimensional and three-dimensional building components (enclosure solutions).

Mass Timber—Log System. Based on the North-European *Blockbau* technology, or the Canadian log system, traditionally realized through piled wood trunks, this system uses massive linear elements, horizontally laid and piled up to define wall components. The currently used timber products derive from solid wood (glued and squared), with particular edge profiles to allow the connection between consecutive linear elements along the vertical structure, and the joint of different building components (Fig. 9f). Therefore, the system spatiality results in a close volume, where the Joints' spatial diffusion is linked to the linear and continuous contact surfaces between the singular linear elements.

The level of prefabrication is relatively low, due to the continuous stratum of massive timber, which implies a considerable total weight (>3000 kg) of the single components to be easily enlivened on site. However, the market presents different technical solutions, already studied as *ready-made*, in terms of assembly and thermal performances.

Mass Timber—Slab/Plate System. Based on the big-span planar products of CLT, DLT, NLT, GLT, and MHM technologies, it is considered as one of the most innovative construction systems, thanks to the ease of application and installation on-site and the high load-bearing capacity of the single elements, both used as slabs and plates for a shell-based distribution of the loads along the three-dimensional closed volume. This feature has allowed, indeed, to consider timber as a material for constructions of mid-rise to high-rise buildings, otherwise realized through pre-cast concrete (Fig. 9g).

The construction type is, therefore, a massive structure, with a close spatiality, where the Joints' spatial diffusion is related to the continuous linear connection between the planar elements.

Thin Shells System. Reducing the thicknesses of the single panels, by choosing plywood boards, LVL, or OSB items, this system represents a three-dimensional box system, with pre-shaped planar products of multi-layered timber panels, derived from recycled wood processes, and fixed through specific and patented wood joints (Fig. 9h).

The construction type results, therefore, slenderer than the mass-timber systems, even though it still presents a close volume and a continuous contact between the planar elements, combined with the specific punctual connection.

Integrated Panels System. It is represented mainly by wall elements, realized through timber-based sandwich panels. A pair of prefabricated self-supporting and load-bearing boards, derived from plywood or OSB, is filled with insulating materials, such as EPS foam, in order to grant both the structural and thermal properties required. The construction type is light, thanks to the lower weight of the insulation layer, and closed, due to the presence of a continuous planar layer.

Modular Elements System This last category collects all the experiences derived from the application of timber-based modular elements, which follows the assembling approach of brick-based constructions. The prefabricated components are realized through recycled wood processes; in particular, CNC-cut OSB panels are used to create light brick-shaped elements, with edges specifically designed to allow a mutual connection along with the vertical enclosure. The inner void could be filled with insulating materials, directly on-site by pouring granulates, or within the prefabrication process, likewise the previous Integrated Panels system.

2.3 Timber Construction Strategies for Building Transformation: Applied Solutions from Realized Case Studies

Structural lightness [41], positive environmental footprint [9, 10], and high prefabrication potential are the key features that are driving the decision-makers towards timber-based solutions today.

The added value of timber-based constructions relies, indeed, on the natural high recyclable content and the capacity to store the CO_2, reducing the GHGs' net emissions, and positively affecting the balance of the overall ecological footprint for the renovated building.

These features embody the natural potential of wood as a construction material, in particular when applied to building transformation, reducing its impact on existing buildings, which is one of the main issues related to sustainable management of the built environment. Moreover, the structural lightness of timber-based solutions allows to several positive implications, such as the trivial reduction of the overloads for the existing structure, which means: (i) to ease the structural verifications and (ii) to minimize the eventual reinforcement of the existing structure elements, if compared to other construction materials. It suggests, thereof, an optimization of the process, in terms of time and resources consuming, during both the design and the construction phase. These circular economies grow even more if adding the benefits of prefabrication and ease processing/assembling, which characterizes timber construction systems and points to a lower impact on the worksite, for the sake of function and business continuity within the existing buildings, and the quality of the final result.

The different timber-based construction systems represent, therefore, different options, flexibly suitable to satisfy the variety of requirements of building transformation practices, especially for the environmental and structural aspects, which are specifically entailed with the technological choices.

2.3.1 Timber Construction Systems Within the Additive Retrofit Strategies: The Outcomes from the Case History Analysis

The above guesses have been confirmed through the analysis of a wide portfolio of case studies, some of reported in the last chapter of this dissertation. The final discussions over the data-collection enhance, indeed, a considerable application potential for timber-based constructions for building transformation. The identified solutions are suitable both to meet the initial need and aims of the retrofit strategies and to be flexibly applied to the different existing contexts, in terms of varied building typology and urban scenarios.

2.3.1.1 Distribution Trends

As outcomes of the survey, the circular distribution graphs illustrate the trending fluxes of the different parameters. In particular, the graphs of Fig. 2.10 resume the mutual distribution between retrofit strategies and timber construction systems. It needs to be noted that the shown trends have to face the limitations of the survey, mainly due to the boundaries of the investigation domain: by drawing on for information from a strictly defined data source, the results cannot avoid being influenced by the actual trends of the Italian network experiences. The national market of timber constructions, indeed, relies on 55% slender systems and 38% massive timber panels (CLT) [8]; a similar distribution is traceable on the graph of Fig. 10b, where Structural Frame Systems (42%), Timber Frame System (26%) and the Mass-Timber—Slab and Plate System (32%) define the 100% of the experiences of a vertically-up expansion (so-defined Building Above strategy).

Besides, the choice of the proper timber system for the spatial re-functioning and re-organization of existing indoors (Building Inside and Building Under strategies) is strictly related to the level of prefabrication and the work-site conditions: the trends show, indeed, that Mass Timber panels are frequently used—35% as Building Inside and 30% as Building Under -, as walls or box-shaped volumes, with a high level of prefabrication content. However, the analyzed cases of the survey present situations where the spatiality of the existing building offered the possibility to access the existing building spaces with ready-made—and quite hulking—elements; otherwise, the most suitable solution is represented by the Timber Frame solutions, where the prefabrication potential is more variable, and the level of assembly from the factory to work-site is always adjustable.

In conclusion, the results of the survey prove the effective reliability of timber-based construction systems—some more than others—as valid solutions for building transformation, flexibly suitable to satisfy its variety of requirements and final aims.

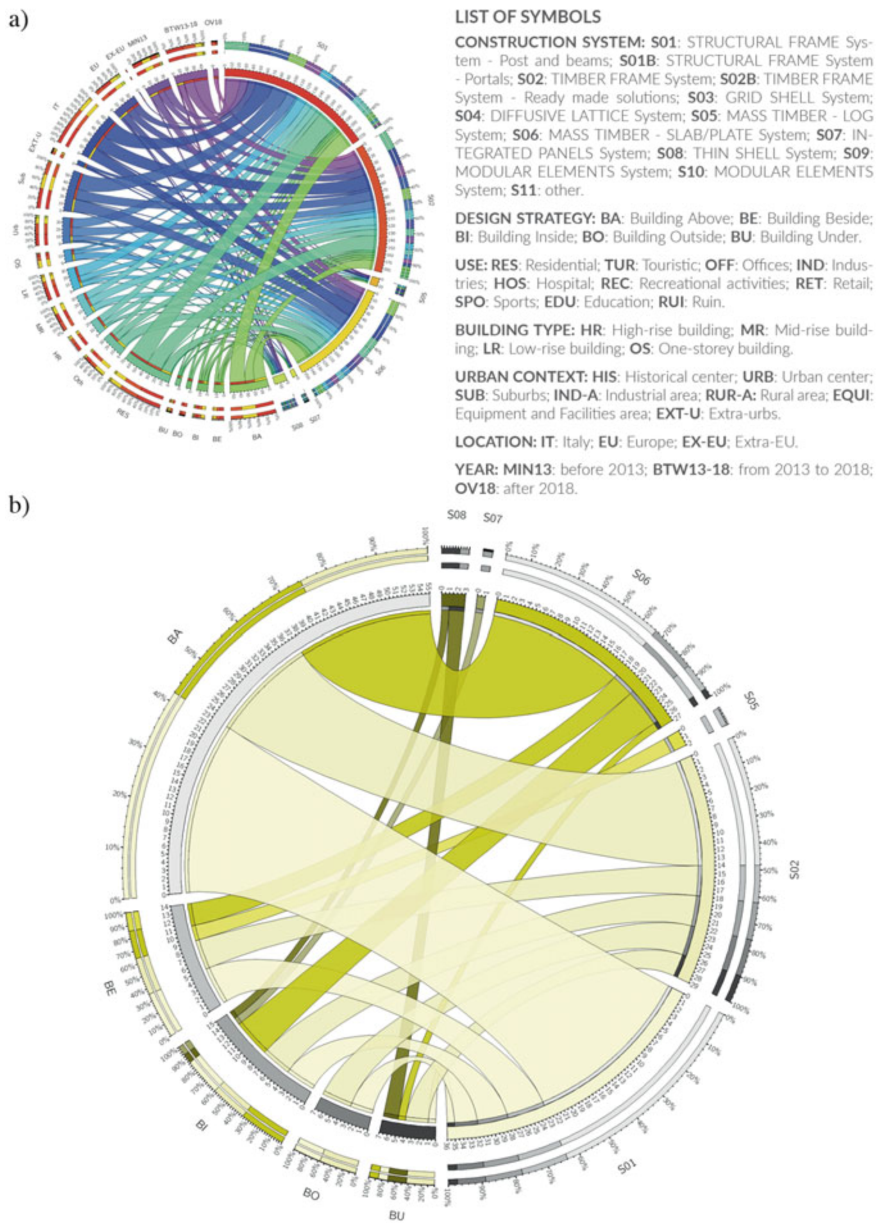

Fig. 2.10 Data elaboration about the timber construction technologies application on building transformation. *Source:* Author's elaboration performed on Circos Table Viewer http://circos.ca/

References

1. Legno (2001) L'enciclopedia dell'Architettura Garzanti. Garzanti Editore, Milano
2. Bertolini L (2010) Legno. In: Materiali da costruzione. Volume primo. Struttura, proprietà e tecnologie di produzione, II edn. CittàStudi edizioni, Milano
3. Follesa M, Maione F, Palanga G (2011) Edifici a struttura di legno. Progettazione e realizzazione. Ticom S.r.l, Milano
4. Li H, Guo X, He Y, Zheng R (2019) A green steam-modified delignification method to prepare low-lignin delignified wood for thick, large highly transparent wood composites. J Mater Res 34(6):932–940. https://doi.org/10.1557/jmr.2018.466
5. Löschke SK, Mai J, Proust G, Brambilla A (2019) Microtimber: the development of a 3D printed composite panel made from waste wood and recycled plastics. In: Bianconi F, Filippucci M (eds) Digital wood design, Lecture notes in civil engineering, vol 24. Springer, Cham
6. Bianconi F, Filippucci M (2019) WOOD, CAD AND AI: digital modelling as place of convergence of natural and artificial intelligent to design timber architecture. In: Bianconi F, Filippucci M (eds) Digital wood design, Lecture notes in civil engineering, vol 24. Springer, Cham
7. Centro Studi Federlegno Arredo Eventi SpA. (2015) Rapporto case ed edifici in legno 2015. Milano
8. Centro Studi Federlegno Arredo Eventi SpA. (2018) 3° Rapporto Case ed Edifici in Legno. Milano
9. Hammond GP, Jones CI (2008) Embodied energy and carbon in construction materials. Proc Inst Civil Eng—Energy 161(2):87–98. https://doi.org/10.1680/ener.2008.161.2.87
10. Brunone F, Lavagna M, Imperadori M (2018) Wood-based construction systems and life-cycle assessment—a review. In: The life cycle thinking in decision-making for sustainability: from public policies to private businesses. University of Messina, Department of Economics, Messina, Italy
11. PEFC—Programme for the Endorsement of Forest Certification. Available online at https://www.pefc.it/
12. FSC—Forest Stewardship Council. Available online at https://fsc.org/en
13. Follesa M, Maione F, Palanga G (2011) Gestione forestale e sostenibilità. In: Edifici a struttura di legno. Progettazione e realizzazione. Ticom S.r.l., Milano
14. Wood (2019) Cambridge English Dictionary. Cambridge: Cambridge University Press 2020. https://dictionary.cambridge.org. Retrieved Online from https://dictionary.cambridge.org/dictionary/english-italian/wood
15. Timber (2019) Cambridge English Dictionary. Cambridge University Press 2020, Cambridge. https://dictionary.cambridge.org. Retrieved Online from https://dictionary.cambridge.org/dictionary/english-italian/timber
16. Timber (2005) Dictionary of architecture & construction, 4th edn. In: Harris CM (ed). McGraw-Hill Education, London. Retrieved Online from https://doi.org/10.1036/0071452370
17. Lumber (2005) Dictionary of architecture & construction, 4th edn. In: Harris CM (eds). McGraw-Hill Education, London. Retrieved Online from https://doi.org/10.1036/0071452370
18. Piazza M, Roberto T, Roberto M (2005) Strutture In Legno Materiale. In: Hoepli (ed). Calcolo E Progetto Secondo Le Nuove Normative Europee
19. Bernasconi A, Schickhofer G, Fr K, Traetta G (2005) Il materiale legno. Promo_legno. Retrieved from www.promolegno.com
20. Mordà N, Raimondi G (2017) Progettazione degli edifici in legno. Maggioli Editore, Santarcangolo di Romagna
21. Mazzucchelli ES (2016) Il legno come materale da costruzione: le caratteristiche principali. In: Sistemi costruttivi in legno. Maggioli Editore, Santarcangelo di Romagna
22. Mordà N, Raimondi G (2017) Prodotti a base di legno. In: Progettazione degli edifici in legno. Maggioli Editore, Santarcangolo di Romagna
23. Bernasconi A, Schickhofer G, Traetta G (2005) I prodotti di legno per la costruzione. Promo_legno. Retrieved from www.promolegno.com

24. Follesa M, Maione F, Palanga G (2011) Legno strutturale e materiali a base di legno. In: Edifici a struttura di legno. Progettazione e realizzazione. Ticom S.r.l, Milano
25. Mazzucchelli ES (2016) Il legno come materale da costruzione: i prodotti derivati. In: Sistemi costruttivi in legno. Maggioli Editore, Santarcangelo di Romagna
26. Ribera A (2015) LEGNO L'universo costruttivo di un materiale nuovo. Ribera legnoformazione, Milano
27. CSI (2012) OmniClass—A strategy for classifying the built environment—Table 21 elements. Retrieved from https://www.csiresources.org/standards/omniclass
28. Imperadori M, Feifer L, Salvalai G, Vanossi A, Brambilla A, Brunone F (2019) Costruzione stratificata a secco e Active House: paradigmi convergenti per l'innovazione sostenibile. In: ACTIVE HOUSE: Progettazione e innovazione con tecnologie di costruzione stratificata a secco, Maggioli Editore, Milano
29. Dataholz EU (2018) Finger-jointed solid construction timber. Retrieved from https://www.dataholz.eu/fileadmin/dataholz/media/baustoffe/Datenblaetter_en/kvh_en_01.pdf
30. UNI Ente Italiano di Normazione (2013) UNI EN 14080:2013 Timber structures—Glued laminated timber and glued solid timber—Requirements
31. Hans BJ, Streib J (2016) Ingenious hardwood BauBuche Microlamellare di faggio Guida alla progettazione e al calcolo strutturale secondo l'Eurocodice 5 (2a ed.). In: Pollmeier (ed)
32. Dataholz online database. Available online at: www.dataholz.eu/
33. UNI Ente Italiano di Normazione (1981) 8290–1:1981 + A122:1983 Building elements. Classification and terminology
34. Mazzucchelli ES (2016) Fisica tecnica delle costruzioni in legno. In: Sistemi costruttivi in legno. Maggioli Editore, Santarcangelo di Romagna
35. Imperadori M (2001) Costruire sul costruito Tecnologie leggere nel recupero edilizio. Carocci Editore, Roma
36. Corrado V, Ballarini I, Corgnati SP (2014) Building Typology Brochure—Italy. Fascicolo sulla Tipologia Edilizia Italiana. In: Politecnico di Torino (ed). Nuova edizione. Torino. Retrieved from http://areeweb.polito.it/ricerca/episcope/tabula/
37. Zambelli E, Vanoncini PA, Imperadori M (1998) Costruzione stratificata a secco Tecnologie edilizie innovative e metodi per la gestione del progetto. Maggioli Editore, Milano
38. Imperadori M (1999) Le procedure Struttura/Rivestimento per l'edilizia sostenibile Tecnologie dell'innovazione. Maggioli Editore, Milano
39. Schrentewein T (2008) Casaclima Costruire in legno. Raetia Edizioni, Bolzano
40. Canadian Wood Council (2019) Building Systems. Available online at https://cwc.ca/how-to-build-with-wood/building-systems/
41. UNI Ente Italiano di Normazione (2003) UNI EN 338:2003—Structural timber—strength classes (updated 2009). https://doi.org/10.1016/j.jglr.2014.11.012

Chapter 3
An Innovative Method for the Management of the Building Process

Abstract Through always more innovative IT applications, the construction industry is moving towards the digitalization of the building process, from digital design to automated manufacturing and smart buildings. Big data are now able to take us into an augmented reality—the virtual sibling of the real one—where buildings become cognitive and predictive, capable to actively interact with people. Towards this direction, the capability to store and organize building information at any level of its lifecycle is essential, especially when the multi-criteria evaluation of buildings' behavior is required. Within this framework, the chapter introduces the review of the standards and best practices, mainly focusing on BIM as the driven method for the management of the entire building process. Hence, the methodology to develop a new assessment tool is presented, according to the investigation of the current platforms for the evaluation of buildings' performances, and the pursued methods to define new additional shared parameters, specifically customized for the application to retrofit design solutions with timber-based construction systems.

Keywords Building transformation · Building information modeling · Design optioneering · Cognitive building · Multi-dimensional analysis · Evaluation process · Active house

3.1 Building Design Process and IT: Ongoing Developments

Through always more innovative IT (Information Technology) applications, the construction industry is moving towards the digitalization of the building process [1, 2], from digital and parametric design to automated manufacturing and smart constructions.

Building Information Modeling (BIM), Computer-Aided Manufacturing, Robotics Construction Process, Building Automation are a few of the keywords representing the most innovative practices that are increasingly entering the building sector and its processes, from design to production and construction.

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Besides, every day cheaper sensors' equipment, interconnected by the "invisible technologies" and platforms of cloud computing, are driving the constructions field towards the same development direction that has been already gained, e.g., by the automotive sector, and further opening the built environment to the Internet of Things (IoT), where big data are now able to take people into an augmented reality, the virtual sibling of the real one.

Furthermore, buildings are becoming Cognitive and Predictive, capable to actively interact with people and environments, learning from them, and improve their operating features almost in real-time.

Towards this direction, the capability to store and organize building information at any level of its lifecycle is essential, especially when the multi-criteria evaluation of buildings' behavior is required.

3.2 A BIM-Based Active House Tool for the Parametric Evaluation and User-Centered Visualization of Data

Today the most innovative practices of building design and construction management follow the stream of BIM, which is conceived as an assessed methodology to manage the cross-field fluxes of information across the entire building process [3]. Data and information define the knowledge about any system, and underlie the related assessment procedures, which result possible only when those fluxes are systematically organized.

According to this perspective, the analysis of BIM-based processes and procedures allows outlining the set-up of any evaluation method, hereby conceived for the management of buildings across their entire lifecycle, from design to operation. Its development and structure should be based, therefore, on BIM features, to allow:

- Accessing the different stages of the building process, following a deepening level of definition of information—as per LODs (Level Of Developments) language [3–7];
- Crossing multiple areas of evaluation—as per BIM Dimensions (as further analyzed in Chap. 5).

Besides, the aim to guide the building process should pass by the definition of a set of robust principles, specifically designed to meet needs and requirements, that always more nowadays have to be the first drivers of a vision for a more sustainable built environment.

Energy efficiency, environmental-friendly attitude, and indoor comfort and well-being are, indeed, evaluation criteria already shared at an international level driving several established protocols for building validation [8].

Therefore, by considering those principles as a valid starting point, the author proposes a set of additive principles and related evaluation criteria, displayed through quantitative parameters and indicators, that could be always customized and infinitely implemented.

The result is *taleah*, an innovative methodological approach for the management of the construction process, from design to production, operation, and maintenance, based on a multi-dimensional analysis, which refers to information-integrated environments and multi-criteria evaluation methods, and specifically customized to identify innovative models of process, product, and design (project) of wood-based construction technologies as additive solutions of urban and architectural, technological and energetic, seismic and structural transformation of the existing building stock. *TALEAH* is indeed the acronym of *Tecnologie Additive in Legno per Edifici Active House* (wood-based additive technologies for Active House buildings); here, principles, evaluation criteria, quantitative parameters, and indicators are derived from both the uptake of the Active House [AH] Vision (following analyzed) and the previous investigation of timber construction systems, applied to additive retrofit design.

3.2.1 A BIM-Based Management of Data, Information, and Evaluation Parameters

Beginning with the end in mind [4] is the core of BIM processes. It means to be able to set the framework of the building process development with the clear uptake of its final aim, identifying the downstream uses of data and information. Since buildings are complex items to be described, the early recognition of only essential inputs is necessary to smooth the knowledge and perform the evaluation according to specific targets.

Even if there are consistent differences between terms and acronym definitions [9], the most authoritative institutions related to BIM have stated, indeed, the overall need to outline the initial requirements at the beginning of the building process. Following the international vocabulary [10], this step is identified in the Exchange Information Requirement (EIR), which collects the information to be used, and the standards and processes to be adopted [4]. The last ones are, then, structured within the BIM Execution Plan (BEP) [10], a plan prepared by the suppliers to explain how the information modeling aspects of the project will be carried out [4]. This document has to set the information asset management, as a general proposal within the BEP Pre-contract [4] or Pre-appointment [10], till more specific directives with the BEP Post-contract [4]. All over these two sections, the LOD (LOD/LOI) of the required information is here indexed, according to the breakdown structure of the project.

As a transfer of BIM directives to the development of a building performance evaluation method, the definition of the initial requirements has to match the technical specifications that describe the assessment procedures, according to specific evaluation principles, parameters, and criteria (step I of Fig. 3.1):

- principles express the thematic drivers of the evaluation;

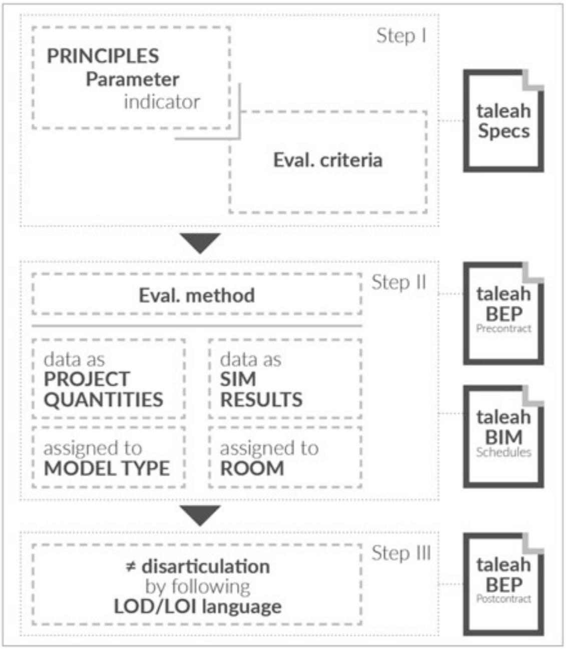

Fig. 3.1 The scheme represents the application of BIM standardized procedures to the development of the *taleah* method: (i) the evaluation principles, parameters and indicators (whose asset will shape the architecture of the final *taleah* assessment tool) define the fields for the evaluation; (ii) the selected criteria from the assessment specifications outline the initial requirements, with the definition of the EIR; (iii.i) the BEP Precontract listed the association between the evaluation methods and the corresponding project data (project quantities or simulations/monitoring results); (iii.ii) the BEP Post-contract closes the procedure, listing the LOD/LOI requirements as linked to the WBS of the specific project. *Source* Author's elaboration

- parameters represent the variables to illustrate a specific aspect of the building behavior;
- the associated indicator translates the evaluation into quantifiable values as attributes to measure the building performances [11];
- finally, the evaluation criteria give the acceptable boundaries and thresholds for each parameter, to obtain a satisfying result and pursue the objective [11].

Acknowledging the evaluation criteria and the corresponding evaluation methods helps, indeed, identifying and collecting the related project data (step II of Fig. 3.1) to be defined within the BIM environment. The digital representation of the building, indeed, represents the database of all the information describing the construction according to those matters recalled within the assessment specifications—i.e. the EIR. Those project inputs could be both data directly retrievable from the model, as well as re-elaborated information, i.e. simulations results and/or monitoring campaign outcomes. The overall required data are listed as minimum requirements to allow performing the multi-dimensional evaluations, for each level of the design process.

3.2.2 The Active House Vision as a BIM-Ready Platform of Requirements

The BIM-based information management rests on the first definition of the Initial Requirements, addressing the final aim of the entire process. Within an evaluation procedure, this request is translated into the definition of the evaluation criteria to drive the assessment according to specific evaluation principles.

In these terms, the AH protocol—whose vision aims to conceive healthier and more sustainable buildings, by guiding the design process through a holistic evaluation of quantitative and qualitative parameters, collected under the three principles of Comfort, Energy, and Environment [12]—represents a BIM-ready platform of requirements.

An open-source tool for the evaluation of constructions, and already set to cross the building process between the design phase and building operation [13], this protocol has been chosen among all the other certification systems also because of its capability to integrate the three dimensions of environmental, social and economic sustainability, with mean averages if compared to the peer ones [8] (Fig. 3.2). Moreover, focusing especially on energy efficiency—as a specific aspect of the environmental sphere and the main focus of the current European policies to face the climate change challenge—the AH Specifications are able to meet all the thresholds set in each country by the official and mandatory standards [14, 15].

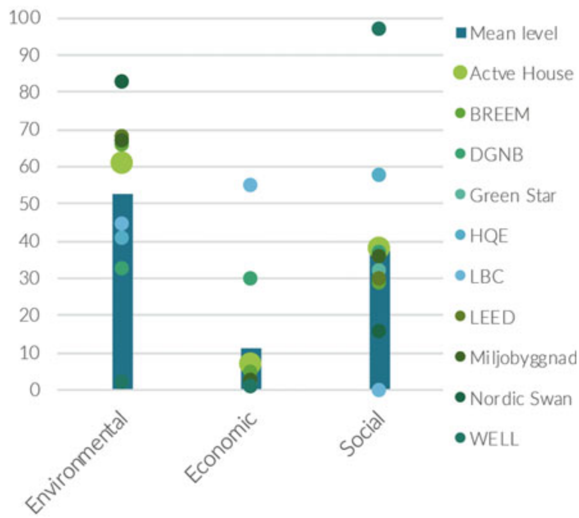

Fig. 3.2 The graph summarizes the comparison among the ten most used globally diffused certification systems across Northern Europe: Active House is the evaluation protocol that gets closer to the average value over the three dimensions of sustainability. *Source* Author's elaboration based on [8]

Therefore, the AH approach has been considered as a valid starting point, thanks to:

- Its trustworthy as the result of a globally shared conversation among experts and stakeholders [16] and a representative recap of the peer sustainability approaches [8, 14];
- Its BIM-ready framework of principles, parameters, and evaluation criteria [12], which facilitates the transition towards BIM Initial Requirements;
- Its availability as an open-access tool for building validation [17];
- Its wide range of applications, from the design phase to building operation monitoring [13].

3.2.2.1 AH Principles, Parameters, and Evaluation Criteria

Comfort, Energy, and Environment are the three key principles of the AH evaluation process, whose integration aims to lead towards a holistic evaluation of buildings' behavior. Underneath, the corresponding evaluation parameters define the quantitative indicators of building performances, as follows [12, 15].

Daylight—it accounts for the indoor visual comfort, addressed mainly to the sun-light availability and spatial diffusion, and the visual connection with the outer surrounding, as factors that have positive effects on health and well-being; it is evaluated according to the Daylight Factor calculation/simulation;

Thermal Environment—it stands for the indoor thermal comfort, considering the hourly trend of the Operative Temperature, resulting from dynamic simulations;

Indoor Air Quality—it considers the fresh-air supply as an essential factor to avoid health disease like asthma, evaluating the CO_2 concentration calculated/simulation concerning the outdoor conditions;

Energy Demand—it represents the final energy demand, including both the energy consumption related to the heating/cooling systems and the electrical consumption for systems and other devices (lighting, …) operation; the sum derives from both simulations and calculations;

Energy Supply—it accounts for the part of the energy supply—generated by renewable sources, nearby the building as well as a shared system within the community; it derives from the calculation of the energy production of building system;

Primary Energy Performances—it defines the energy efficiency of the construction as Net Zero Energy Building, by evaluating the final energy demand;

Environmental Loads—it considers the environmental impact of the construction accounting for its complete lifecycle, with a cradle-to-cradle approach, performing a Life-Cycle Assessment;

Freshwater Consumption—it promotes the minimization of the water consumption, asking for a reduction if compared to similar building and the National mean values;

Sustainable Construction—it sponsors the circular-economy approach, asking for the selection of construction materials, products, and components that have a large percentage of recyclable content.

3.2.2.2 The AH Radar: A Validation Tool

The AH Radar chart (Fig. 3.3) is the final output of the evaluation process that follows the three principles of Comfort, Energy, and Environment.

Its visualization features allow considering the AH Vision as a holistic evaluation approach: the graph is indeed able to show the assessment of all the parameters as well as the correlations and mutual influences among them. This visual effect is aided also by 1–4 weighting system, which makes the comparison between different quantities and characteristics simpler, and already user-friendly oriented.

Fig. 3.3 The AH Radar is the graphic tool able to visualize the AH evaluation holistic approach: the integration of quantitative indicators which belong to the three principles of Comfort, Energy, and Environment. *Source* Active House Alliance

Fig. 3.4 The current workflow of the AH evaluation procedures. *Source* Author's elaboration, based on retrieved data from AH portfolio of case studies [18, 19]

3.2.2.3 AH Evaluation: The Current Workflow

In order to perform the evaluation and obtain the final score for each parameter, the AH current workflow (Fig. 3.4) asks to operate several simulations and calculations, whose resulting values describe the building performances and behavior, according to each specific indicator [12]. Its application, indeed, involves mainly the validation of buildings using, as project data sources, the information available at the end of the design stage. At this step of the building process, indeed, most of the design choices have been already defined with great reliability about their compliance to the real final building, but also with a little margin to operate changes over the project features towards an optimization of the evaluation results. Of course, this *modus operandi* empowers the designer's role and skills to define a sustainability-oriented design strategy since the first steps of the creative process, but it also entails a lack of support/control over the overall decision-making process.

3.2.2.4 A BIM-Based Management Perspective of the Building Process Applied to the AH Approach

As stated, the AH protocol represents a ready platform for a BIM-based management of data and information, by looking at the AH Specifications as a list of requirements to start with. Indeed, the analysis of the AH tools drives to the identification of the AH principles, parameters, and indicators with the corresponding assessment methods and, thereof, the essential project's data to perform all the calculations/simulations as Initial Requirements.

On the other side, the BIM management procedures systematize the same project data and information following the development of the building process and introducing the LOD/LOI coding systems on geometrical and not-geometrical information (Table 3.1)—related to the project as attached to its virtual sibling within the BIM-based environments.

Table 3.1 A simplified proposal for the integration of the BIM language with the different stages of the building process.[1] [3–5, 7]

Building process		Project data		LOD		
		Required representation	Required data	USA	UK	ITA
				–	1	–
Design	Conceptual design	Generic and symbolic representation of the building model		100	2	A
	Early design [preliminary]	Approximated geometry—of the outer envelope (3D geometry shape of the building model)	Approximated information—as defined from outer references, i.e. standards average values	200	3	B
	Detailed design	Specific system representation with quantities directly measurable of the building model—outer envelope and indoor partitions, rooms	Generic information—derived from similar technological solutions and construction materials first definition	300	4	C
	Final design	Specific object representation, with connection parts	Detailed information—as defined for similar products	350		D
Construction	Design for construction	Specific representation, with detail and accuracy for fabrication	Specific information—of chosen products	400	5	E
	As-built	Field verified representation	Specific information of used products, with managements and maintenance indications	500	6	F
Operation	Operation and monitoring		Updated information—retrieved from monitoring surveys	–	7	G

Source Author's elaboration based on

[1] By simplification, the integration with the BIM language—based on LOD and LOI—follows the development of the building process and the sequence of the different levels of the design process, despite the Italian standards on BIM [7] specifies that this match is not fully reliable.

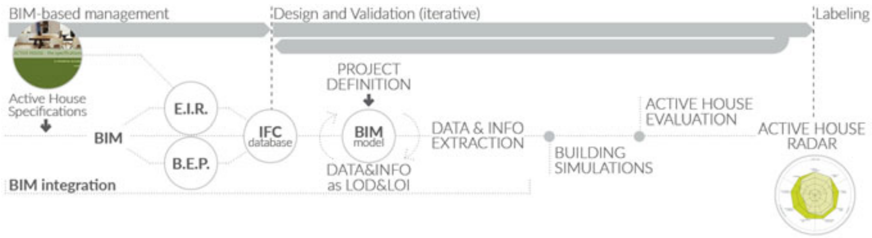

Fig. 3.5 The scheme represents the integration of the AH workflow with the principles of BIM-based data management and language, resulting in the definition of the building model, within its IFC format, as the project's database. *Source* Author's elaboration

Finally, by crossing the review of the AH tools with the BIM-based information management and breakdown structure, the data available within a specific level of the building process can match the related possible data-elaboration, according to the AH parameters. The AH evaluation protocol as BIM-integrated (Fig. 3.5) is now applicable to the building at each step of the design process, where the increasing level of detail of the project data and information feeds the always more confident and accurate evaluation method.

3.2.3 From Active House to Taleah: A Parametric Upgrade of Multidimensional Evaluation

The evaluation method rests on the three principles and evaluation systems of the AH approach, whose applicability could be improved and implemented if considered as a part of a wider parametric evaluation system.

Adding new dimensions to the evaluation procedure means being able to set a framework of additional principles, parameters, and indicators, which have to be reliable in describing the dynamics of the new specific applications. Then, a set of corresponding evaluation criteria and methods has to be defined, accounting for the proper weighting system to perform the evaluation and make it equally comparable among the different parameters. New additive specifications have to be drafted, as a parametric upgrade of the AH approach, towards a multi-dimensional evaluation.

3.2.3.1 New Evaluative Criteria on Timber-Based Additive Solutions for the Transformation of Existing Buildings

The performed analyses and related outcomes of the previous chapters set the domain of the newer evaluation method, specifically customized upon the application of timber construction systems and technologies as an additive solution for the technological and performance implementation of existing buildings.

Therefore, the current dissertation becomes a matter of *process*, applied to specific *products* and *projects*:

- The first (a matter of process) consists in the assessment procedures of the evaluation method, which support the entire building process from the decision-making tasks of the design and construction phases to the facility management during the building operation;
- The second (application on products) concerns specific technological solutions based on timber products for constructions;
- At last, the third (application on project design) involves the design strategies operating with additive solutions over the existing building stock.

Therefore, in order to lay down the rules of the proposed evaluation and define its background, the two main application topics had been investigated, through the literature review of academic and technical journals, along with the survey over the current best practices, and the interviews with the experts of the construction sector, especially with connections to timber industries. At first, the framework of all the matters and issues related to timber construction systems applied as technological solutions for retrofit design has been outlined; afterward, the experts' opinion has become an additive source for the definition of the evaluation criteria and the related weighting system, by relying on research techniques that derive from the value analysis science.

By referring to the different methods available to perform an assessment procedure, indeed, the evaluation system belongs to the wide field of multi-criteria tools. It is provided with a multitude of different dimensions as areas of investigation, always available for implementations; it presents a weighting system for the evaluation criteria that gives a final score for each parameter flatting the different indicators' quantities to comparable values.

By choosing among all the available techniques of the value analysis science [20], the Delphi Method [21] has been used, because of its strong bases over the stakeholders' expertise, when standards or literature review were not enough to give the boundaries and thresholds of the evaluation criteria. Conceived by the Rand Corporation in the 50 s, it has a consolidated structure, designed to maximize the pros of referring to a pool of experts—like the multi-disciplinary knowledge—while minimizing the cons of an interview-based method—such as the arbitrariness of personal opinions [11].

The outcome of this process consists of the definition of the new technical Specifications (Figs. 3.6 and 3.7), relying on the same structure of the AH Specifications described above. Even the AH approach could be defined, indeed, as a multi-criteria evaluation method, whose definition had passed through a similar procedure. The AH Vision represents the result of a globally shared conversation among experts and stakeholders, about the need for sustainable development, towards which the Active House Alliance is proposing an innovative holistic approach to buildings design [15, 16].

PRINCIPLE	PARAMETER	INDICATOR	EVALUATION CRITERIA
STRUCTURAL LOADS	STRUCTURE	Structure Loads	1. < 0.5% 2. < 1% 3. < 2% 4. < 5% on existing building weight
	ENVELOPE	Permanent Loads	1. < 5% 2. < 10% 3. < 20% 4. < 50% on existing building weight
	BUILDING SYSTEM	Total Loads	1. < 5% 2. < 10% 3. < 20% 4. < 50% on existing building weight
CONSTRUCTION FEASIBILITY	TIME SCHEDULING	Construction Time	1. 75% 2. 90% 3. 100% 4. 115% compared to initial predicted time
	REGULATION CHECKS	Urban standards compliance	1. <1 2. <0,8 3. <0,5 4. >1 with a double check on each indicator <1
	COSTS EVALUATION	Construction Economical Balance	1. 80% 2. 90% 3. 100% 4. 110% compared to initial budget
		Operation Costs Saving	1. >1 2. =1 3. <1 4. <0,5
INDUSTRIAL CONSTRUCTION	OFF-SITE PRODUCTION	Off-site Production Time	1. > 80% 2. > 50% 3. > 30% 4. > 10% of the building time
	ON-SITE CONSTRUCTION	On-site Construction Time	1. < 20% 2. < 50% 3. < 70% 4. < 90% of the building time
	PREFABRICATION POTENTIAL	Prefabricated Ratio	1. <0,5 2. <1 3. =1 4. >1
ECONOMIC AFFORDABILITY	CONSTRUCTION COST	Construction cost	1. 80% 2. 90% 3. 100% 4. 110% compared to initial budget or forecast operation budget
	REAL ESTATE EVALUATION	Real estate re-value	1. +100% 2. +50% 3. +30% 4. +10% compared to the initial value
	OPERATION COST	Operation Cost	1. 80% 2. 90% 3. 100% 4. 110% compared to National Average

Fig. 3.6 Principles, quantitative parameters, and indicators, as derived from the outcomes of the multi-level analyses performed and additive to the already defined and validated structural items of the AH approach. *Source* Author's elaboration

PRINCIPLE	EVALUATION PARAMETER AND INDICATOR		EVALUATION METHOD
STRUCTURAL LOADS	STRUCTURE		
	Structure Loads	Qs / QT(existing) [%]	Weight calculation for structural checks
	ENVELOPE		
	Permanent Loads	Qp / QT(existing) [%]	
	BUILDING SYSTEM		
	Total Loads	(Qs+Qp+Qa) / QT(existing) [%]	
CONSTRUCTION FEASIBILITY	TIME SCHEDULING		
	Construction Time	Total Construction Time x 100 / Total Forecast Construction Time [%]	Construction Time calculation or simulation
	REGULATION CHECKS		
	Urban standards compliance	(Height Compliance + Volume Compliance + Area Compliance) / 3 [-]	Maximum height, volume and area comparison with reference values from standards
	COSTS EVALUATION		
	Construction Economical Balance	Existing Building RE value - Total Construction Cost + RE value / Initial Budget [%]	Cost calculations and real estate evaluation according to location and gross area
	Operation Costs Saving	Final Operation Cost / Initial Operation Cost [-]	Cost calculation/estimation for building operation as energy consumption
INDUSTRIAL CONSTRUCTION	OFF-SITE PRODUCTION		
	Off-site Production Time	Off-site Production Time x 100 / Total Building Time [%]	Off-site Production Time estimation, compared to Project Life-Time
	ON-SITE CONSTRUCTION		
	On-site Construction Time	On-site Production Time x 100 / Total Building Time [%]	Construction Time calculation, compared to Project Life-Time
	PREFABRICATION POTENTIAL		
	Prefabricated Ratio	On-site Production Time / Off-site Construction Time	Prefabrication Ratio calculation
ECONOMIC AFFORDABILITY	CONSTRUCTION COST		
	Construction cost	(Total cost - Bonus) / Initial Budget [%]	Construction Cost calculation
	REAL ESTATE EVALUATION		
	Real estate re-value	Gross Area x RE-value quotation x 100 / Existing building RE-value [€]	Real Estate evaluation according to location, gross area and construction features
	OPERATION COST		
	Operation Cost	(Primary Energy Performance x Gross Area x Local Energy Cost) x 100 / Representative Building Operation Cost [%]	Cost calculation/estimation for building operation as energy consumptions

Fig. 3.7 List of principles, parameters, and indicators associated with the corresponding evaluation method that can return the physical quantities as measures requested for the evaluation procedure. *Source* Author's elaboration

The new evaluative criteria on timber-based additive solutions for the transformation of existing buildings are listed below, with specific references to their relevancy in pursuing the evaluation.

Structural Loads. Acting on the built environment with additive strategies for new and/or renewal features and performances means to work on existing and previously verified structures, which cannot be overloaded for safety reasons. According to the European codes for constructions and the Italian transposition within the NTC 2016 [22], additive loads are allowed only if less than 10% over the existing foundations; otherwise, the standards require also a structural retrofit for seismic prevention reasons.

Furthermore, lighter construction systems better face the challenges of seismic loads, precisely because of the Second Law of Dynamics: $F = m \cdot a$. Less mass means decreased horizontal forces over the acceleration effect of seismic events, avoiding, therefore, the explosive phenomena that characterize massive constructions, such as the masonry and/or cement-based ones.

By referring to construction technologies, lightness is mainly evoked by dried and layered solutions, which involve the advantages of prefabrication and fast execution [23], implying a lighter impact and fewer interferences on building functioning and operation.

Structural Loads' corresponding measurable parameters and quantitative indicators[2] are:

- *Structure*—it accounts for the weight of the structural elements and components within the additional parts of the building system, calculated by the quantity take-off from the BIM model;
- *Envelope*—it considers the permanents loads, intended as the total weight of non-structural layers, such as the insulation elements and the inner and outer envelope components within the additional parts of the building system, retrieved by the quantity take-off from the BIM model;
- *Building System*—it stands for the total additional loads, considering both the structural and permanents loads and adding the accidental loads defined by building function.

Construction Feasibility. Compliance with standards requirements and forecast time and cost is essential to start any kind of construction work. In particular, new planar or spatial elements of the retrofitted building have to respect the local regulations and urban indexes, which are usually already fully exploited by the existing construction.

Construction feasibility involves, hence, the evaluation of costs—implicitly influenced by construction time schedules—and promotes the real estate value increasing and operation costs minimization, as respectively related to the architectural and energy-efficiency retrofit.

[2] The evaluation cannot account for structural validation, which requires more accurate calculation and very deep knowledge about the existing building features.

At last, by referring to construction time directly, its optimization is particularly essential when operating on existing and functioning buildings: in these cases, indeed, the disrespect of the tight time limits could be the cause of functional interferences, and economical losses if considering, e.g., the retrofit or spatial expansion of commercial buildings.

Therefore, the quantitative parameters and indicators to account for Construction Feasibility are:

- *Time Scheduling*—it considers the compliance to construction time forecasting by the estimation, calculation, and verification of the total construction time;
- *Regulation Checks*—it represents the compliance to standards' requirement, with specific reference to the urban indexes, such as the maximum height, volume, and gross area allowed;
- *Costs Evaluation*—it summarizes the contribution of total construction costs, real estate evaluation, and operation costs, by considering a pre and post scenario between the initial conditions of the existing building and the final conditions of the retrofitted construction.

Industrial Construction. Prefabrication, or even automated production, is quite always considered an added value, as shown by the 4.0 industry advancements that are finally involving also the construction sector. It can address simple building elements and components, developed along the linear or planar dimension of, e.g., ready-made walls, as well as the production of three-dimensional modules.

An Industrial Construction stands for higher quality and thorough control over the execution of the works, resulting in reliability and repeatability of the final product. It integrates modularity with customization, towards the optimization of transport for work-site supply. It implies high time-savings during the construction phase, with fewer interferences and minor sensitivity to outer and unpredictable factors.

Shifting the construction/building production from site to factory means, indeed, working inside a closed and controlled environment, responding to predefined quality standards.

Furthermore, it adds environmental benefits across the entire building production cycle, if compared with conventional constructions: the minimization of resource consumption and the related waste reduction, the optimization of transportation impacts are the main examples.

Hence, looking at the works on the built environment, the Industrial Construction value represents a lighter impact, thanks to faster worksites that may otherwise disturb the existing functions.

The corresponding quantitative parameters and indicators are:

- *Off-site Production*—it accounts for the prefabrication content of the building, being represented and quantitatively evaluated through time-related to the production of building components;
- *On-site Construction*—it considers processes that are performed outside the factory, by referring to time spent at the worksite for constructing and/or assembling parts of the buildings that have not been prefabricated;

- *Prefabrication Potential*—it defines the prefabricated content of the construction, by the analytic ratio between the Off-site Construction Time and the On-site Construction Time; it can be evaluated also through the total weight of prefabricated elements and components on the overall building weight, as the AH evaluation proposes for the calculation of the Recycle Content or Responsible Sourcing.

Economic Affordability. A branch of the most recent AH international research is investigating the need to make an Active House accessible also with tight budgets. The RenovActive project has been developed towards this aim, defining a set of simple retrofitting strategies for the energy-efficiency. The improvement of energy performances has its equivalent in the economic value, which includes the total construction costs, the real estate, and operation cost re-evaluation.

The quantitative parameters and indicators for the Economic Affordability principle are, indeed:

- *Construction Cost*—it considers the global investments for the construction, by computing the construction costs evaluated through BIM-5D methods, and the eventual bonuses, available for structural, social, and/or energy retrofit of the built environment;
- *Real Estate Evaluation*—it considers the improvement of the real estate value;
- *Operation Cost*—it stands for the costs due to the building operation, assessed through the unit cost of energy and the total amount of the demanded energy.

Finally, the new technical Specifications include the AH Specifications and propose new additive objectives, with their related attributes and criteria to perform an implemented evaluation (Fig. 3.7).

3.2.3.2 New Criteria as New Dimensions Towards a 360° Evaluation Tool

The implementation of the evaluative principles enriching the AH Vision corresponds to the definition of four additive dimensions, settled according to the peculiarities of the current application, but potentially unlimited. Indeed, by following the same procedures of the current research—(i) investigation of the application field, (ii) definition of principles, parameters, indicators, and evaluation criteria and (iii) data management based on the digitalization of the building process—the method becomes endlessly relevant for any possible use.

Therefore, the same flexibility should be reported to the visualization tool, the up-dated sibling of the AH Radar, where the multi-dimensional aspect of the evaluation turns out into a dimensional upgrade of the flat chart (Fig. 3.8). The spherical development of the upgraded visualization tool reflects the complexity of multiple evaluation dimensions, towards an always more complex and holistic approach.

The sphere grid, indeed, pigeonholes the tool structure, as follows (Figs. 3.8 and 3.9).

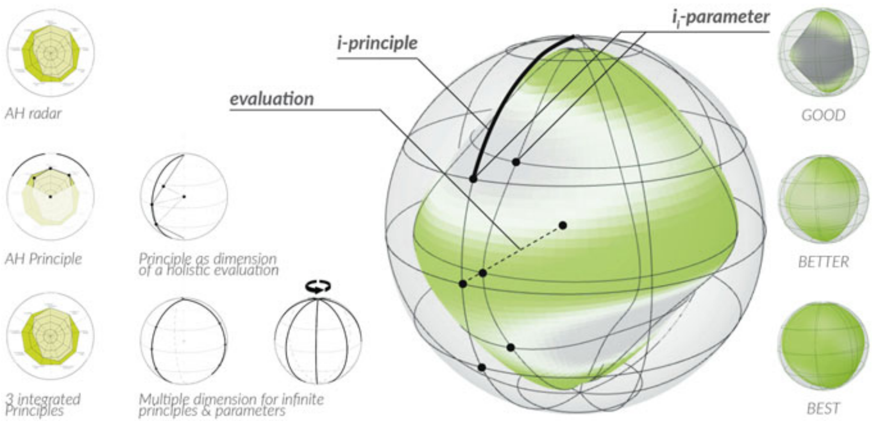

Fig. 3.8 Starting from the Active House Radar chart with its three principles of comfort, energy and environment, the upgraded tool has been enriched by a set of additive principles, displayed through quantitative parameters and indicators, which give additional dimensions to the evaluation, recalling a 360° development where the type and number of parameters could be always customized and infinitely implemented. *Source* Author's elaboration

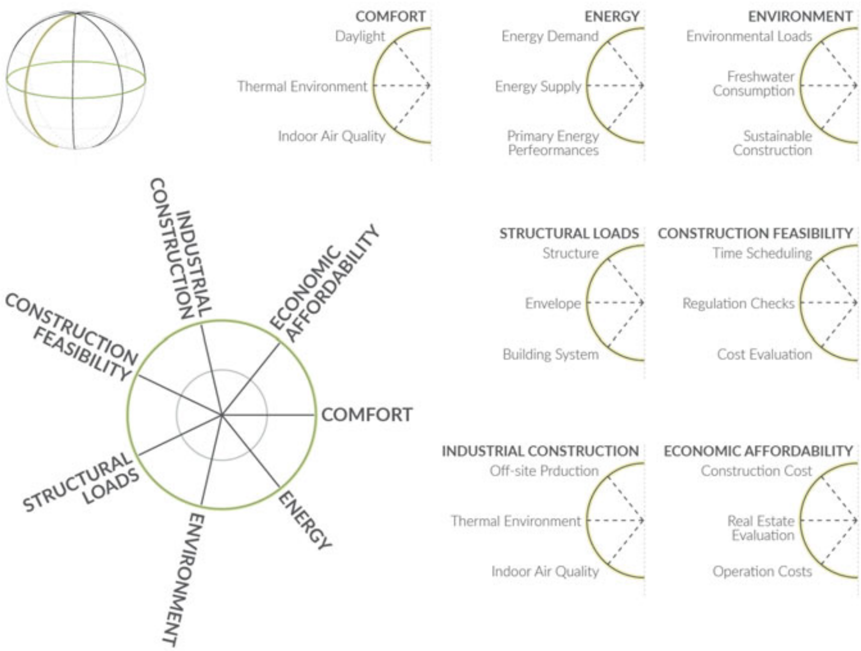

Fig. 3.9 Tool architecture, with the evaluation principles and parameters, specifically defined for the research aim. *Source* Author's elaboration

- The meridian lines represent the evaluation principles, as a translation from the sector of the AH Radar chart to the circumference of the spherical graph;
- Over those lines, at the crossing points with the parallel ones, the dots represent each parameter belonging to the upper level.

The result of the evaluation is a weighted value between 1 and 4, in order to not divert from the already consolidated AH evaluation system, and is represented by the inner distance between the midpoint of the sphere and the parameter dots over the external surface. Therefore, the holistic evaluation results in a polyhedral, three-dimensional mass, inside the sphere, whose maximum enlargement represents the best optimization of all the building features in order to meet the initial requirements. Moreover, in order to provide the reader with clear information about the result of the performed evaluation, the resulting values are mapped also according to a chromatic visualization over the mass surface (Fig. 3.8).

Besides, flat radar charts are also available as two-dimensional extractions from the spherical mass (Fig. 3.9), offering the additional possibility to analyze and compare different scenarios, by the overlapping of two-dimensional graphs.

3.2.4 The Evaluation Across the Entire Building Process: Design Optioneering, Construction Check, and Cognitive Building

The previous sections of this chapter have outlined the specific path of the research resulting in the definition of an evaluation methodology that merges the AH approach with new additive principles, inside the framework of a BIM-based management of processes. Thus, the final outcome is a set of tools to support the building process: (i) the new Specifications, displayed into (ii) a visualization graph, which elaborates the project information through BIM procedures and platforms. This last segment describes the scope and goal of the taleah tool, its proposed application within the entire building process, its architecture, and its innovated workflow. These features are presented as open to whichever number of evaluative dimensions would be used, with full respect to the infinite potential applications of this parametric system, and corresponding fields of application within the AEC sector.

3.2.4.1 Scope and Goals

The final research product has been conceived in order to propose a holistic validation tool able to support the decision-makers along the building process in facing the challenge of a sustainable change for the construction sector. The so-defined scope, indeed, mirrors the initial vision and is reflected in the final goal of identifying innovative models of process, products, and projects, here in the specific field of wood-based construction technologies, applied as additive solutions for the transformation of the existing building stock.

Thus, by referring to the different stages of the building process, the scope of the tool implies the definition of its architecture and workflow, which present slight differences when moving on from design to construction and operation.

Besides, the goal defines the field of application within the construction sector, specifically referring to the results from the case-studies experimentation.

3.2.4.2 Applications Within the Building Process

The national and international construction practices, even with slight differences from country to country, identify mainly three stages of the building process: (i) planning and design, (ii) production and construction, (iii) operation. Furthermore, the analyses BIM standards break down the building process with higher detail, aiming the rearrangement of its information management, by the definition of different levels of development (and related contents): Brief, Concept, Early (or Preliminary) design, Detailed design, Final Design, Design for Construction, As-built, and Operation [4, 7] (Table 3.2).

As already anticipated and according to these definitions, Table 3.2 appoints the Level of Development progression—referred to as information contents of the model—to the gradual evolution of the building process, introducing the progressive stages of the process and their related information contents, gathered in three main time-frames, corresponding to the main tasks required to the application of the tool:

Table 3.2 The building process, revised according to the proposed evaluation method and integrated into BIM language. *Source* Author's elaboration based on [3–7].

			[6, 3]	[4, 5]		[7]	
Design	Design optioneering			1	Brief		
		Conceptual design	LOD 100	2	Concept	A	Symbolic
		Early design (preliminary)	LOD 200	3	Definition	B	Generic
		Detailed design	LOD 300	4	Design	C	Defined
		Final design	LOD 350			D	Detailed
Construction	Construction check	Design for construction	LOD 400	5	Build and commission	E	Specific
		As-built	LOD 500	6	Handover and closeout	F	Built
Operation	Cognitive building	Operation and monitoring	–	7	Operation	G	Updated

Source Author's elaboration

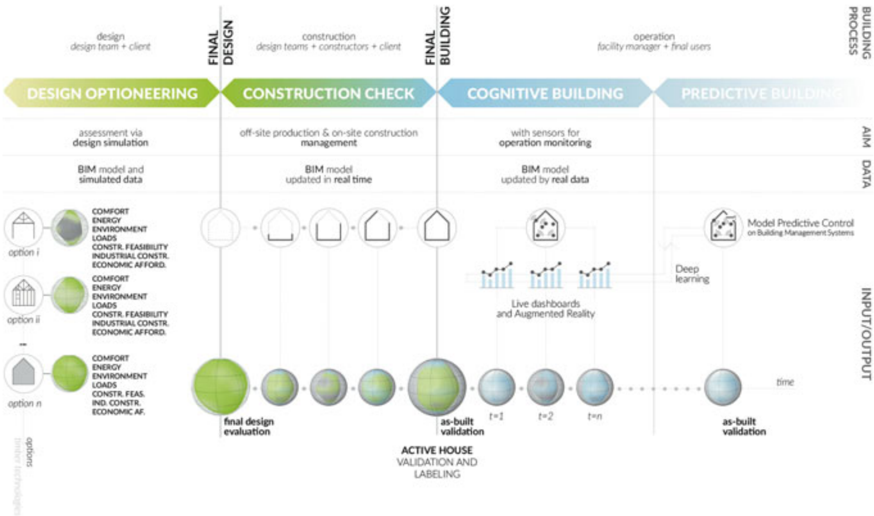

Fig. 3.10 Application of the methodology to the building process. *Source* Author's elaboration

the *Design Optioneering*, the *Construction Check*, and the *Cognitive Building*, where the Final Design and the Final Building are the transition moments (Fig. 3.10).

Design Optioneering. During the design phase, the decision-maker (i.e. the client and/or the designer) is asked to consider multiple options, as possible solutions for the specific project, from various design strategies to different construction technologies, all of them bringing lots of data, information, and variables into the discussion. At this moment, the tool helps firstly to manage the input/output fluxes of data and information, by relying on the building model as the database of the project information. This database is, indeed, progressively implemented according to the development of the design process, and/or slightly changed, case-by-case, to describe the multiple scenarios to be compared. Through the technical specifications, the tool also gives the instructions to perform the required simulations and calculations, and get the results to be assessed according to the defined evaluation criteria. Therefore, it can dynamically analyze and compare different design choices, exactly according to the Design Optioneering approach, assessing which solution better satisfies the project aims.

Once this solution is defined, the project arrives into the Final Design stage and is ready to be processed by the constructor, entering the Design for Construction phase.

Construction Check. Stepping out in the construction phase, the virtual decisions become real construction items, with a possible update of all the products' information. The virtual sibling of the upcoming building becomes more specified and reliable, referring to real construction materials, elements, and components, as intended to be used (Design for Construction). Other changes could be detected also during the construction when the constructor is asked to progressively update the model to the As-built status. Here the tool performs iterative checks, back and forth, of the work-site operations, until the final evaluation and possible Active House labeling of the project.

Cognitive Building. After the realization of the building, its performances are assessable through monitoring surveys, where sensors-retrieved data can show—with interactive dashboards—the evolution of the building behavior during its operation. At this moment of the building process, the tool is used to compare different scenarios where the discriminating variable is time and the consequent evolution of systems conditions. Defining the monitoring set-up, the Zero time ($t = 0$) is the initial condition, in which the building is empty, and the real performances of its components could be tested as a reaction to real outdoor conditions. By $t = i$ (with $i = 1, 2, \ldots n$), instead, occupants start to use the building, interacting with the operating systems and envelope components, such as windows or shadings, to customize the indoor spaces according to their preferences. By using the evaluation tool, in this stage the facility manager or the final user can assess the real-time monitored data, discovering the impact of real users' interaction, and checking performance decay and needs of maintenance. The building, indeed, has become cognitive, giving the users the information and knowledge to better manage its components and spaces.

At last, a clarification is due: within the evaluation principles, some of the corresponding indicators could be improper to be used as dynamic variables, because of the lack of related sensors, capable to retrieved assessable data or simply because de-scribing static features, that are defined once the construction is realized.

Predictive Building. At last, as a further development of this process, the flux of data monitoring/mining/evaluating could be integrated by a Model Predictive Control on Building Management Systems, thanks to machine learning mechanisms driving the operation of the building components towards the optimization of the evaluation parameters (further details at Chap. 5).

3.2.4.3 Tool Architecture and Workflow

The multi-purposes application of the evaluation tool is possible thanks to the flexibility of its architecture (Fig. 3.11). Indeed, it has been conceived to be adaptable to the varied application scenarios of Design Optioneering, Construction Check, and Cognitive Building, by allowing different sources of data and information input, with different levels of details.

Data are collected within the BIM model of the building, by filling it with the required information. The latter derives, indeed, from the definition of the shared parameters of the model, appositely created during the translation of the new specifications into Initial Requirements and become part of the research final product. As a matter of fact, the final workflow (Fig. 3.12) absorbs already the processing procedures of the technical specifications, by listing the essential information to perform the final assessment, according to the BIM-based management setup.

After data collection, the tool architecture works on the extraction of information, which could have multiple forms:

Fig. 3.11 The scheme represents the structure of the tool architecture, as part of the overall workflow of the assessment procedures. *Source* Author's elaboration

Fig. 3.12 The scheme resumes the overall workflow of the evaluation procedures, as the evolution of the same ones based on the Active House certification system and its up-grade according to BIM-based processes for data management. *Source* Author's elaboration

- Project's quantities, assigned to model types and basic data to perform design simulations, during the Design Optioneering;
- Quantitative results from project simulations and/or calculations, performed outside BIM environments, in order to allow the maximum openness and adaptability of the procedures to work with different software;
- Link to bigger data-set—in order to not overload the BIM model—as derived from the dynamic and real-time monitoring surveys of the Cognitive Building phase.

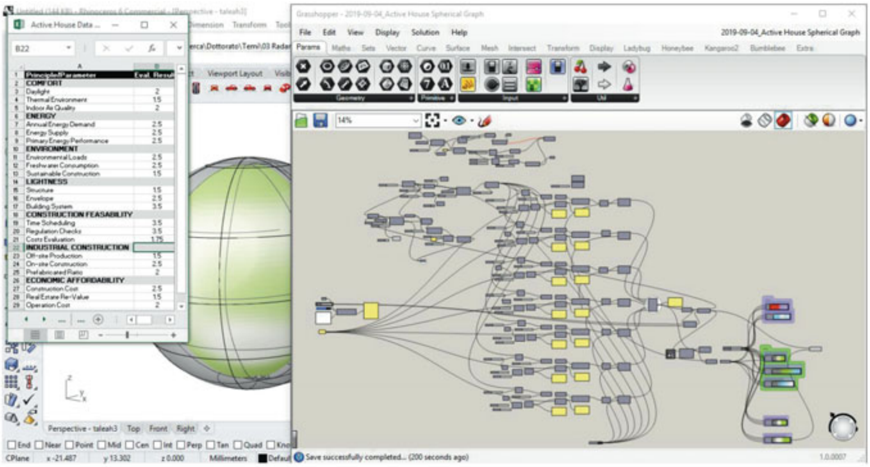

Fig. 3.13 The parametric structure of the visualization tool has been realized within grasshopper software, able to read numerical sheets and transform quantitative data into visual output. *Source* Author's elaboration with the support of Mahmood Tammoli and Andrea Vanossi

This part of the process is realized through projects' scheduling and quantities take-off procedures, inherited as best practices from the from BIM coordination.

Then, the results of data extraction—from Design Optioneering simulations or Cognitive Building monitoring surveys—are processed within specific spreadsheets, according to the new evaluation criteria, in order to achieve the final assessment values.

Finally, these values are displayed within the three-dimensional visualization tool, created within a parametric design platform able to read data from spreadsheets and transform them into a geometrical layout (Fig. 3.13).

3.2.5 The Matter of Data Visualization: Engagement and Communication with the Final User

Data visualization is the graphical display of abstract information for two purposes: sense-making (also called data analysis) and communication [24].

In the definition of the taleah tool, data-visualization—as well as data-management—has played a key role in representing, indeed, the way to translate data into information and knowledge, to communicate with the final reader. It could be both the building expert (the designer, builder, or the facility manager) or the occupant, untrained, e.g., to building physic. The tool has been conceived, indeed, to be the mediator for the interpretation of building behavior, from the simulated performances of the design phase to the monitored ones of building operation and interaction with final users. Thanks to the toolset, the specialist's eye could immediately understand the causal relationship between action and reaction, also seeking more deeply into a multitude of analyses that speaks the building-science language, while the common final user is aided to recognize the effect of human action over the building, as benefiting (or not) the achievement of the final objectives.

3.2.5.1 Engagement and Science Communication Through Data Experience

Buildings don't use energy: People do [25]. The final users' engagement within the building management and increasing awareness of their impact over building operation performances is an essential factor for the achievement of the sustainability aim since their legitimate ignorance is one of the main causes of today buildings' inefficiency [25–28]. It results in the misuse and mismanagement of building components and systems, which is, therefore, not completely predictable for making good assumptions during the design phase, and critical for building operation, doubling, e.g., the forecast total energy consumptions [26]. Buildings are, indeed, complex machines, and the high-efficient ones like those that will be mandatory by 2020—the NZEBs—even more; if the occupants are not aware of their functioning mechanism, even with a lite and aided perception, all the efforts that come before building operation towards the energy-efficiency of the built sector would be vain.

Therefore, while in the design phase the decision-making process would have to focus on people as its first main driver [15], and the simulations would have to account for always more reliable models of building-occupants interaction [28], the other stage of possible actions is the final-users' training and education. Through the user-friendly communication of scientific and reliable data, it can work by leveraging on multi-dimensional factors, from the economic one, which is usually the first driver, to the social (health and well-being) or the environmental dimensions of a more sustainable and holistic approach.

Truly towards this direction, indeed, visual analytics is becoming nowadays always more a data experience. By integrating digitalization and design, it is used to engage people into sustainability issues, increasing their awareness on topics that were limited to the expert and technical audience.

A master example of this spreading phenomenon is represented by the works between art and science of the Dutch Studio Roosegarde [29]: the outstanding design exhibition called Waterlicht (Fig. 3.14), e.g., has been conceived as a visualization of the actual sea level over land, to make people aware of the issue of the rising oceans by an engaging three-dimensional experience. Another example is The Air of the Anthropocene project [30], a collaboration between digital artists and environmental scientists, who have used experimental photography to visualize the levels of PM2.5 in the air.

Using sensors to retrieve data is, indeed, the first step; hence, data-mining and visual analytics help to find the behavioral patterns, whose visualization can better convey a shared knowledge.

Fig. 3.14 Waterlicht in Toronto, October 2018, realized by Studio Roosegarde [29]. *Source* Author's photo credit

Stephen Jay Gould's quote *the mind is a pattern-seeking machine* means exactly that it's easier to learn by the bigger picture, using patterns to simplify reality, as a basic and innate learning mechanism truly inherited from the past.

3.2.5.2 Data Analytics Techniques: Pros and Cons of the New Tool Visualization

Besides the outstanding experiences on the edge between art and science, data-visualization proves its rising matter also observing the starting-up of multiple platforms and services of visual analytics (also for different research fields) [31], parallel to the huge boost of the job market around data analysts (+372%), especially with data visualization skills (+2475%) [32]. Furthermore, the use of sensors and the related big amount of real-time data that characterized the IoT field of the AEC sector need always more the help of visual analytics in order to empower and enable people to understand the impact of their interaction with buildings and, thereof, to change their behavior for a better indoor and outdoor environment. Towards this direction, indeed, a lot of real experiences [33, 34] have been developed within the research fields, accounting on the digital application for smartphones or online dashboards, capable to plot the data into a user-friendly format for the democratization of knowledge and better interaction and remote control of building components.

These realities have inherited a set of principles, which have been outlined across the long history of data-visualization from the Cartesian graph at first, resulting from the investigations and analyses about the efficiency and effectiveness of different graphic tools and visual techniques [35–38]. The latter has indeed helped the definition of the tool visualization strategy, addressing the aim to use the tool with a communication purpose, and stressing out the following considerations:

- The objective intelligibility of the graph is better when the forms are simple, generally based on a two-dimensional platform, and close to the language used in the field of application (e.g. in the medical one, the graphic language has become so consolidated that it makes no sense to change it);
- The visualizations in context consist in the comparison of the presented value with the final target or the average of the population to which the sample be-longs (for example, the heartbeats trend graphs could have not an absolute value for the average user if not visually compared to the mean values registered for people with the same characteristics); this technique becomes useful in order to transform data into information and knowledge;
- The abstract visualization allows defining a good/medium/poor / very bad judgment already mediated with respect to the context, to overcome the obstacle of understanding the raw data (as the tool weighting system already does).

Thereof, as related to the final visual output of the new evaluation method, a list of possible weaknesses and proposed strengths to overcome them is following:

- The 3D visualization is a dimensional upgrade of the 2D radar chart, in order to convey the integration of multiple parameters to the evaluation procedure (Fig. 3.9);
- The choice of a 3D visualization, however, could become a critical limitation for the sake of a good comprehension of the graph: the final geometry is an unknown and unconventional mass that becomes a proper sphere only when all the evaluation values reach their optimum; thereof, the comparison between different options could be difficult to interpret and should pass through another level of visualization.
- In order to overcome the issues of a 3D geometry, the information redundancy is given, with shape and colors, whose contrast (gray/green) helps to make a distinct evaluation (bad/good), while a different saturation reflects the possible nuances of the assessment values;
- As additive visual supports, 2D bar-plots, listing the parameters' evaluation results compared to the lower and upper thresholds, help in alerting on critical aspects (Figs. 3.15 and 3.16);
- B0esides, 2D radar charts, like the AH one, group different principles to give addressed perspectives for the interpretation of the results (Figs. 3.9, 3.17 and 3.18); 2D radar charts are indeed visual forms that could be very usual for the

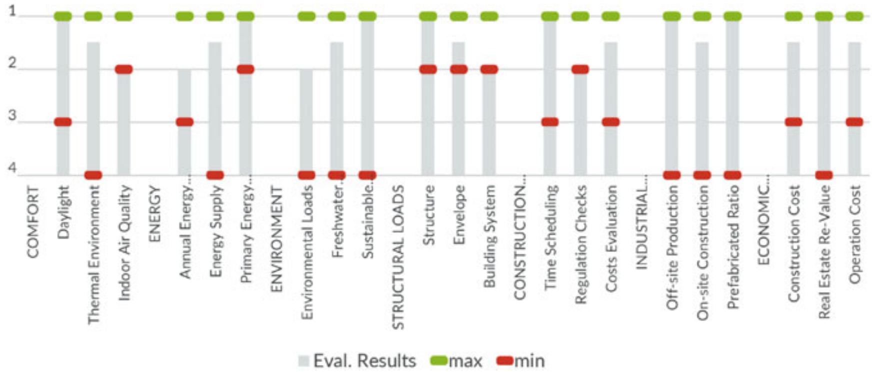

Fig. 3.15 Real-time dashboards, additional to the 3D graph, plotting out the patterns of monitored (and/or simulated) data; in particular, the graph here above reports the indoor temperature profile, hourly-based, retrieved by environmental sensors by Leapcraft (co-partner in this work) and available on online platforms of data-visualization (http://labs.leapcraft.dk/milan/#). *Source* Author's elaboration on Leapcraft dashboard output

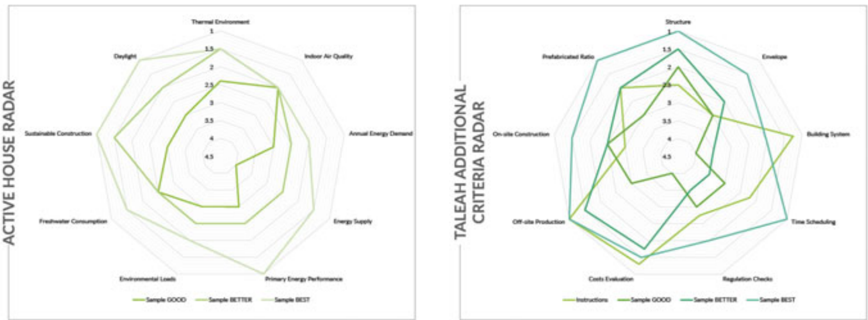

Fig. 3.16. 2D bar-plots, listing the parameters' evaluation results compared to the lower and upper thresholds, help in conveying the alerts or critical aspects; in particular, the graph refers to the sample 3D graph which represents the BEST configuration (see Fig. 3.7). *Source* Author's elaboration

comparison on different scores between multiple options.

The final aim of the three-dimensional visualization is, therefore, to suggest qualitatively the impact of the performed simulations or monitoring surveys' results, as given by the chromatic scale over the graph surface and its anamorphic shape (Fig. 3.8), while the deeper quantitative values are available through parallel dashboards plotting the patterns of raw data (Fig. 3.15).

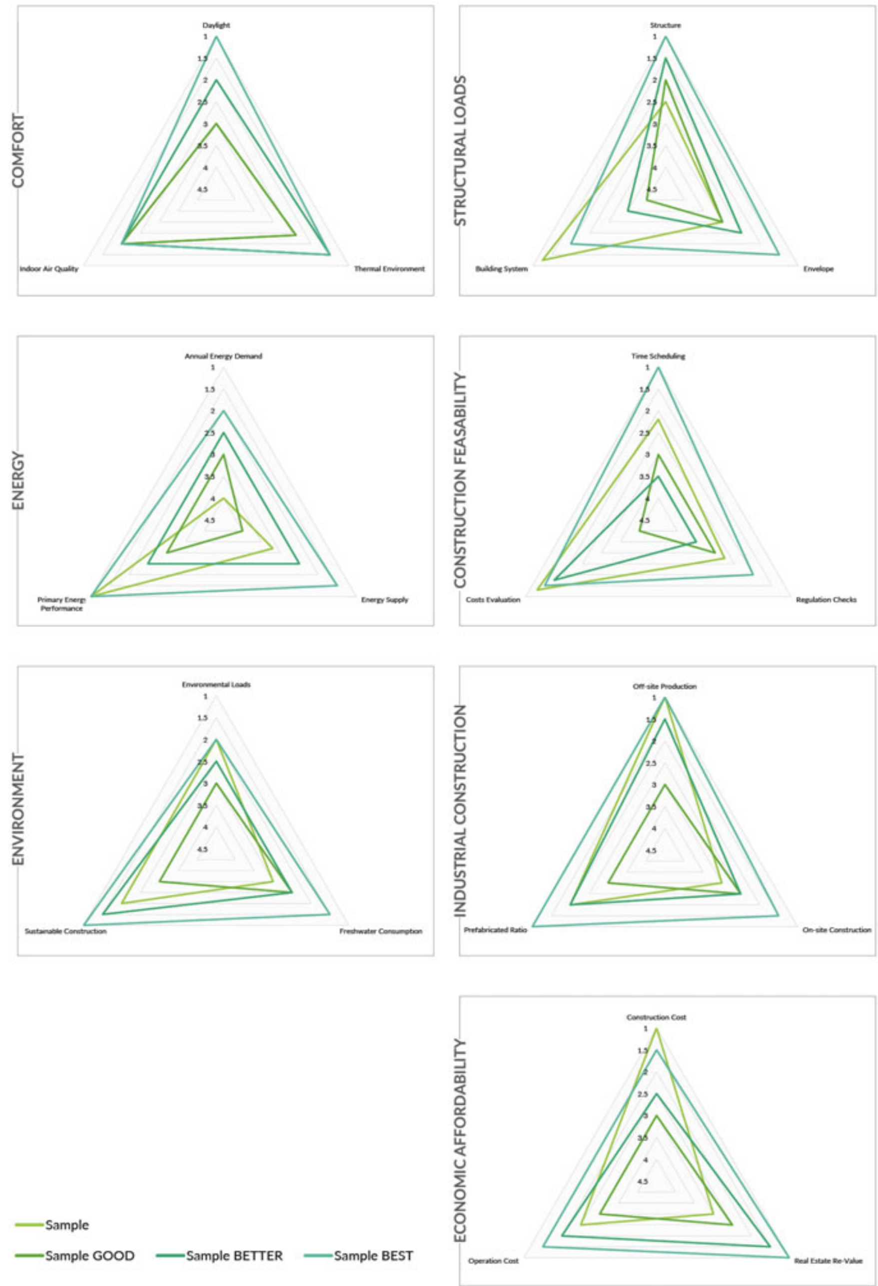

Fig. 3.17 The 2D radar charts, like the Active House one, group different principles to give special perspectives on the interpretation of the evaluation results and related building behavior features; in this case, the output is useful to compare different options on the same dashboard. *Source* Author's elaboration

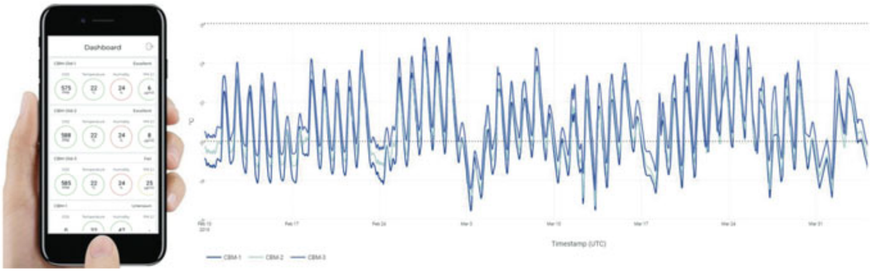

Fig. 3.18 The 2D radar charts, sorted by following the different principles to give the evaluation for each of them, according to the related parameters and indicators; in particular, the graph refers to the samples of the 3D graph which represents the three configurations: GOOD, BETTER, and BEST. *Source* Author's elaboration

References

1. Celaschi F, Lucchio LD, Imbesi L (2017) DESIGN E PHIGITAL PRODUCTION: PROGETTARE NELL'ERA DELL'INDUSTRIA 4.0. MD Journal, 4 (2017 Design & Industry 4.0 revolution), 6–13
2. Eastman C, Teicholz P, Sacks R, Liston K, Di Giuda GM, Villa V (2016) Il Bim. Guida completa al Building Information Modeling. In: Hoepli (ed)
3. BIMForum (2018) Level of development specification 2018. For Building Information Model
4. BSI (2013) PAS 1192–2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling
5. BSI (2013) PAS 1192–3:2014 Specification for information management for the operational phase of assets using building information modelling
6. AIA (2013) G202™–201. Project building information modeling protocol form
7. UNI (2017) UNI 11337:2017 Edilizia e opere di ingegneria civile Gestione digitale dei processi informativi delle costruzioni
8. 3XN/GXN. (2012). Sustainable building certifications. In: Jensen KG, Birgisdottir H (eds) SBi and GXN. Retrieved from https://gxn.3xn.com/wp-content/uploads/sites/4/2018/08/Guide-to-Green-Building-Certifications-August-2018-weblow-res.pdf
9. Bolpagni M, Ciribini ALC (2016) The information modeling and the progression of data-driven projects. In: Proceedings of the CIB World Building Congress 2016, vol. III. Building up Business Operations and Their Logic. Shaping Materials and Technologies, pp 296–307. Retrieved from http://www.bimthinkspace.com/2016/07/the-many-faces-of-lod.html
10. International Organization for Standardization (2018) ISO 19650:2018—Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling. Retrieved from https://www.iso.org/standard/68078.html
11. Discetti P (2005) Doctoral thesis "L' Analisi Del Valore Per La Valutazione Comparativa Dei Tracciati Stradali." Università degli Studi di Napoli Federico II.
12. Active House Specifications. Retrieved from www.activehouse.info
13. Active House Guidelines. Retrieved from www.activehouse.info
14. Brambilla A (2014) mediterranean active house: analysis of climate and users impact on energy and indoor comfort in the new efficiency standard for sustainable. Politecnico di Milano, p 7
15. Feifer L, Imperadori M, Salvalai G, Brambilla A, BRUNONE F (2018) Active house: smart nearly zero energy buildings. SpringerBriefs in Applied Sciences and Technology. Springer, Cham
16. Hegger M, Fafflok C, Hegger J, Passig I (2016) Aktivhaus—the reference work: from Passivhaus to Energy-Plus House. BIRKHAUSER VERLAG AG, Basel

17. www.activehouse.info
18. Feifer L, Imperadori M, Salvalai G, Brambilla A, Brunone F (2018) Relevant case studies: a benchmark for future design. In: Active house: smart nearly zero energy Buildings. SpringerBriefs in Applied Sciences and Technology. Springer, Cham
19. Imperadori M (2019) Costruzione stratificata a secco e Active House: paradigmi convergenti per l'innovazione sostenibile. In Maggioli Editore (ed) ACTIVE HOUSE Progettazione e innovazione con tecnologie di costruzione stratificata a secco. Santarcangelo di Romagna
20. Velasquez M, Hester P (2013) An analysis of multi-criteria decision making methods. Int J Oper Res 10(2):56–66
21. Pill J (1971) The Delphi method: substance, context, a critique and an annotated bibliography. Socioecon Plann Sci. https://doi.org/10.1016/0038-0121(71)90041-3
22. Ministero delle Infrastrutture e dei Trasporti (2017) Costruzioni esistenti. In: NTC 2016—Norme tecniche per le Costruzioni 2016
23. Imperadori M (2010) La meccanica dell'architettura, Il Sole 24 ORE, Milano
24. Few S (2013) Data Visualization for Human Perception. The Encyclopedia of Human-Computer Interaction, 2nd edn.
25. Janda K (2011) Buildings don't use energy: people do. Archit Sci Rev 54:15–22. https://doi.org/10.3763/asre.2009.0050
26. Fabi V, Andersen RV, Corgnati S, Olsen BW (2012) Occupant's window opening behaviour: a literature review of factors influencing occupant behavior and models. Build Environ 58:188–198
27. Masoso OT, Grobler LJ (2010) The dark side of occupants' behaviour on building energy use. Energy Build 42:173–177
28. Brunone F, Brambilla A, Sangiorgio M, Imperadori M (2018) Inter-ActiveHouse: users-driven building performances for nearly zero energy buildings in mediterranean climates. In: 7th International building physics conference, IBPC2018 proceedings, healthy, intelligent and resilient building and urban environments, Syracuse, NY, USA, 23–26 Sept 2018, pp 671–676
29. https://www.studioroosegaarde.net/project/waterlicht
30. Price R (2019) Written in the wind: visualising air pollution levels—in pictures | Cities | The Guardian. Retrieved 7 Aug 2019, from https://www.theguardian.com/cities/gallery/2019/apr/09/written-in-the-wind-visualising-air-pollution-levels-in-pictures
31. Gray J, Bounegru L, Milan S, Ciuccarelli P (2016) Ways of seeing data: toward a critical literacy for data visualizations as research objects and research devices. In: Kubitschko S, Kaun A (eds) Innovative methods in media and communication research. Palgrave Macmillan, Cham
32. Learning and earning—Special Report (2017) Retrieved from https://www.economist.com/sites/default/files/learning_and_earning.pdf
33. Imperadori M, Salvalai G, Brunone F, Fumagalli MA, Scoccia R (2018) The sense of sensors. In: International conference on smart, sustainable and sensuous settlements transformation (3SSettlements) proceedings, Technische Universität München (TUM), Germany, 7–8 March 2018, pp 169–175
34. Imperadori M, Brunone F (2019) Active House and user-friendly visualization of sensors' monitored data: VELUXlab, a real cognitive and smart NZEB prototype. In: 9 IOP conference series: earth environment science 296 012042
35. Munzner T (2018) Visualization analysis and design. Vis Anal Des. https://doi.org/10.1201/b17511
36. Few S (2012) Show me the numbers: designing tables and graphs to Enlighten, 2nd edn. Analytics Press. Retrieved from http://www.stephen-few.com/smtn.php
37. Tufte E (2001) The visual display of quantitative information, 2nd edn. Technometrics, vol 2
38. Rees D, Laramee RS (2019) A survey of information visualization books. Comput Graph Forum 38(1):610–646. https://doi.org/10.1111/cgf.13595

Chapter 4
A Validation Opportunity: Case-Studies Analysis and Outcomes on the Application of the Method on Real Buildings

Abstract By closing the current dissertation, this chapter presents the practical implications of *taleah* methodology and tools, through the opportunity of testing them on two concrete case studies: *1 + 1 house* and *n + 1 dome*. The first one represents the vertically-up densification phenomenon, small-scaled on the widely spread one-family houses; the second one identifies the same phenomenon at an urban scale; two diversified applications of the Building Above strategy, realized through timber-based construction systems. As per Galileo Galilei's words, *sensata esperienza, necessaria dimostrazione* represents the spirit and structure of the research method, and the importance to resort to the demonstration of deducted hypothesis, as based on the observation of real phenomena. Working with real buildings is fundamental, indeed, in order to understand the reliability of the set procedures, as tested on different scenarios.

Keywords Wooden post & beams construction system · Timber frams construction system · Massive cross-lam panels construction system · Building transformation · Design optioneering · Cognitive building · Multi-dimensional analysis · Evaluation process · Case studies

4.1 Set-Up of the Methodology for the Real Case Studies

Previous chapters have already defined the key aspects of *taleah* procedures and tools, by describing the research methodology that had lead to their definition, and by outlining the specifications, the calculation methods, and the visualization tool architecture, functioning, and application across the entire building process.

From *Design Optioneering* (DO) to *Cognitive Building* (CB), the methodology is now applied on two real buildings, here considered as building prototypes of timber-based technologies application within the transformation of previously-existing buildings. In both of the two cases, the *Design Optioneering* phase evaluates the different outcomes of three construction systems: (i) post & beams, (ii) timber frame, and (iii) massive cross-lam panels. Hence, a set of sensors has been used for a three

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months monitoring campaign of the indoor environmental conditions, in order to detect the dynamic behavior of the so-defined *Cognitive Buildings*.

Since the two examples were both already built at the beginning of this experimentation, the *Construction Check* (CC) phase has not been tested.

4.1.1 Design Optioneering Set-Up

The first step of the demonstrative process is the set-up of the *Design Optioneering* phase, which compares different scenarios as different possible options, which are evaluable through the same quantitative parameters and indicators.

In the following dissertation, the design stage considers the optioneering method as applied of different construction technologies, which have been defined by following the previous analyses on timber-based systems. The evaluation compares three different construction systems, selected among the others because considered the three most wide-spread ones; according to [1], indeed, the framed slender systems cover 55% of realized timber buildings, while the 38% is built with massive cross-laminated panels, finally overcoming the 90% of the actual Italian timber constructions market. Almost the same results have been confirmed by the trends shown in Chap. 2: for the Building Above retrofitting strategy, almost 100% of the experiences belong to Structural Frame Systems (42%), Timber Frame System (26%), and the Mass-Timber—Slab and Plate System (32%).

The three technological solutions have been defined as three different possible options (Figs. 4.1 and 4.2), which address all the same specific performances:

- Thermal transmittance U: 0.113–0.124 W/m^{2}k for the external walls, 0.126–0.130 W/m^{2}k for the roof;
- Thermal delay: ≈17 h for the walls, ≈20 h for the roof;

of the technological units that belong to the real envelope of the building prototypes. This choice underlies the need to allow the comparison between two different moments of the building process: the design simulations and the monitoring of the indicators related to the control of the indoor environment conditions during the building operation.

According to these starting inputs, the BIM models of the two buildings have been created, by following the indications of *taleah* BEP. The definition and detailing of the models have been considered already at LOD 350—as the pre-defined and already built prototypes which have defined the BIM Library of the current experiment set the level of information at the highest stage of the design.

The projects' information has been then extracted and processed within the simulation platforms and calculation tools, in order to derive the quantitative values of *taleah* indicators and to perform the assessments. The final results are shown within the *taleah* graphs, for each one of the validated options.

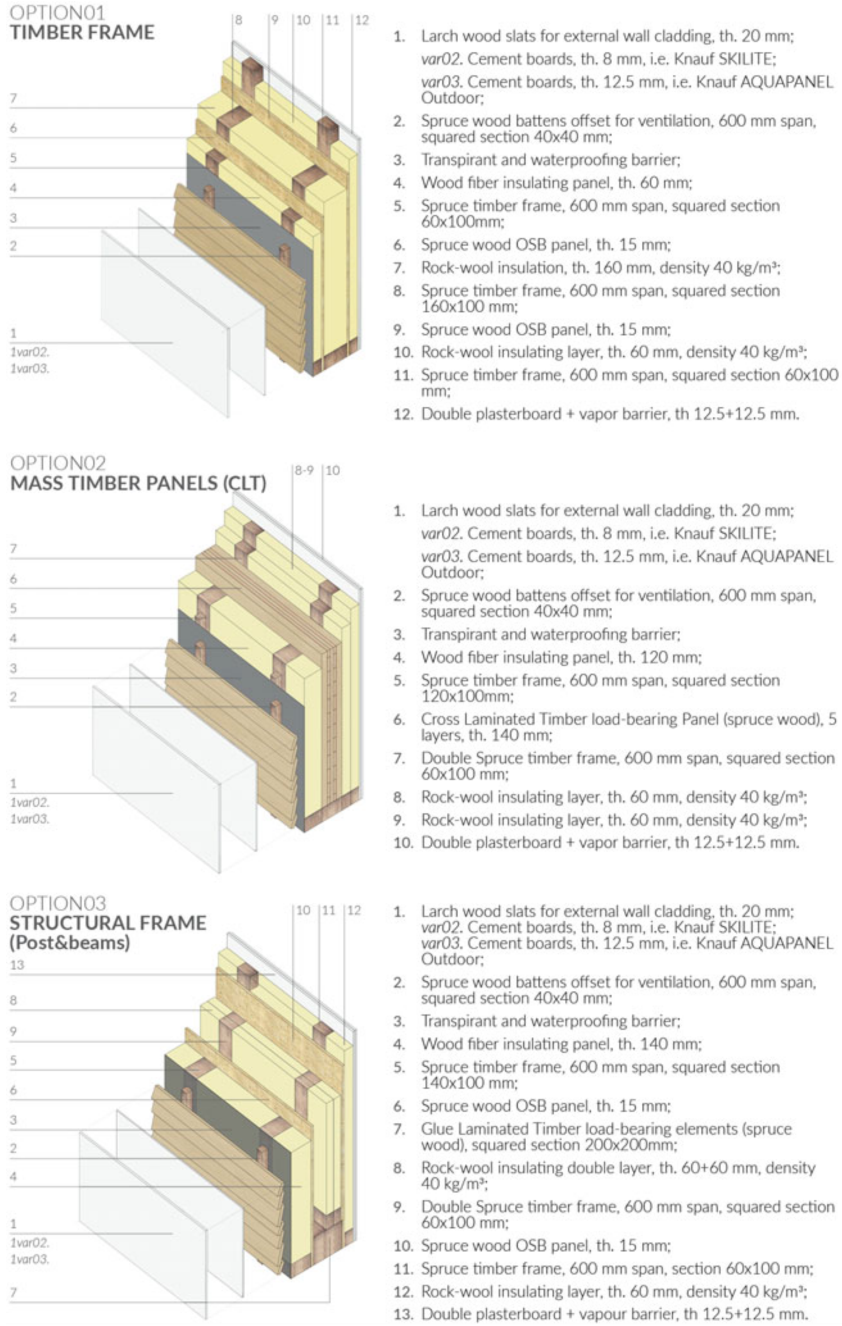

Fig. 4.1 Design optioneering over the three different technological solutions: OPT01—Timber Framed, OPT 02—CLT, and OPT 03—Post & Beam (evaluated with different finishing materials (1), in order to test the corresponding weight evaluation). *Source* Drawings have been extracted from the BIM model and graphically edited by the Author

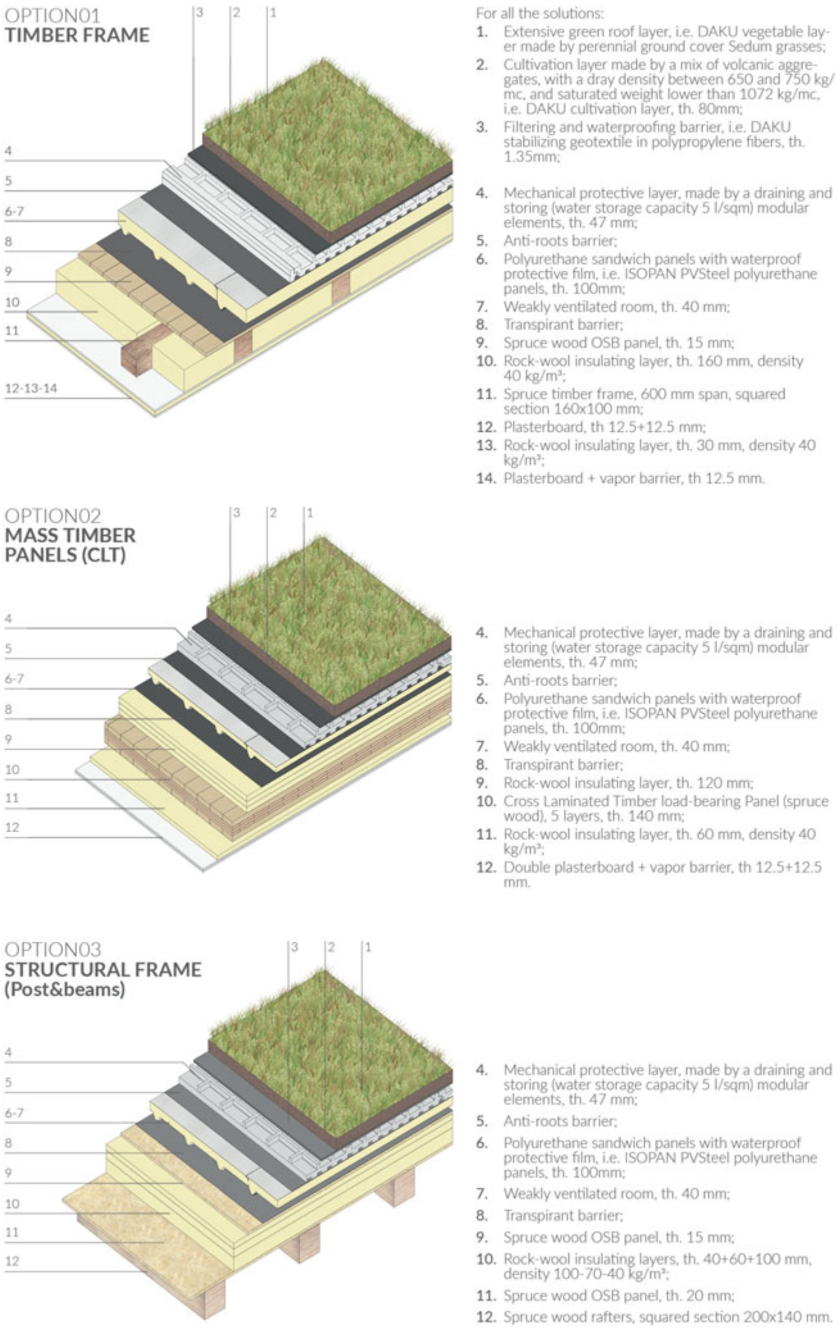

Fig. 4.2 Design optioneering over the three different technological solutions: OPT01—Timber Framed, OPT 02—CLT, and OPT 03—Post & Beam, for the roofing components of the buildings. *Source* Drawings extracted from the BIM model and graphically edited by the Author

4.1.2 Cognitive Building Set-Up

Cognitive building relies on sensors, being smart buildings equipped with systems that are able to collect data and information to let the final user acquire the knowledge to manage their operation.

Therefore, the two building prototypes have been equipped by a WSN (Wireless Sensor Network), whose devices measure data to quantitatively represent the indoor environment conditions:

- Visual comfort, measured through lux-meters that read the availability of hybrid light on specific work plans [LUX];
- Thermal comfort, compute as derived from the indoor temperature values [°C] and their comparison with standards thresholds [2];
- Indoor Air Quality, considered by measuring the concentration of pollutant elements in the indoor air, i.e. CO_2, PM2.5 PM10, VOC [ppm and/or mg/m^3].

These parameters, and corresponding indicators, can be dynamically assessed, retrieving also information about the users' interaction with the building, and giving them feedback about the related impacts, through data visualization.

Besides, the smart building experiences demonstrate that also the system production could be monitored through sensor equipment, collecting data and information about the real-time energy demand and production, and remotely control the operation of the installations in order to optimize the energy savings and the overall building energy efficiency. Indeed, this experimentation set-up has considered also:

- Annual Energy Demand [kWh], sensors retrievable;
- Energy Supply [kWh], sensors retrievable;
- Primary Energy Performance, evaluable from the correlation between the Energy Demand and the Energy Supply [3].

Furthermore, other parameters of the *taleah* method are sensitive to (almost) real-time modifications, after the building completion, i.e.:

- Costs Evaluation, dynamically variable in the parts corresponding to Real Estate value updating and Operation Costs;
- Real Estate Re-Value, updated accordingly to real estate market trends and indexes;
- Operation Cost, estimated through the monitoring of Energy Demand and related prices.

4.2 Case Studies: 1 + 1 House and N + 1 dome as First Examples

1 + 1 house	**Location**	Cassano d'Adda, Bergamo, Italy
	Project type	Spatial addition
	Use	Residential
	Client	Private Owner
	Project	**Design** ATelier2—Gallotti e Imperadori Associati; **Constructor** Hanse Haus
	Year	2012

Intro

1 + 1 house (Fig. 4.3) is a volumetric addition to an existing one-story family house, doubling its volume with newer spaces and proposing its architectural restyling.

Located in the province of Bergamo, the project represents the feasibility of a densification phenomenon that could involve the Italian small residential stock as a wider strategy for the renovation of the built environment.

Interaction with the Existing Building

Under an architectural and energetic profile, the added volume works to achieve high standards of indoor comfort, for both the existing and the newest spaces: the insulated wooden structure that lay on the existing walls defines a thermally controlled space, which balances the energy exchanges between the existing house and the outer environment, better than the original existing roof. Finally, the project testifies that the vertical volume extension could be a good design strategy to combine urban densification with energy retrofitting.

Timber technology

The newer part of the building was originally designed and realized with a Post & Beam construction system. The system is based on glue-laminated timber elements as structural components, and, in this case, completed by ready-made timber panels for the outer envelope. This technological option aimed to boost construction time, reduce the functional impact on the existing lived spaces below, and consequently address one of the main requirements of the building transformation strategies.

Fig. 4.3 *1 + 1 house*: drawings of the plan and section views (scale 1:30), and some photos of the construction works and final building. *Source* Author's photo credit and editing of the original technical drawings by ATelier2 and Hanse Haus

n + 1 dome	**Location**	Milan, Italy
	Project type	Spatial addition and urban densification—Energy efficiency improvement
	Use	Residential
	Client	Private Owner
	Project	**Design** ACXT/IDOM studio (original demo-house), ATelier2 (retrofitted building prototype for Politecnico di Milano); **Constructor** Marlegno
	Year	2012/2019

Intro

n + 1 dome is a project which aims to guess the potential transformation of urban areas, center and suburbs, overcrowded by mid-rise and high-rise condos (Fig. 4.4). By adding smaller volumes upon them, like small nests over their roofs, the goal is to circularly create renovated economies for the built environment, in terms of real estate improved evaluation, increased energy efficiency, and, thereof, urban regeneration.

Interaction with the Existing Building

This vision truly belongs to the AH research, as testified by the realization and validation of several demo-houses [4], conceived to be a vertically up extension of existing buildings, and which have underlaid, thereof, the definition of the current project features. The *n + 1 dome* project has, indeed, inherited the construction features of VELUXlab, the first NZEB laboratory of Politecnico di Milano and the first Italian AH certified as-built.

Therefore, the current experimentation has virtually proposed the building as an additive modular volume for the spatial transformation of existing buildings, with an infinite repetition potential.

Timber Technology

The actual envelope, realized through dry construction technologies, has been considered as made with timber-based technologies, whose definition aimed to reach the same thermal performances as the real building components. The newer volume lays down on the existing rooftop by loading the existing cement-based (or masonry-based) load-bearing structure and being anchored through hold-down connectors. The access to the rooftop is possible through pre-designed and prefabricated modular elements, with skylights to get light and natural ventilation through spatial connectors. In the end, the newer floor could be both formally integrated into the existing building, by the continuity of the finishing layers of the envelope, or designed as an iconic volume, as conceived by the parasite architecture.

Fig. 4.4 Technical drawings and building prototype of *n + 1 dome*, imagined as a modular volume, possibly multiplied with different spatial configurations and added on the top floor of a mid-rise or high-rise buildings. *Source* Author's elaboration based on the initial geometry of VELUXlab

4.3 Application Results and Discussions

The first output of the described analyses is the evaluation of different construction systems, following the Design Optioneering method.

The resulting radar graphs (Fig. 4.5) show a similar evaluation of the thermal performances, due to the initial condition of the current optioneering analysis (same thermal transmittance and thermal delay). Besides, all the other computations are strictly bonded to the QTO of volumes and weights. By crossing them with the construction Costs calculation, indeed, it has been possible to derive interesting evaluation about the construction and production time, while the estimation of the Construction Time is based on the costs' values, given by the local price lists [5].

By the specific comparison of the three structural options, it is possible to observe that the Construction Time values reflect the advantages of prefabrication, especially for the CLT solutions, since the structural product is shipped directly to the work-site, ready to be assembled and covered by the insulating and finishing layers. Afterward, the Post & beams and the Timber Frame systems are following, since through the prince lists data-set those solutions are considered as necessarily assembled at the work-site, without any kind of prefabrication (after the first sawing processes of timber elements). Among them, the Timber Frame results to be even more time-consuming, because of the multitude of smaller elements (studs and beams) to be assembled. However, the values overturn when considering the entire solution (and not only the structural components): the Timber Frame additional layers (especially with the insulation ones) are already integrated within the studs' spans, both if the assembling of the building element is made at the factory or at the work-site. However, the discussion could not be very detailed about the related Prefabrication Potential, since the entries of the prices list refer to standardize practices, with a lower grade of prefabrication, and not updated to the most innovative technologies, available nowadays in a constantly updating and upgrading industry.

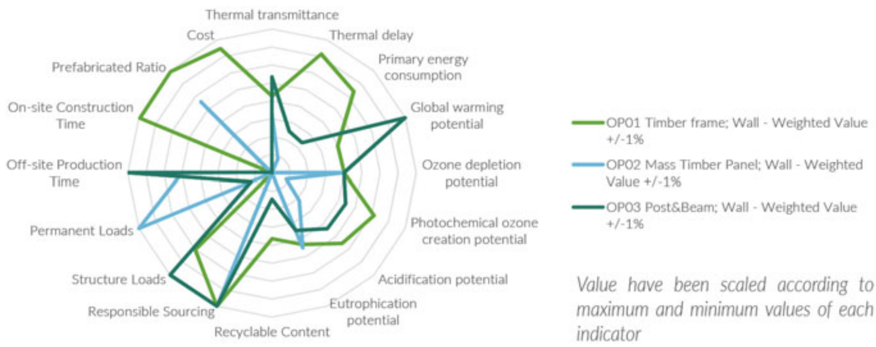

Fig. 4.5 Design optioneering results over the three different technological solutions: OPT01—Timber Framed, OPT 02 CLT, and OPT 03—Post & Beam; the graphs have been extracted from *taleah* calculation tool, which input data derive directly from the BIM Library models. *Source* Author's elaboration

The resulting data describing the performances of each technological option have been then imported within the BIM models of the two case studies in order to start the evaluation procedure: the results are schemed within Figs. 4.6 and 4.7.

The following main insights for further discussions about the outcomes of the multiple analyses have been considered by comparing the resulting values among: (i) different options (DO) or scenarios (CB), (ii) different stages of the building process, with a validation purpose between design and operation, and (iii) different projects (*1 + 1 house* vs. *n + 1 dome*).

4.3.1 Design Optioneering, Construction Check, and Cognitive Building Results

DO—Daylight. Both the case studies present different values for the daylight factor evaluation, when changing the technological solutions. Even if the differences among the three outcomes are not enough sensitive to change the final evaluation results on the 3D graphs, the values outline that the minimum requirements (FLDm > 2%), and the higher daylight uniformity are granted especially by the Post & beam solution, as affected by the thicknesses of the envelope, differently characterized within each scenario.

DO—Environmental Loads. As related to the LCA of the construction material, the trends of the buildings' evaluation follow the DO outcomes of the related environmental values.

DO—Sustainable Construction. All the technological options are dry layered construction solutions, being completely disassembled, dismantled, and possibly reuse into an up-cycle process or recycled to a new life, especially for the timber components.

DO—Structure, Envelope, and Building System. The specific ratio between the built and new volumes plays here a fundamental role (1 + 1 or n + 1). In particular, for *1 + 1 house*, only the Post & beam solution complies with the limit values to proceed without a structural adjustment of the existing for seismic prevention. However, by considering also the possible variable loads due to building destination, this further structural verification results mandatory, as proven by the work-site operations.

CB—Thermal Environment. The values of Indoor Air Temperature (approximated to the Operative Temperature specified for the evaluation of this parameter) testify to the reliability of the envelope solutions and their high performances.

CB—Indoor Air Quality. The values of Indoor Air Quality (evaluated on CO_2 concentration) demonstrate the great impact of the human factor inside a lived space. The final users, indeed, have (and pretend) the control of building components, such as the opening and closing of windows, which have an important effect on the availability of fresh air through natural ventilation.

CB—Annual Energy Demand, Energy Supply, and Primary Energy Performance. The monitoring survey of these parameters has been available only for the *n*

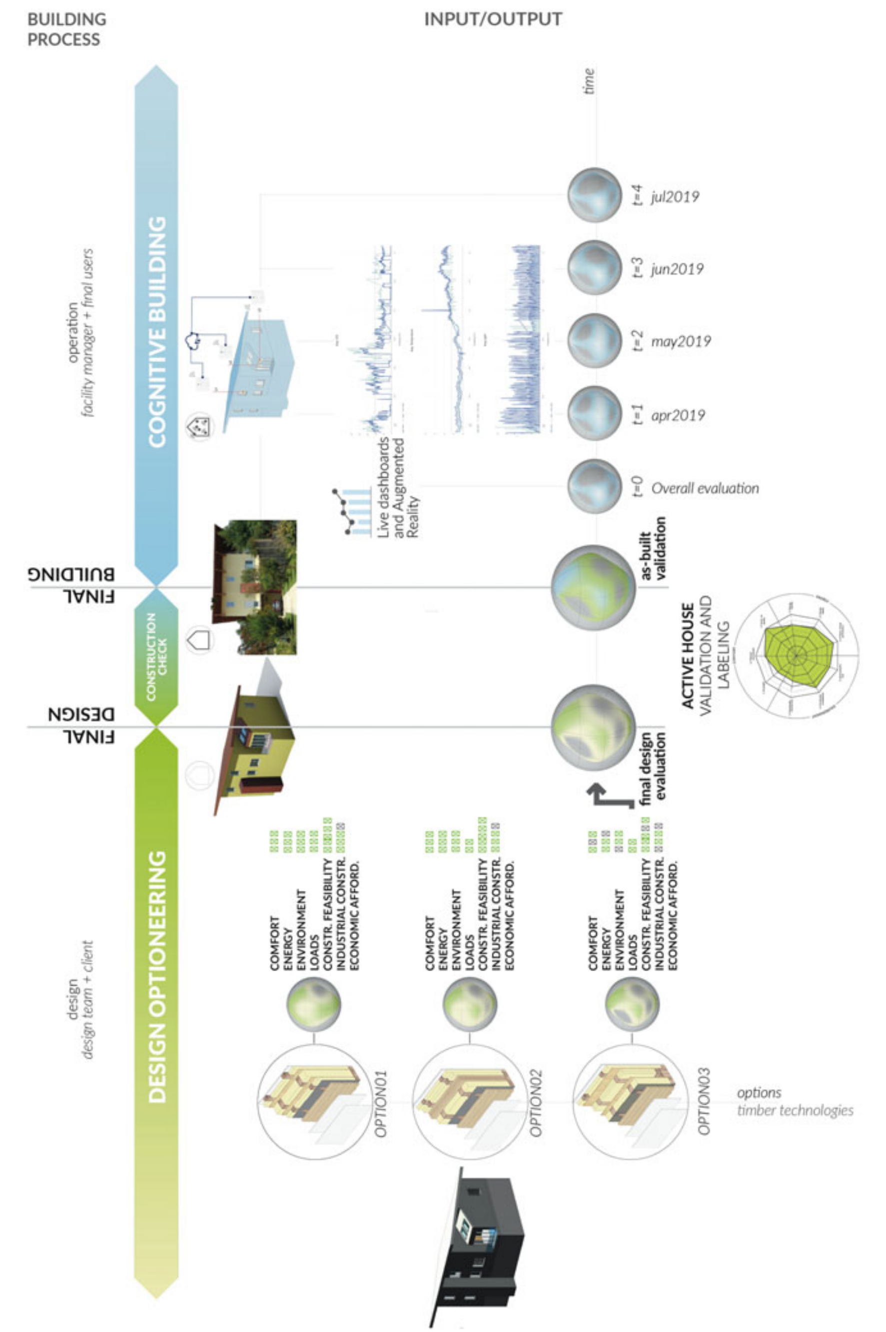

Fig. 4.6 Application of *taleah* methodology to the building process to *1 + 1 house* case-study. *Source* Author's elaboration

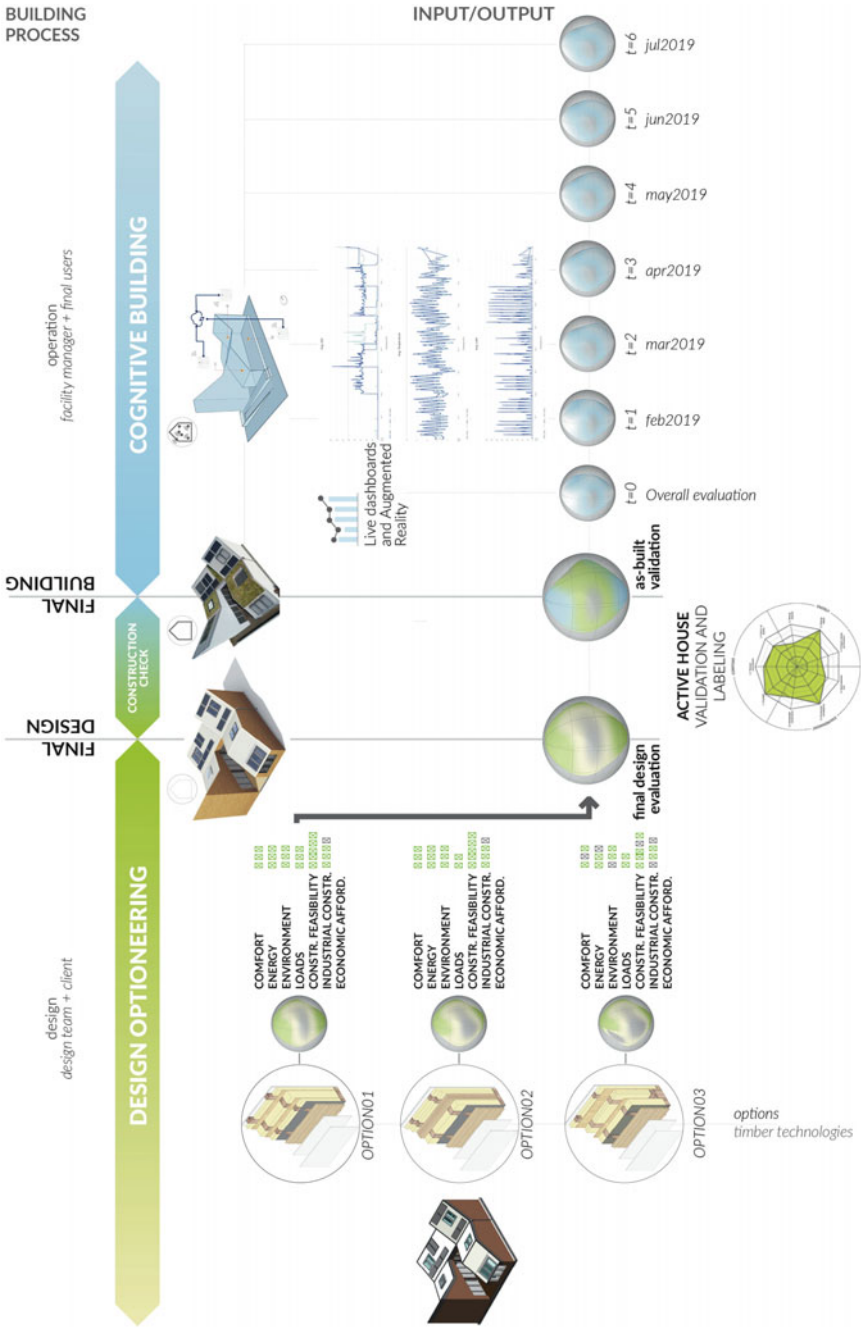

Fig. 4.7 Application of *taleah* methodology to the building process to *n + 1 dome* case-study. *Source* Author's elaboration

+ *1 dome* project since it was already equipped with the specific sensors network. The survey confirms the high energy efficiency of the building, which have been already validated to be the first Italian NZEB, both thanks to the envelope and systems solutions, and the adoption of renewable energy sources, such as the PV panels on the roof and the outdoor heat pump with heat exchanger.

4.3.2 1 + 1 House and N + 1 dome: The Comparison Between Two Different Transformation Strategies

The comparison between the outcomes of the two opposite transformation strategies (1 + 1 and n + 1) results interesting especially about:

DO—Structure, Envelope, and Building System. The analyses have evaluated the volume (and weights) addition by considering both the effective geometries and the related quantities to be added on the existing buildings. In particular, the 1 + 1 strategy is suitable only after a structural reinforcement of the building foundations, and vertical elements of the existing building, whichever technical solution is chosen; contrariwise, the n + 1 proposal is available with any solution, since the volumes ratio is inevitably advantageous. In any case, however, the structural calculation needs to pass by the proper procedures, as specified by the Eurocodes and derived standards [6].

DO—Real Estate Re-Value. Almost the same considerations could relate to this parameter, even if with opposite advantages for the two solutions. Indeed, because of its proportional dependency by the total additional area, the n + 1 strategy is less sensitive to a direct improvement of the entire building value, than the 1 + 1 (+23 vs 400%). However, it has to be noticed that the visionary transformation of the existing building could be extended to other parts, such as the façade recladding, activating a virtuous cycle of circular economies.

CB—Operation Costs. The high level of both the two case studies on this parameter is justified by the high energy efficiency of the technical and technological solutions adopted, which allowed to reach also high standards among other protocols for energy performance certifications. Both the sample, indeed, have been evaluated as Active Houses and through the Lombard certification protocol of CENED, reaching the A-Class for *1 + 1 house* and the A + Class for *n + 1 dome*. The Operation Costs have been considered, indeed, as proportional to the consumed energy for building operation.

4.4 Research Outcomes and Conclusions

The main focus of the research work has been the development of a new and innovative approach to the whole life cycle building performance evaluation, specifically applied to the field of additive retrofit in timer construction. Hence, its application on two real case studies, and the retrieved results have helped to prove and outline the great potential that timber-based technologies have as a varied portfolio of solutions for the transformation of the built environment.

Different construction systems represent different options, suitable to satisfy the variety of requirements in a versatile way. In particular, the two case studies—*1 + 1 house* and *n + 1 dome*—have represented the possible transformation strategies for two opposite stereotypes of half of the Italian existing buildings, proving the high catching potential of those additive solutions on the building market and the impact of the proposal. 53% of the residential building stock—which represents 90% of the entire built environment—consists, indeed, of one-unit buildings (21%), or better single-family houses, and +9 units (32%), or multi-stories constructions [7, 8].

References

1. Centro Studi Federlegno Arredo Eventi SpA (2015) Rapporto case ed edifici in legno 2015. Milano
2. EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics
3. Active House Specifications. Retrieved from www.activehouse.info
4. Feifer L, Imperadori M, Salvalai G, Brambilla A, BRUNONE F (2018) Active House: smart nearly zero energy buildings. SpringerBriefs in applied sciences and technology. Springer, Cham
5. http://www.elencoprezzi2018.provincia.tn.it/
6. Ministero delle Infrastrutture e dei Trasporti (2017) Costruzioni esistenti. In NTC 2016—Norme tecniche per le Costruzioni 2016
7. Centro Studi Federlegno Arredo Eventi SpA (2015) Rapporto case ed edifici in legno 2015. Milano
8. Centro Studi Federlegno Arredo Eventi SpA (2018) 3° Rapporto Case ed Edifici in Legno. Milano

Chapter 5
From Cognitive Buildings to Digital Twin: The Frontier of Digitalization for the Management of the Built Environment

Abstract The BIM holistic approach leads the AEC sector to manage all the different disciplines involved in the construction process. Its nDimensions, indeed, concern geometry, structure, systems (3D), work-site management—also in terms of time and costs—(4D, 5D), safety, energy performances (6D), maintenance and building management (7D). Besides the analysis of the state of the art, the $n + 1$ *dome* case study has been used to explain the advantages of BIM, sensitization and digital tool application for both product and asset management (PIM, AIM). Finally, the chapter illustrates the potential of Internet of Things (IoT), Machine Learning (ML) and Artificial Intelligence (AI), moving from Cognitive to Predictive buildings, nowadays conceived as the new perspective of 4.0 construction.

5.1 CAD/CAM/BIM: New Codes for an Integrated Building Process

The building process' digitalization has started with introducing computer-aided practices in the AEC sector, even though without a cohesive integration between the design and the production phases mutual development. On one side, Computer Aided Design (CAD) changed architects' and engineers' work [1] irrevocably, while Computer Aided Manufacturing (CAM) has involved the construction industry with the invention and development of, e.g., CNC-based machinery (Computer Numerical Control). These machines moved the assembly processes from the work-site to the factory with the advent of prefabrication (Fig. 5.1), or moving the factory to the work-site, towards Robotics Construction processes. This step is particularly relevant for the timber production system, leading wood to become an industrialized construction material as described in Chap. 2.

By emerging as a cure to the illness of poor interoperability in the industry [2], in the recent decade, BIM (Building Information Modeling) has stepped in [3–7]. The acronym unveils a new paradigm, today already accepted as a new strategy for information management, and, more recently, as a new construction management

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Fig. 5.1 The timber construction industry is an example of the 4.0 revolution: here the prefabrication potential is maximized, starting from the first sawing processes moved to factory decades ago, to the development of CNC assembling processes. *Source* Author's photo credit at HOME TECHNOLOGY plant, October 2018

method [2]. According to its definition [3], Building Information Modeling is a set of collaborative processes defined to realized, manage, obtain and share information among multiple players. It refers to a unique, shared model (coordination model) containing numerous types of data and information that engage various fields and different stages of the building process itself.

Following the global market trend (one billion euro only in Italy), the policymakers began to promote [8] the digitalization of the design processes to lay the groundwork to further smart management of the built environment. The comparison of the international and national standards [9–16] considered as the leading guidelines for BIM use results in the definition of different but interconnected ways to approach the building process: (i) by following the development of the consecutive phases of the process and the detailing of the BIM language [9–14, 17–19], suitable to share information and knowledge about the project, or (ii) by defining the BIM dimensions where data, information, and knowledge could be displayed and used [3, 4, 15, 16].

5.2 Building Process and BIM Dimensions

BIM is the most relevant application of IT to the construction sector due to its advantages, such as the 30% costs cut-off [20, 21]. The informatization of a simple 3D model led construction to the use of digital tools having a more informed decision process during the project's whole life cycle.The BIM model is enriched with information during the process steps, increasing the LOD from a Geometry Object (2D, 3D size defined) to an AEC Object (with data information). Side by side to LOD implementation, the model application's possible dimensions get determined and implemented (Fig. 5.2).

The first three dimensions are nowadays standard practices for BIM construction companies to optimize coordination tasks and clash detection (3D), building execution process and scheduling (4D), cost estimation and automatically performed Quantity Take Off (QTO). The last two nDs dimensions (6D, 7D) [15] are mainly related to the Internet Of Things (IoT), if considering the BIModel as virtual storage of the data exchanged through the invisible network that nowadays connects all the computing devices (sensors, software, etc.). Digital transformation revolutionized the building business, moving it from a product to a service market. In a 4.0 perspective, Servitization transforms the sector's outlook from a statical temporary relation with the client to a continuous, never-ending connection. Thanks to digitalization, it is possible to give value to the Big Data coming from the sensorization of internal and external spaces.

Fig. 5.2 BIM nDimensions. *Source* Author's elaboration on Syncro Software

5.2.1 BIM Tools and Environments for the Evaluation of the Building Behaviour into a Data-Driven Process (6D)

The sustainability dimension (6D, or GreenBIM) is today considered at the frontier of the most innovative development and application of BIM. It deals with the reduction of energy consumption from the early stage till the End of Life (EoL) in a circular economy approach. Its outcome can be an accurate prediction of the future energy behaviour, performed during the design phase, or the virtual storage of real and measured data, acquired during the operational phase. The BIM platform simplifies the data drawing and parameters encoding for all the multicriteria certifications of energy performance analysis or BEM (Building Energy Modeling) [15] and Life Cycle Assessment (LCA), even if calculated through several methods [22, 23, 35]. Numerous plugins and simulation software becomes cloud-based services and operations by automating the calculation procedures.

While LCA can be performed only for new buildings, the approach for existing assetscould be twofold: (i) define a flexible and machine-readable database, or (ii) create a detailed Asset Information Model (AIM) by retrieving data for the evaluative methods through those instruments that are typical of refurbishment operation (see 4.1.6). In these cases, in order to ease the sustainability-aimed assessment, the BIM procedure could be lightened by promoting shallow geometric information (LOD) and a very high information content [29], based on COBie (Construction Operations Building information exchange) semantic. COBie outlines a standardized methodology to collect information in the design and construction process within the IFC (Industries Foundation Classes) files: the object-oriented data model of buildings that specifies physical or abstract items relationship to describe, exchange, and share information.

Therefore, two issues are emerging nowadays in the application of BIM-6D to new and/or existing constructions: (i) the possible loss of standardization of interoperability protocols, and (ii) the choice to rely on a single software to which tie the plugins' implementation, that may decrease tools' flexibility [22, 29].

5.2.2 From Design to Operation: IoT in the AEC Sector for the Management of Building Assets Towards the Definition of Cognitive Buildings (7D)

The 7D-Facility Management dimension serves specifically the operational phase, where the "as-built" model can be used as a database of all the specifications, operations and maintenance manuals and warranty information, useful for the management of building life, after construction.

IoT is the interconnection, via the Internet, of computing devices embedded in everyday objects, enabling them to send and receive data. Its introduction within the

AEC sector and its integration into BIM processes enhance real-time asset tracking through a framework of data retrieved from a network of equipment, sensors, wearables, etc. Those devices can detect and collect huge amounts of data shared on cloud-based databases that could be mined to seek behavioural patterns and introduce the building scale into Big Data science's broad and trend topic. In particular, this new frontier is going further the more straightforward building automation by collecting the experiences of high efficient, smart, and active constructions under the wider definition of Cognitive Buildings. Pasini et al. [36] has defined them as items that could be delivered as services, thanks to the innovation in products evolution (from Building Automation Systems to micro-controllers), in building processes (thanks to BIM interoperability) and technologies [31, 32]. Therefore, cognitive buildings can: (i) actively react to users' activities and interactions; (ii) understand and memorize occupants' preferences; (iii) learn from past experiences; (iv) communicate and collaborate among themselves within an interconnected grid of assets (such as smart districted).

By the definition of Cognitive Buildings and its integration with BIM methodologies, it is possible to open infinite doors that can connect multiple dimensions or even develop additional ones. A potential application, which integrates multiple aspects of building operation, has been proposed in the proposed methodology (Sect. 3.2). It has been conceived to analyze of the interaction between the building and the outdoor environment, as well as the impact of the final users' action on indoor conditions and building performances.

5.2.3 *Informed Building Processes for the Existing Building Stock Management and Transformation*

An interesting application context of the 7D of BIM is represented by the existing building stock's management (and the potential transformation).

This scenario unveils as potential assets both (i) the valuable items of the architectural heritage and (ii) the most ordinary buildings which populate the built environment accounting for most of it. Only by referring to the Italian context—one of the world's most culturally enriched—only one hundred thousand buildings are considered with remarkable value, over a population of 14 million [25]. Thus, the application's potential market is double, with differences for final aims and strategical solutions, but with the same prime need: defining a different methodology to manage the working process with the same wished interoperability of new construction.

In order to meet the requirements of renovation and restoration practices with the development of BIM methodologies, the Italian standards [13] have implemented their specifications, i.e. by defining appropriate LODs (F and G) for this kind of scenario. At the same time—or even in advance—several real experiences have tested the potentials (and actual limitations) of BIM as applied to conservation projects [26] and the techniques that could help the information acquisition. Indeed, the latter is fundamental to get the proper knowledge about the existing building (not always so easily retrievable), while BIM integration helps organize and maintain it updated, with the global and final aim to define a correct operative choices building renewal and/or transformation. The challenge is therefore three-fold:

- To form a progressive in-depth knowledge of the existing building object, winning the poor availability and reliability of data and information—tracked back to the documentary;
- To transfer it to a digital environment, so that it becomes integrated into the building process for the entire building lifecycle;
- To constantly adapt the Standards' requirements for high LODs content, to the capacity to acquire information of even the most updated and digital survey techniques and to store them within BIModels.

In particular, the asymmetry between the information retrievable from the standardized technical documentation and the "as-built" status of the built item could relate to several factors: (i) The action of time, causing alterations of forms, appearance and characteristics of elements and materials because of degradation phenomena; (ii) The difference between what has been planned and then reported in the documentation and what is actually built; (iii) Stratification of interventions, incorrectly documented.

In this perspective the application of 3D laser scanning (TLS) for a detailed and accurate geometry (LOD) and material/performances information definition (LOI) can be integrated with digital IoT tools. Another innovative and under development intuition of the potential interaction between the 6th and 7th dimensions, even if on a different scale, is represented by the GIS maps able to acquire and share information about entire building districts' energy profiles both for new and existing buildings.

In the end, the BIM-aided work-plan has to include:

- The definition of specific parameters to allow the model customization and the future upgrading and maintenance use;
- The creation of a BIM library, with ad hoc modelled objects, whose LODs, especially graphic, is defined in relation to the project requirements.

In conclusion, the interoperability of BIM procedures, in terms of (i) management of information fluxes at different scales and different levels of the building process, (ii) coordination of different disciplines, and (iii) management and integration of cross-wise dimensions, has shown the already solid bases of a methodology that has transformed the AEC sector and is still evolving in infinite potentials.

5.3 N + 1 Dome a Case Study for the Application of BIM

The n + 1 dome is a case study for the innovative management method of the building process. It consists of three steps concerning the three main phases of its life: from the Early Design Stage (EDS) to the final one, validating of the As-Built and the

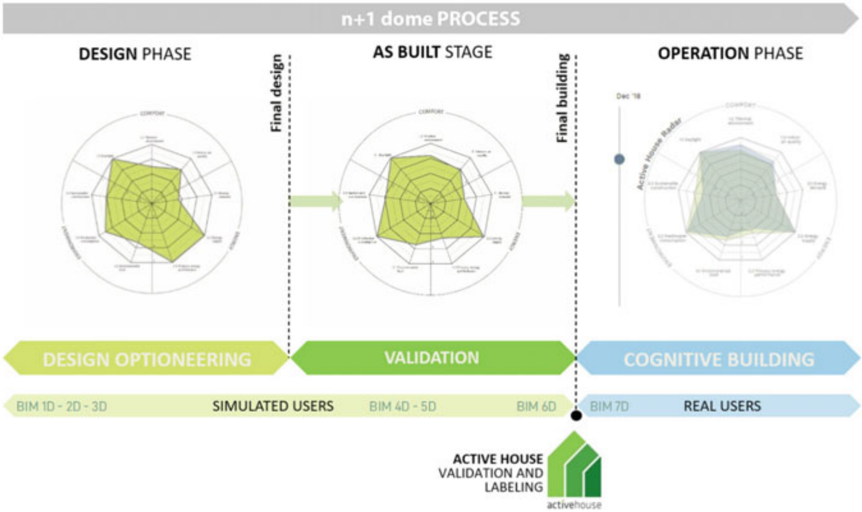

Fig. 5.3 The n + 1 dome checking process from Design Optioneering, to validation and Cognitive buildings through the BIM nDimensions. *Source* Author's elaboration

operation phase. The first two steps concern simulated users because there are no people inside the building, while the third is based on real users behaviour. The innovative method for managing the building process starts from creating a BIM model able to reach data from designers and return information coming from the sensors.

The Design Optioneering (DO) [30] [33, 34] multicriteria analysis allows for a more effective decision process thanks to examining all the involved parameters, from the construction till the end of life phases. This design loop, based on interoperability, is an Active process of the design phase based on the first three dimensions of BIM. The validation involves the as-built stage and the 4D, 5D, 6D, while the operation phase of cognitive building deals with 6D-7D (Fig. 5.3).

Starting from the design, all the involved teams provide for different models: geometrical, technological, structural, services and building. All of them are federated models created with the open BIM Industry Foundation Classes (IFC) standard to interact for clash detections and geometrical issues (3D). Also, time and cost management and planning (4D-5D) to optimize the construction phase thanks to digital tools since the early adoption of BIM in the construction sector. So, the traditional BIM approach is implemented year by year by applying innovative digital instruments: the sensorization of the physical model and the data sharing process to the digital world creates a loop, typical of the 4.0 concept of Phygital (physical-digital). Its main application is in the 6D BIM dimension: sustainability is now conceived as the lower environmental impact for the best comfort conditions. The NZEB (Nearly Zero

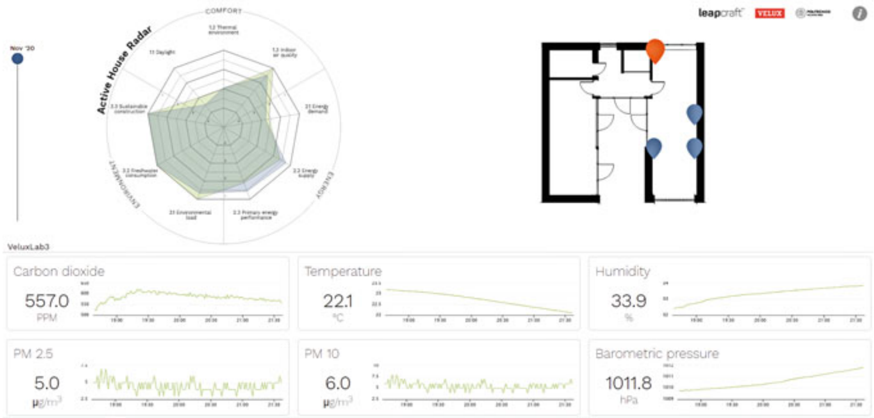

Fig. 5.4 Web dashboard of sensors and parameters modifying the live Active House radar *Source* LeapCraft)

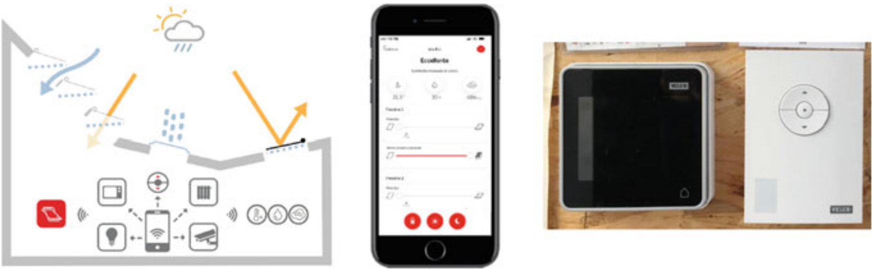

Fig. 5.5 User-friendly sensorization based on automatic and app management. *Source* Author's elaboration on Velux

Energy Buildings) achieves this purpose by having high performances through technological innovations of layers and materials of the envelope, including the constant monitoring of the indoor air quality (Fig. 5.4).

This "neurological" synapsis built by sensors and data is the humble for facility management (7D): a Wireless Sensor Network (WSN) live monitoring of the envelope-service-environment check the performances of the indoor comfort according to the boundary conditions. WSN is a high-level sensor monitoring for experts and technicians users, but there is also a more accessible, user-friendly sensorization level (Fig. 5.5). A new sensors generation[1] manages passive (natural light and ventilation) and active (HVAC) systems to minimize resource consumption.

The integration of these dual-layer sensors networking with advanced technologies, such as the Phase Changing Materials (PCM), allows to monitor the construction (cognitive building) but also to create the database for the Digital Twin (predictive

[1] Developed together with BloxHub research center. It is composed by Ambinodes, Airbirds and Netatmo from, respectively, Leapcraft with 3XN-GXN design and Velux.

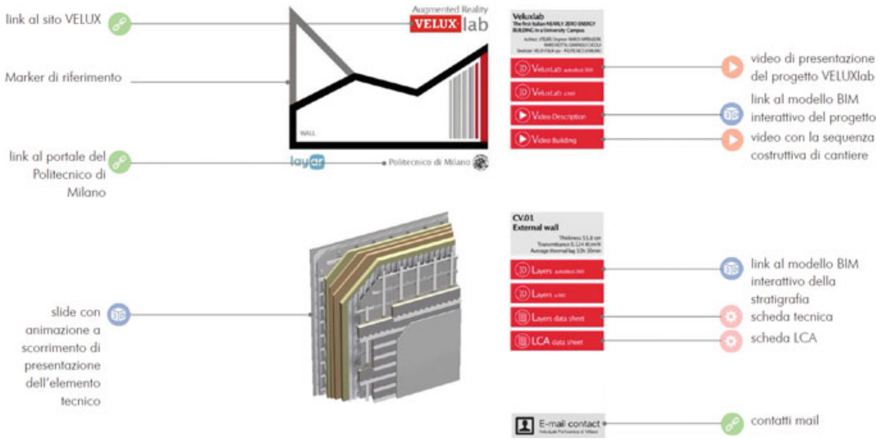

Fig. 5.6 Augmented Reality system checking technical elements and LCA performances thanks to the BIM environment. *Source* Author's elaboration on Layar

building). All the data are live collected and analyzed by a gateway and online shared, splitting them by location and typology (Carbon dioxide, PM 2.5, PM 10, Temperature, Humidity, Barometric Pressure, Lighting, dB) with the help of visual analytics. The BIM oriented approach is completed by real-time scanning and augmented reality. The informed model can be interrogated by users simply scanning bar-codes on the walls or the roof and showing all the elements' information and layers. It also implements the 6D-7D in the LCA perspective, monitoring the single material and phase impact on the whole building during the entire life cycle (Fig. 5.6).

All the complex monitoring system participates in an active construction definition, as in the Active House conception. The building is a sort of test facility building where all the technologies can be integrated into a platform approach and, by adding Machine Learning and Artificial Intelligence to Big Data, to predict the building's future behaviour. The input (the digital DO model), the viewing (the Augmented Reality on the physical element), the construction check (the as-built model in Real-Time Scanning) and the cognitive phase (Active Radar of as-is by sensorising) are yet-ready technologies and the baseline for predictive building application.

5.4 PIM and AIM: The Integration of BIM for Facility Management

Facility Management is the BIM 7D; it concerns the management of buildings during the usage stage. The last market trend pushes constructors also to offer the management phase to the building owner, thanks to the deep knowledge of every aspect of the product. The construction process allows the company to precisely understand every building's critical point, enabling them to preserve and prevent all the issues related

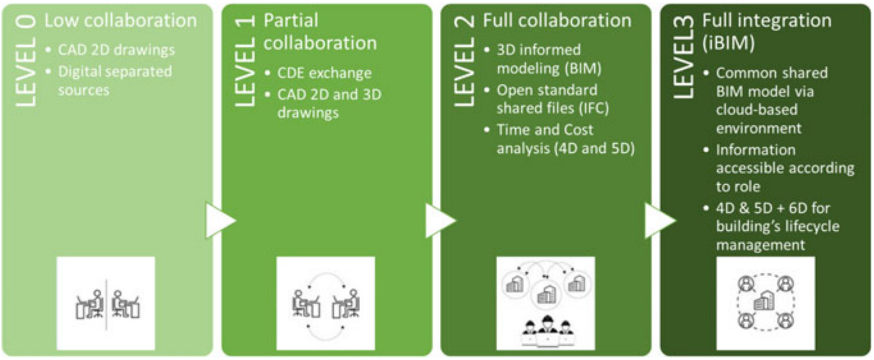

Fig. 5.7 Maturity Level of BIM. *Source* Author's elaboration on https://bim.acca.it/livelli-di-maturita-bim/

to it. Furthermore, the "as-built" model coming from the same company is optimized for the facility management purpose, avoiding the information decay typical of the IFC model deliver. Finally, BIM allows buildings transformation from product to a strategical asset, matching the Servitization process.

According to the National Building Specification, there are four different maturity levels of BIM (Fig. 5.7):

- Level zero, low collaboration: CAD information shared from different sources
- Level one, medium collaboration: CDE data collection and sharing between teams of 2D/3D CAD
- Level two, full collaboration: 3D models shared in one IFC BIM model together with time (4D) and cost (5D) information
- Level three: full iBIM collaboration: BIM cloud sharing model. All the stakeholders fill the data according to their roles. Inclusion of Asset Management (7D) information

The Benefits Measurement Methodology (BMM), born in the UK, is applied to analyze the Return Of Investment (ROI) timing. It standardizes Public Administration (PA) private clients and asset owners, reporting and practices processes, reducing the effort. This methodology was adopted in 2015 and, according to the 2017–2019 survey,[2] it figures out a management time reduction by 50. Furthermore, the Federated Model (FM) with CoBie and CAFM (Computer Aided Facility Management) as enabled standard optimizes asset performance, decreasing facility management by 60%. The percentage grows up to 70% for the single task during operations, while the only digitization of documents avoids the manual input or conversions by 30%. Another approach is to create collective contracts instead of a single commission, enabling economies of scale, thanks to the centralized geography-based management. All these strategies lead to a Total Cost Operation (TCO) saving by 1,5–3% for the single project, but it is much more for the whole asset operation.

[2] PwC 2017–2019 Survey.

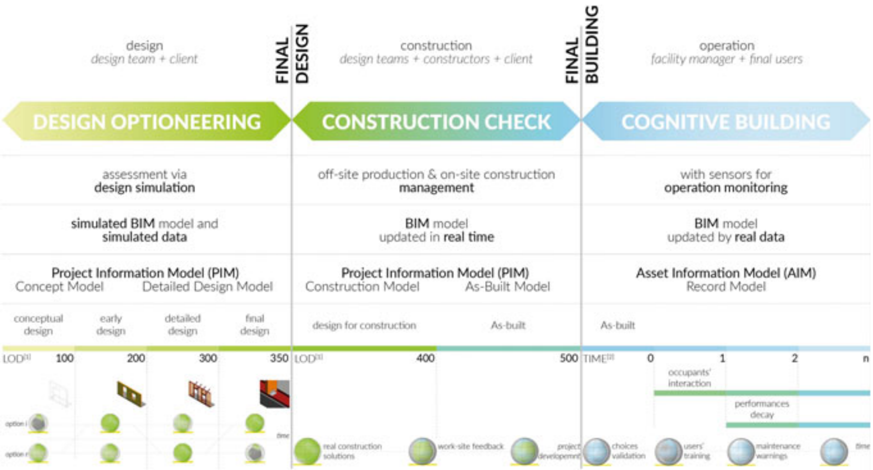

Fig. 5.8 Project Information Model (PIM) and Asset Information Model (AIM) transformation

This different business model is based on a CDE instrument that manages the data acquisition in the project's subsequent steps. The Project Information Model (PIM) [27] starts from construction documents produced during the design phase and ended with the technical documentation added throughout the build. Asset Information Model (AIM) adds the management documentation of the Operation phase to the PIM, creating an information flux parallel to the life stages of the building: from "as designed" to "as build" and finally to "as is" (Fig. 5.8). This process's vision is to move from the work model to the building model, having total management from the initial Project and Construction to the Property & Facility plus the Operation & Maintenance Service. The framework evolution categorizes object (CDE typology), process (construction, logistic, etc.) and activity (checklist, tasks, etc.).

5.5 Digital Twin: IoT for the Construction Sector and Existing Building Management

The next step in the Informative Model approach is Platformization. The sum-up of geometrical and informative data in one single environment can analyze data from the source model, integrate them with real-time sensors and scanning, process them, and give them back to the platform. It is the Digital Twin concept: a virtual model that replicates the existing physical construction. The clone can live-show the current situation and predict its future behaviour from the cognitive building to the predictive one. The data resume inside a "mastermind" (the integrated open BIM solution) allows having a Total Service Asset, combining all the sensors data of different IoT devices in one single live room. The project intelligence network collect data from different levels: tools for modelling (Revit, Archicad, Tekla, Allplan, etc.), platform (Navisworks, Solibri, etc.) and environment (Trimble, A360, BIMPlus, BIMCloud, etc.). This strategy led the Real Estate Management, Portfolio and Project Management, Enterprise Asset Management, Health and Safety from a simple cloud on-premise Core Processes to a Cloud Platform. IoT plays a key role for Services and Platforms acting directly on the Digital Boardroom (Cloud for Analytics) for a mobile asset management application. In this way, the business changes from product to service, activating a Business Network where Project and Asset Intelligence are connected into a Cloud for Real Estate from *design, plan and build* to *operate* and *maintain* products, assets and facilities.

After the data acquisition of as-built models from different file formats, the models are read, visualized and connected by back-end and layers. The project's platform is enriched with additional data coming from owners, technicians and—mainly—users thanks to simple app fault reports and workspace management. All the actors have individual access to models and data according to the role assigned them by the Tenant. Furthermore, an ERP portal dialogue with the maintainer manages the modifies on Master Model to have complete control by checking and authorizing all the single activities. Such a complex interaction of Phygital object requires a multi-disciplinary approach from various professional figures with different backgrounds: construction (architect), technical (engineer), technological (technologist), aesthetical (designer), managerial (strategist), digital (informatic), analytical (data analyst) and much more. The data lake coming from this extensive system involves different competencies of Big Data management:

- Data collection and integration of smart solutions
- Data analysis and interoperability
- IoT architecture design of processes and technologies
- Personal data management

The purpose is to have live monitoring of the building to prevent the decay of the good (the product) managed as an end-to-end service instead of a black-box model. Thanks to sensorization and digitalization, the building's actual approach leads from the black box—where the single element condition is unknown—to the grey box—a bottom-up analysis.

According to the British Standards Institution, *terochnology* combines management, financial, engineering, and other physical assets practices. It deals with reliability and maintainability considering installation, commissioning, operation, maintenance, modification, and replacement processes. The Life Cycle Cost (LCC) introduction into the asset management pushes the terotechnology from downtime costs because of failure to a cost-effective approach. In this perspective, predictive maintenance by sensorization, real-time monitoring of KPI through a dashboard and automatic surveying based on Machine Learning and Artificial Intelligence are combined having a more informed decision process through a decision support system.

With the *BIM design and build*, the *saving and sharing* approach guarantees an objective optimization of the asset management, involving and encouraging the stakeholders' relationship and partnership. The different actors' sharing responsibilities led to economic savings on the budget. The “management entropy” of the traditional process is avoided thanks to the clear and precise procurement phase, in a win–win strategy for all the involved stakeholders.

The Plan-Do-Check-Act or Deming Cycle is used in advanced customer relationship management, having an iterative improvement of product and process quality [28]. By switching from this product-based approach to the Servitization also the required instruments are different.

BIM-based dashboards are the platform able to collect the multi-value “kaleidoscope” (theoretically infinite) of DO into a horizontal and vertical connected project. Info-graphic, gaming and deep learning are key aspects to feed the live model in continuous innovation. In this future outlook perspective, good practice collected—e.g. from ISO 19,650 and UNI 11,337 or the ISO 16,739 about interoperability—helps define a common language for a standard process. Still, they can only describe one of the three big families of instruments: the modelling and informed software. The interaction of this “common” software with specialistic ones for economic and quantity take-off data extraction or time and performance planning is defined time by time by every single service provider. They use the third family—a cloud BIM-based platform—to incubate data and models and share them with different stakeholders. Here communications, planning, orders, bills and check are digitalized, avoiding the information loss between the actors (General Contractor, Project Management, Owner, Client, Suppliers, etc.) and optimizing the on-field tasks (Fig. 5.9).

The aim to have a complete Digital Twin of the physical building is still further development because of the infinite aspects (BIM nD) that construction involves. Although the dialogue between reality and virtuality is present for many years, the

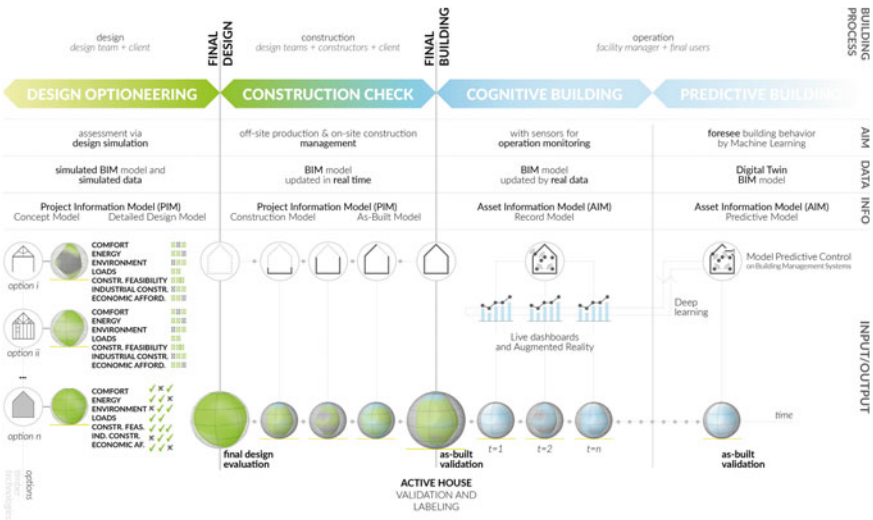

Fig. 5.9 Aim, data, info and input/output process from concept design and simulated BIM model to predictive building and digital twin

digital revolution's acceleration is evident in the last few years, involving all the operative phases of the process and production. The "technological Esperanto" language develops the built materialization where communication and construction live in a continuous stimulation synergy. Using an historical parallelism, the Building sector entered the Medieval period of digital transformation, where only few pioneers start to act in a revolutionary way. The question is: when will we reach the Renaissance period where this will be the standard way?

References

1. Brown P (2009) CAD: do computers aid the design process after all? Intersect 2(1):52–66
2. Isikdag U (2015) The future of building information modelling: BIM 2.0. In: Enhanced building information models: using IoT services and integration patterns, pp 1–121. https://doi.org/10.1007/978-3-319-21825-0
3. Eastman C, Teicholz P, Sacks R, Liston K (2008) BIM handbook—a guide to building information modeling for owners, managers, designers, engineers, and contractors. In: Notes and queries, vol s7–II. https://doi.org/10.1093/nq/s7-II.32.110-e
4. Eastman C, Teicholz P, Sacks R, Liston K, Di Giuda GM, Villa V (2016) Il Bim. Guida completa al building information modeling. In: Hoepli (ed)
5. Borrmann A, König M, Koch C, Beetz J (2018) Building information modeling. Springer, Cham
6. Bolpagni M, Ciribini ALC (2016) The information modelling and the progression of data-driven projects. In: Proceedings of the CIB World Building Congress 2016. Building up business operations and their logic. Shaping materials and technologies, vol III, pp 296–307. Retrieved from http://www.bimthinkspace.com/2016/07/the-many-faces-of-lod.html
7. Pavan A (2017) Employer Information Requirements (EIR) e BIM Execution Plan (BEP), quanta confusione! Retrieved 1 Aug 2019, from https://www.ingenio-web.it/6713-employer-information-requirements-eir-e-bim-execution-plan-bepquanta-confusione
8. Anafyo (2015) Il BIM in Italia: un quadro della situazione. Retrieved from www.impresedilinews.it/files/2016/12/Italian_Bim_Report_2015_Anafyo_TecnicheNuove.pdf
9. AIA (2013) G202™–201. Project building information modelling protocol form
10. BIMForum (2015) Level of development specification 2015. For building information model
11. BIMForum (2016) Level of development specification 2016. For building information model
12. BIMForum (2018) Level of development specification 2018. For building information model
13. UNI (2017) UNI 11337:2017 Edilizia e opere di ingegneria civile Gestione digitale dei processi informativi delle costruzioni
14. International Organization for Standardization (2018) ISO 19650:2018—Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling. Retrieved from https://www.iso.org/standard/68078.html
15. O'Keeffe SE (2012) Developing 6D BIM energy informatics for GDL LEED IFC model elements. In: International conference on industrial engineering and operations management Istanbul, Turkey, 3–6 July 2012
16. Dallasega P, Marengo E, Nutt W, Rescic L, Matt DT, Rauch E (2015) Design of a framework for supporting the execution-management of small and medium sized projects in the AEC-industry. In: 4th International workshop on design in civil and environmental engineering, vol 1. Taipei, Taiwan, pp 12. Retrieved from https://www.researchgate.net/profile/Patrick_Dallasega/publication/283578494_Design_of_a_Framework_for_Supporting_the_Execution-Management_of_Small_and_Medium_sized_Projects_in_the_AEC-industry/links/5640b12808ae24cd3e40911b.pdf

17. Italian Law 373/1976 D. lgs. 18 aprile 2016. Attuazione delle direttive 2014/23/UE, 2014/24/UE e 2014/25/UE sull'aggiudicazione dei contratti di concessione, sugli appalti pubblici e sulle procedure d'appalto degli enti erogatori nei settori dell'acqua, dell'energia, dei trasporti e dei servizi postali, nonche' per il riordino della disciplina vigente in materia di contratti pubblici relativi a lavori, servizi e forniture. Gazzetta Ufficiale della Repubblica Italiana, Serie Generale n.91 del 19-04-2016—Suppl. Ordinario n. 10. Retrieved online from https://www.gazzettaufficiale.it/eli/gu/2016/04/19/91/so/10/sg/pdf
18. BSI (2013) PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling
19. BSI (2013) PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling
20. https://www.ingenio-web.it/2180-bim-la-migliore-soluzione-per-efficientare-e-risparmiare
21. Gerbert P, Castagnino S, Rothballer C, Renz A, Filitz R (2016) Digital in engineering and construction: the transformative power of building information modelling. Boston.
22. Maltese S, Moretti N, Re Cecconi F, Ciribini ALC, Kamara JM (2017) Un approccio semplificato per la valutazione di sostenibilità dell'ambiente costruito attraverso il BIM. Techne 13:278–286. https://doi.org/10.13128/Techne-19743
23. 3XN/GXN (2012) Sustainable building certifications. In: Jensen KG, Birgisdottir H (eds) SBi and GXN. Retrieved from https://gxn.3xn.com/wp-content/uploads/sites/4/2018/08/Guide-to-Green-Building-Certifications-August-2018-weblow-res.pdf
24. Kolesar PJ (2005) [1994] What Deming told the Japanese in 1950. In: Wood JC, Wood MC (eds) W. Edwards Deming: critical evaluations in business and management, vol 2. Routledge, New York, pp 87–107. ISBN 9780415323888. OCLC 55738077; Reprint. Originally published: Quality Management Journal 2(1) (1994): 9–24
25. ISTAT Database of the Italian statistical institute. Available at https://www.istat.it/en/analysis-and-products/a-z-statistics
26. Ciribini ALC, Ventura SM, Paneroni M (2015) BIM Methodol Integr Approach Heritage Conserv Manag 149:265–276. https://doi.org/10.2495/BIM150231
27. D'Uva D, Handbook of research on form and morphogenesis in modern architectural contexts, IGI Global, 2018—Chapter 8 interaction and intersection between digital modelling and design in architecture: different approaches in parametric design, pp 152–174
28. ISO (2015) EN/ISO 9001:2015 Quality management systems—requirements
29. Gerber D, Flager F (2011) Teaching design optioneering: a method for multidisciplinary design optimization. Cong Comput Civil Eng, Proc 883–890. https://doi.org/10.1061/41182(416)109
30. Vanossi A (2014) DO Design Optioneering. Politecnico di Milano
31. Imperadori M, Clozza M, Vanossi A, Brunone F (2020) Digital design and wooden architecture for Arte Sella Land Art Park. In: Della Torre S, Daniotti B, Gianinetto M (eds) Digital transformation of the design, construction and management processes of the built environment. Springer, Cham
32. Bianconi F, Filippucci M (eds) (2019) Digital wood design. In: Lecture notes in civil engineering, vol 24. Springer, Cham
33. Holzer D, Downing S (2010) Optioneering: a new basis for engagement between architects and their collaborators. Archit Design 80:60–63
34. Vanossi A, Imperadori M (2015) BIM and optioneering in dry technology small-scale building, (May), 0–13. https://doi.org/10.13140/RG.2.1.2353.0400
35. Kiviniemi A (2005) Requirements management interface to building product models, center for integrated facility engineering, stanford, 2005
36. Pasini, D. et al. (2016) 'Exploiting internet of things and building information modeling framework for management of cognitive buildings', IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016–Proceedings, 40545387(40545387). https://doi.org/10.1109/ISC2.2016.7580817.

Chapter 6
Timber-Based Transformations of the Built Environment: A Portfolio of Case Studies

Abstract The case studies collection is based on a literature review on architectural databases and a survey among the enterprises network. Twenty are the individual tabs among + 100 projects, these are selected mainly in the Italian context because of the high-density building stock composition perfectly fittable for this purpose. Finally, European projects choice starts from the Active House catalogue to point out these transformations sustainable approach. Case studies are catalogued according to the BAEIOU taxonomy described in chapter 1: building Above, bEside, Inside, Outside, Under. Tabs show buildings before and after the intervention, their architectural concept, relation with the existing volume relationship and the timber-based system used for the extension, according to chapter 2 taxonomy.

Keywords BAEIOU taxonomy · Case study · Timber-based system · Refurbishment · Building extension

6.1 Timber-Based Solutions: Best Practices and Beyond

The case study portfolio shows the best renovation practices of the existing building stock. A survey data-collection selects projects based on the BAEIOU theory (Fig. 6.1) of retrofit strategies described in chapter 1.

Thanks to its flexibility, the timber structure adapts itself to different kinds of intervention (Fig. 6.2). They go from punctual protrusion like balconies (Fig. 6.2e), to inner revolution due to staircase installation (Fig. 6.2d) or new layout arrangement with a "box in a box" approach (Fig. 6.2f) but also more "traditional" extensions like floors (Fig. 6.2a) or lateral volume addition (Fig. 6.2b, c).

The technology subdivision of the timber-based construction systems is chapter 2 referred, according to their lightness (slender-massive systems), the single elements frequency (open-close) and the connection typology (punctual-linear). Additional parameters are:

This chapter is authored by Marco Cucuzza.

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F. Brunone et al., *Wood Additive Technologies*, Springer Tracts in Civil Engineering,
https://doi.org/10.1007/978-3-030-78136-1_6

Fig. 6.1 The survey investigates the application of timber-based construction systems as additive solutions for building transformation, read through the BAEIOU taxonomy. *Source* Author's elaboration

- Location: city and country, with clustering the Italian and European cases;
- Year of realization, from 2010 to 2020 as boundary thresholds;
- Existing building function, defined according to the Italian Law DPR 412/93 (Italian Law DPR 412/93), and type, dividing the cases into high-rise, mid-rise, lowrise, and one-storey building transformation [1];
- Urban context, according to DM 1444/68 (Italian Law DM 1444/68) [2].

The collection of the case studies started from industries and firms, which belong to the national and international networking and a literature review across the Google Scholar database. As search strings, the keywords used and combined were: "parasite architecture", "retrofit design", "additive solution". Other sources were the more significant architecture and technology browsers, such as:

- UNFINISHED: the website of the Spain Pavilion at Biennale di Venezia 2016 (unfinished.es/en/) [3];
- DATALABAA: laboratorio di architettura ambiente of the University of Florence (datalabaa.blogspot.it) [4];
- PROMOLEGNO and MATERIALEGNO—the catalogue specifically dedicated to timber-based realizations (promolegno.com/materialegno) [5].

Among all the + 100 case studies, 20 are selected and described with a single report referring to data and information availability, including the sharing-rights related to each project. In this perspective, most of the cases are based on the members and partners of Federlegno Arredo in the Italian context and to Active House Alliance for the European ones. This selection is due to the Italian building stock composition and the diffusive market application of this strategy. The high density of Italian cities is the perfect location for this transformation approach, and it is also confirmed by the market trend, as the construction enterprises certified. Finally, European case studies selection among the AH catalogue refers to its holistic approach to construction: comfort, environment and energy are analyzed together. This approach highlights the quality of the intervention suggesting it, not only as a real estate phenomenon increasing the economic value but also as a virtuous phenomenon in a sustainable aim.

Fig. 6.2 **a** Building Above, vertical extension of Gasthof Tanzer - Issengo (BZ), Alto Adige - EM2 Architekten (©Rubner Haus); **b, c** Building bEside, before and after the lateral extension of Picollissima in Val Gardena - C. Schwienbacher (©Rubner Haus); **d** Building Inside, the new CLT staircase at Hotel Plaza Esplanade in Jesolo (VE) (©Wood Beton); **e** Building Outside, new balconies installation at Cameri (NO) (©Galloppini Legnami); **f** Building Under, the Cube installation at Santa Marta students residences in Venice (VE) by EXiT Studio (©CMB Carpi)

House by the Garden of Venus ***6.1 A***

Location	Willendorf, Austria
Project type	refurbishment
Use	family house
Client	private company
Design	**Planning and site supervision** Valker Dienst, Inprogress Architektur Consulting and C. Feldbacher; **Static** Merz Kley partner GmbH ; **Daylight planning** VELUX Österreich GmbH; **Artificial light planning** Podpod design; **Building concept** Active House Standard; **Wooden structure and interior construction** K.G.Holz-und Wohnbau GmbH, Tischlerei Herbert Feuerstein, Tischlerei Ing. Gerhard Graschopf GmbH
Year	2013

Intro

The Garden of Venus is to the sprawling fruit garden beside the ancient family's home. To preserve the yard and maintain the double vocation, agricultural and residential, the architect adopts a "House on a house" concept. It allows extending the living surface despite the small Willendorf village's high density, without overlapping the natural external space (Fig. 6.3a).

Interaction with the Existing Building

The new volume stands over the fourteenth century natural stone walls used as a basement for the modern tympan. By the demolition of the third floor, it was possible to embed the overhanging third and fourth slabs (Fig. 6.3b, c). All the new additions are characterized using wood at variance with the original stone material. The south elevation, facing the village road, is closed with massive silver fir slats providing privacy and shade, while the north one is open to the Danube valley. The zenith windows guarantee natural light and ventilation on the roof and the horizontal ribbons windows in the eastern façade finished with small fibre cement tiles decorated by pixelated graphics of the Venus of Willedorf (Fig. 6.4).

Timber Technology

The small site and the high-density neighbourhood are consistent constraints. Prefabricated wooden modular design with massive glulam ceiling elements was chosen to overcome the supply problems and to have a short construction period (Fig. 6.5). Due to static requirements, these elements span between five steel frames. Walls are timber frame structures with wood-fibre insulation, which provides for high-quality ecological solutions. The natural silver fir panels for ceilings and walls, the natural rough-sawn silver fir floor and all the used wood is local. 75% can be recycled at the end of its lifespan, taking care of the environmental impact.

Fig. 6.3 **a** The insertion of a 3rd floor under the pitched roof of the new volume (© AH Alliance); **b** the existing building before the renovation; **c** the steel frame portal replacing the second floor primary structure after the demolition (Ph. Jörg Seiler)

Fig. 6.4 Comparison between the old and the new building. The second-floor roof prominence is reinterpreted in a modern shape having more space adding a 4th floor (Ph. Volker Dienst)

Fig. 6.5 **a** The intervention section drawing. **b** The prefabricated roof panel. **c** The timber frame wall of the new volume. **d** The wooden finishing of the inner spaces (Ph. Jörg Seiler)

Reborn Home	**Location**	Pecs, Hungary	***6.2 A***
	Project type	refurbishment	
	Use	family house	
	Client	private	
	Design	**Architect and developer** Prof., Ph.D., Dr. Habil István Kisteledgi Dla, Kátái Nóra	
	Year	2017	

Intro

The reassembles of all the spaces is the need from which this project is born. It also caused a modification in the external elevations adding new horizontal ribbon windows and roof's particular shape (Fig. 6.6).

Interaction with the Existing Building

Comparing the new volume with the old traditional house, the garage is the only part compliant with the existing one. The pitched roof was rotated of 90° to have a south-oriented chimney and a 27° slope to achieve the maximum yearly yield of solar electricity by PV panels (Fig. 6.7). The mirrored façade between the east and the west elevation are distinguished using transparency. The street elevation is characterized by small openings (Fig. 6.8) and a corner ribbon window, while the internal façade has big openings to the private garden. A door in the big double-height glass conduces to the furnished garden with a deck floor (Fig. 6.9). The zenithal windows distributed the light to all the storeys, avoiding the black spaces in the middle of them because of the long distance between the main facades. Furthermore, this architectural expedient activates the stack effect, providing for night cooling in summer (Fig. 6.10).

The high-quality intervention is verified by the Active House radar, particularly in environmental and sustainability performances. The project full provides freshwater consumption, primary energy performance, energy supply, indoor air quality and thermal environment. The LCA analysis certified construction sustainability.

Timber Technology

100% natural timber clocking covers the facades with horizontal stripes. The finishing emphasizes the horizontal rhythm of the windows that counteracts the verticality of the building. Three-pane glazing, exterior shading, 36 cm wood fibre insulation and internal adobe plaster implement the existing external 30 cm thick brick wall. The whole load-bearing structure was preserved and reused, only windows and the new gallery-solar chimney generated some formal changes.

Fig. 6.6 Reborn Home street front view of the dwelling with entrance and garage (Ph. The Greypixel Workshop)

Fig. 6.7 Reborn Home street back view highlighting the reinterpretation of the pitched roof in a contemporaneous shape (Ph. The Greypixel Workshop, © AH Alliance)

Fig. 6.8 The street elevation characterized by small openings and a corner ribbon window (on the left: Ph. The Greypixel Workshop; on the right: © AH Alliance)

Fig. 6.9 Northern view from the garden of the timber ribs and the window corner. North elevation is more open and transparent to connect the inner space with the external private one (© AH Alliance)

Fig. 6.10 The double bottom (**a**) and upper (**b**) view of the vent stack; the southern (**c**) and northern (**d**) facade (Ph. The Greypixel Workshop); (**e**) and the Active House radar (© AH Alliance)

6.3 A

Vertical extension in Legnano	**Location**	Legnano, Italy
	Project type	refurbishment
	Use	family house
	Client	private
	Design	**Architect** Ugo Oscar Sissa; **Structural design and realisation** Galloppini Legnami
	Year	2013

Intro

Italian historical architectural heritage is a big challenge for the refurbishment and renovation of buildings. The advanced timber technologies allow acting on them without compromising the global uniformity. Requirements are to extend the attic space for a single-family house by creating a new pitched roof. This concept keyword is “mimetic” because of the ability to dissimulate the intervention, showing a perfect integrated shape. It looks like it has always been like so (Fig. 6.11).

Interaction with the Existing Building

The extension intervention main problem is the vapour and air passage between the original wall surface and the new one. Because of the wood necessity to breathe and avoid the water stagnancy risk that led to fungi attack, a concrete kerb was disposed on the roof perimeter. Water barrier and vapour barriers were set and turn-up between concrete and timber elements (Fig. 6.12).

The new tiles roof was built onsite and chosen to have a continuity with the ancient historical centre contest. The rectangular openings adopt the same frame as the existing ones to allow the uniformity of the elevations. The only evidence of the intervention is the string course between the pre-existence and the new raising.

Timber Technology

The mimetism of the intervention is complete: timber elements are dissimulated inside and outside. The grey plaster façade and the inner plasterboard finishing for walls hide the timber frame structure. This technology is uncommon for a vertical extension instead of CLT. It was chosen to integrate plumbs, tubes and insulation inside the structural element, avoiding the step between the old and the new volume caused by the ETICS external application to the new wall. Thanks to this solution, it is possible to have a perfectly planar façade elevation. Walls panels structure of 6×16 cm sections arrived OSB plated only on the outer side, hence the 2D elements prefabrication is only partial. The internal OSB layer was fixed after the services integration and the insulation providings. Finally, a counter wall on timber substructure completed by drywall finishes the inner space (Fig. 6.13). The Timber elements are visible only by the massive primary wooden beams of the pitched roof.

Fig. 6.11 The vertical extension of the last floor with a new roof in Legnano (Milan). The skirt roof and the small rectangular windows point out the building Above (© Galloppini Legnami)

Fig. 6.12 **a** Timber frame walls positioning over the existing last floor. **b, c** Rolling scaffold and crane are the only tools needed to set up the building extension. **d** Internal services set up (© Galloppini Legnami)

Fig. 6.13 Primary and secondary wooden beams are positioned over the timber frame walls; insulation panels and purlins complete the roof (© Galloppini Legnami)

Vertical extension in Nerviano ***6.4 A***

Location	Nerviano, Italy
Project type	refurbishment
Use	family house
Client	private
Design	**Architect** Fabio Pravettoni; **Structural design and realisation** Galloppini Legnami
Year	2013

Intro

The Legnano project's vertical extension shows the timber systems revolution potential applied to the existing buildings. A single-family house is transformed into a double family one by the adding of a new floor. The use of two different grey tones for the basement and openings replacing the old greenfinch and negative spaces on the main façade transforms an anonymous building into a contemporary one (Fig. 6.14).

Interaction with the Existing Building

Masonry structure is one of the most common used in the Italian residential building stock. Thanks to the low cost of material and skilled labour's unnecessity, most single houses built after the second world war use the same technology. The construction shows the typical conformation of fifties-sixties buildings with one mezzanine floor and a basement with a pitched roof inaccessible. This kind of structure refurbishment offers an excellent response to vertical loads because of the bricks' compression resistance. Still, they have shallow foundations that limited the high of the raising. According to this situation, the vertical extension needs to be well anchored to the existing body to recreate the box behaviour with the roof's redesign, typically the weakest point of these buildings.

Timber Technology

The CLT walls lean on the concrete kerb shaped according to the openings and the wooden beam position (Fig. 6.15). The existing and new structural elements are completed onsite by adding an external insulation layer and an inner plasterboard counter wall to improve thermal and acoustic behaviour.

The distinguishing element of this project is the open stairs vane, designed by the architect as a formal component and not only a distribution one. The perception of volume is completely changed in this part, dividing the main front into two different parts: the left one is characterized by density in the lower part counterbalanced by a terrace over the basement. Empty spaces mark the right side with a negative pattern in all its vertical development. The rectangular openings are large, giving a structural challenge to the structural designers (Fig. 6.16).

Fig. 6.14 The anonymous single-family house was transformed into a double-family adding one storey accessible by the open stair vane characterized by contemporary colours and shapes (© Galloppini Legnami)

Fig. 6.15 **a** The CLT anchoring to the concrete slab. **b** The secondary beams of the pitched roof. **c** The lean construction site. **d** Scaffoldings for the external finishing. **d** The timber purlins (© Galloppini Legnami)

Fig. 6.16 **a** CLT walls lifted by crane. **b** CLT is used as structural material also for double-high elements with a lot of openings. **c** The walls structural material is invisible behind a traditional finishing (© Galloppini Legnami)

Vertical extension in Arola	**Location**	Arola, Italy	***6.5 A***
	Project type	refurbishment	
	Use	family house	
	Client	private	
	Design	**Architect** Simona Bianchi; **Structural design and realisation** Galloppini Legnami	
	Year	2019	

Intro

Timber is a construction material that comes from mountain tradition. One of the older technologies is the block haus or block bau. It was born from the diffuse availability of timber on the mountain and the simultaneous shortness of clay at certain altitudes. It is the overlapping of massive length elements to create a loading wall using wood instead of brick. With the industrialization of timber production, CLT massive solution or timber frame for lighter applications overcome this ancient technology. However, block haus is especially suitable in this location because of the recall of traditional construction systems. This project is a perfect example of applying a new solution valorizing ancient construction and preserving old systems' memory (Fig. 6.17).

Interaction with the Existing Building

The layout of the building is simple: the plan is rectangular with services arranged in one corner. The choice is to show the building materials externally: stone downside and timber upside, valorising the characteristic dovetail corner connection between two walls (Fig. 6.18b). A new one replaces the existing pitched roof with the same finishing: the traditional "pioda". These are stone layers of 1–2 cm overlapped exactly like tiles. The difference with clay systems is that the rain resistance is due to mass instead of the geometrical shape: three stone layers connected by mortar which ensures waterproofing. The single wooden listels support a modern single stone layer because of the impossibility to preserve the original ones due to the mortar connection reinterpreting the traditional roof (Fig. 6.18a).

Timber Technology

The loading resistance to vertical loads of stone walls is also bigger than masonry ones. It allows adopting the block haus massive spruce wall technology for the elevation, composed of 12 cm thick GL24h double shaped.

Due to the long side of the rectangular plan, it was necessary to double the ridge beam. It causes the necessity to have knee beams as secondary structure transferring momentum from one flap to another (Fig. 6.19). These beams are laid on a transom because of the need to create door access to the balcony in the wall's higher point of the wall (Fig. 6.19b). The overhang of the roof and its strong angle are required to preserve the structure from snow and climate agents (Fig. 6.19c, d).

Fig. 6.17 Blockhaus is a traditional construction technology coming from the mountain tradition. It is especially suitable for small stone by stone constructions (© Galloppini Legnami)

Fig. 6.18 **a** Pitched roof characterized by a steep slope to avoid the snow permanence on the structure. **b** Typical dovetail on the corner of the block haus. **c** 15 × 15 cm pillars, 25 × 30 primary and secondary beams. All the structural elements are massive timber spruce with C24/C16 loading capacity (© Galloppini Legnami)

Fig. 6.19 **a** Knee-beams of the pitched roof sleeping on a double principal beam. **b** Steel connection between pillars and the transom. **c, d** The unventilated roof with the timber substructure for the "pioda" stone traditional finishing (© Galloppini Legnami)

Vertical extension in Arluno	**Location**	Arluno, Italy	***6.6 A***
	Project type	refurbishment	
	Use	family house	
	Client	private	
	Design	**Architect** Rosario Distaso - Bloomscape Architecture; **Structural design and realisation** Marlegno	
	Year	2014	

Intro

The Arluno project's principal characteristic is the continuous horizontal grey ribbon as a string-track frame (Fig. 6.20a). It starts from the ground, divides the ground floor from the first, and becomes the building's crowing. Its ledge is used as a balcony for the first floor and covers the main glass entrance in the left corner, marked by two small slopes recalling a pitched roof (Fig. 6.20b). This elevation is the private one, from the garden where is also located the private parking. However, it can be considered the main entrance because most people use car mobility in Italian suburbs, requiring a parking place inside the private land. A "bridge" was created on the ground floor by a slab over open spaces to guarantee car access, linking the main street to the internal parking (Fig. 6.21c, d). The street façade is essential and straightforward, with only two rectangular window openings, the "bridge" passage and just secondary pedestrian access on the right side marked by an ocher door (Fig. 6.20b).

Interaction with the Existing Building

Preexistence consists only of a small rectangular construction (Fig. 6.21a, b) that was not demolished because of its walls loading capacity: a C steel profile anchors the timber frame bridge slab to it (Fig. 6.22a).

Street elevation results significantly closed because of the local construction rules, so to led light inside the first floor, they are used windows roof (Fig. 6.22c).

Timber Technology

A structural frame system with post and beams is the timber technology chosen for this vertical extension (Fig. 6.6. 6.22e, f). The timber frame is also used inside for walls partition and OSB layers complete them for three main reasons: a cheaper solution compared to the plaster one; the plate behaviour to horizontal seismic forces that avoid the wind bracket adoption; the architectural choice of a minimalistic industrial ambient, also surrounded by essential furniture (Fig. 6.22e). The two materials stair in wood and concrete and the cement floor finishing together with white walls and OSB also characterize the ground floor's refurbishment (Fig. 6.22f). The pitched roof is ventilated, with a gutter canal integrated (Fig. 6.22b) and metal covering fir purlings and beams (Fig. 6.22d).

Fig. 6.20 **a** The inner elevation characterized by the continuous grey ribbon dividing two floors. **b** The essential street elevation with the “bridge” for the driveway to the backyard (© Marlegno)

Fig. 6.21 **a, b** The existing building. **c** Street elevation during the construction phase. **d** Scaffoldings are required to install ETICS. **e** The first-floor overhang in correspondence to the main entrance. **f** Loading internal walls are wind braced by double side OSB layer (© Marlegno)

Fig. 6.22 **a** “Bridge” timber frame slab is connected to the existing wall by a C steel profile. **b** Gutter canal integrated into the roof. **c** Roof window and waterproof sheat taping. **d–f** Internal finishings (© Marlegno)

Hotel Giberti			***6.7 A***
	Location	Verona, Italy	
	Project type	Vertical extension	
	Use	touristic	
	Client	Private hotel owner	
	Design	**Architect** MMWW STUDIO; **Structural design and realisation** Wood Beton	
	Year	2018	

Intro

Located in a high-density neighbourhood of the city Hotel Giberti is a modern building characterized by a full glass façade. It is prospicient to Giberti street, one of the principal access to the historical centre, leading to one city door. The basement material is the typical Verona's pink marble, as many of the surrounding buildings. The necessity to implement the rooms number led to the two storeys adding. The metal finishing, the curved roof and the metal finishing evoke the traditional churches dome. The seal system is used for roof and façade covering to have a geometrical and material continuity (Fig. 6.23). The result is a uniform body of the building that is aligned to others.

Interaction with the Existing Building

A key aspect of all the offsite technology solutions is the logistic design: all the elements are plant produced (Fig. 6.24b) transported onsite with a truck with a limited length and, mostly, width (Fig. 6.24d). A waterproof layer covers the existing flat roof (Fig. 6.24a). The concrete curb was not provided to lay the massive timber walls to preserve this layer's continuity. For this reason, a horizontal timber beam was set under the CLT wall (Fig. 6.24c), and a hot bitumen sheet is folded over from horizontal to vertical elements (Fig. 6.24f).

Timber Technology

L steel profiles anchor walls in the middle of the length to transfer the bending forces, while the vertical ones and momentum are awarded to hold-down (Fig. 6.24a). Scaffoldings are required to install the outer insulation coat and the metal finishing, impossible to offsite assembly because of its continuity.

The thickness of the cross-laminated timber elements is 15 cm because of the double floor elevation and the body's long span. A structural joint is provided where the building changes its direction. A steel arch portal also absorbs the curve of 9 degrees to supply the eventual torsional forces coming from the two building wings. White walls and OSB rough finishing also characterize the ground floor's refurbishment (Fig. 6.25f). The pitched roof is ventilated, with a gutter channel integrated (Fig. 6.25b) and metal covering on fir purlings and beams (Fig. 6.25d).

Fig. 6.23 The two-storey elevation is highlighted by metal finishing; solar panels are located over the flat roof. The seventh floor's attic skylight is supported by thin metal pillars starting from the sixth-floor balconies (© Wood Beton)

Fig. 6.24 **a** L steel profiles anchor CLT walls to the existing flat roof. **b** Different wall panels plant produced. **c** Wall lifted by crane. **d** Truck transportation from plant to building site. **e** The metal facade finishing installation requires scaffoldings. **f** Walls are sealed with a waterproof barrier to the existing floor to guarantee vapour stop (© Wood Beton)

Fig. 6.25 **a** The existing glass facade building. **b** Section intervention highlighting level 6 and 7 vertical extensions. **c** The street view of the completed intervention (© Wood Beton)

Vertical extension in Rovigo ***6.8 A***

Location	Rovigo, Italy
Project type	Vertical extension
Use	commercial
Client	Private owner
Design	**Architect** : Studio di Ingegneria e Architettura Arch. Simone Costanzo e Ing. Luca Costanzo **Structural design and realization** XLAM Dolomiti
Year	2017

Intro

The two towers square polarises the architectural project of this vertical extension. In the middle of the historical centre of Rovigo, this renovation is part of the refurbishment of the whole public spaces in front of Torre Donà and Torre Grimani (or Torre Mozza, chops off-tower in English) (Fig. 6.26). The existing three storeys building was extended of 2 more levels: a first volume following the existing plan except a terrace facing the square and a second parallelepiped that surmounted the lower one. The upper structure is cantilevering the balcony as a protrusion projecting to the attractive element of the project. A large full glass façade enhances this intention, assisted by a transparent parapet (Fig. 6.26b). The elevation's first storey follows the openings' rhythm in height and is marked by a grey plaster (Fig. 6.27b). The commercial surface was 370 m^2 extended and works are completed in 10 weeks.

Interaction with the Existing Building

The building was entirely renovated by the insulation coat system, new windows, and the stone basement cleaning. A mixed metal and timber structure dock the CLT walls to the existing flat roof. The first level has a post and beams white steel structure supporting the cantilevering box, required to punctually transfer the loadings to the existing post and beam concrete structure in the middle of the plan (Fig. 6.28a). The remaining part of the grey volume and the cantilevering box are timber frame insulated grid structure-based (Fig. 6.28b), loading the boundary new CLT walls and the existing reinforced concrete ones. XPS insulation covers the first 30 cm from the new constructions' floors to prevent the rising damp and have the correct hygrometric behaviour; the remaining part is a wooden fibre coat (Fig. 6.28c).

Timber Technology

CLT walls are led on a concrete curb over the existing double bituminous pad. Massive timber walls are pre-shaped offsite by the CNC cutting machine to welcome transoms and steel beams under the second level elevation (Fig. 6.28a), while the remaining part uses timber beam (Fig. 6.28c). The double solution is chosen to have the identical beams' height for both the materials even if loads are different. Thanks to

Fig. 6.26 In the middle of the historical centre, the two storeys elevation looks to the two towers square (Torre Grimani or Torre Mozza on the left and Torre Donà on the right. The upper box's big glass lands on the large and green garden (© XLAM Dolomiti)

Fig. 6.27 **a** The vertical extension is characterized by a first grey floor surmounted by a white cantilevering box. **b** The external refurbishment involves the whole building facing public space (© XLAM Dolomiti)

Fig. 6.28 **a** The mixed system with CLT walls and steel pillars and beams. **b** Fibre wood insulation of the new volume. **c** White timber beams of the upper box (© XLAM Dolomiti)

CLT technology and timber finishing for internal elements as walls and fir panelling, 72 tonnes of CO_2 are stored over 65 m^3 of timber with only 25 m^3 of glulam.

Vertical extension in Venice	**Location**	Venice, Italy	***6.9 A***
	Project type	Vertical extension	
	Use	commercial	
	Client	Private owner	
	Design	**Architect** : Studio Tomaz **Structural design and realization** XLAM Dolomiti	
	Year	2017	

Intro

Venice is a unique city in the world, famous for its particular construction over the water and its restricted pedestrian ways (Italian "calli"). This fascinating element is also a significant constraint, giving many problems during the construction phase.

The double raising of two buildings of 3 and 5 storeys for 1100 m^2 of commercial surface involved 350 m^3 of CLT elements, only 18 m^2 of glulam and 14 tonnes of stored CO_2. The residential building is located in a suburban part of the city where the landscaping limitations coming from Superintendence are less restrictive. White volumes characterize the project with balconies on the right and a brow strip going from the ground floor to the top of the building in continuous S shape and creating loggias in the main façade (Fig. 6.29a).

Interaction with the Existing Building

One crane lifted the construction materials, and scaffoldings only partially covered the buildings because of the problematic logistic (Fig. 6.30a). The two existing storeys are used as a basement, but they are only partially used as loadbearing walls because of the high number of added plans (Fig. 6.31). Even if the material is not coherent with the external contest—Venice is laying over timber posts, it is impossible to understand the construction material because of the white external plaster over the insulation coat (Fig. 6.27b). The intervention is completed in only 5 weeks.

Timber Technology

The structural system adopted is massive timber walls and slabs: CLT walls are used as perimetral and internal partitions plus for the lift shaft (Fig. 6.31). This application demonstrates that timber has good behaviour in seismic zones also for medium–high rise buildings. Concrete elevators shaft would be tough to realize in these short spaces, while wood allowed a more straightforward dry assembly system without water use. Steel beams give the box behaviour to the structure, helping the timber elevator shaft's wind-bracing effect. However, the construction material is visible only in the pitched roof's exposed wooden beams (Fig. 6.32b).

Fig. 6.29 **a** The five storeys elevation with the white plaster finishing. **b** The brown external ceilings comings from the S strip loggias (© XLAM Dolomiti)

Fig. 6.30 **a** The complex construction site between the Venetian “calli”. It is light and lean thanks to dry assembly avoiding concrete and water use. **b** The S strip characterizing the south elevation of the vertical extension (© XLAM Dolomiti)

Fig. 6.31 Internal partitions and list shaft also adopted CLT structure. Steel beams guarantee lower high compared to timber and give the box behaviour for seismic resistance (© XLAM Dolomiti)

Fig. 6.32 **a** Scaffoldings are only partially used because of the difficult access to the construction site. Only one crane was enough for both the buildings. **b** Construction material is visible only in the single pitched roof's exposed wooden beams (© XLAM Dolomiti)

Hotel Corte Ongaro	**Location**	Verona, Italy	***6.10 A+E***
	Project type	Vertical and horizontal extension	
	Use	touristic	
	Client	Private hotel owner	
	Design	**Architect** Rani Alice Carrara; **Structural design and realisation** Wood Beton	
	Year	2014	

Intro

Hotel Corte Ongaro is a pilot project for the wooden extension of medium-size buildings. Most of the timber technologies are for residential buildings; here, the touristic destination of use requires more oversized loads and larger spaces. The historical building is vertically and horizontally extended, adding one floor and one room corresponding to one window on the north side (Fig. 6.33). The black fibre cement finishing marks building extension (bEside and Above), the external sun-shading in the principal street access (Fig. 6.34) and balconies renovations.

Interaction with the Existing Building

The original structure of the building was preserved. The facades' antique pink remains intact to maintain the building coherent with the contest (Fig. 6.35). The building is one of a twin couple: the second, housing used, is located next to it on the west side, with the same crown (Fig. 6.33). The insertion of one room's floor obliged to town the pitched roof; over it was settled a shared terrace with a small green roof and a jacuzzi, related to the rooftop lounge bar protruding in the middle of east and west façades. Over the bar are located services and solar panels. The lateral adding obliged to have an external fire escape stair; it is in the north-west corner, next to the building beside adding. The white metal structure was completed by the same black finishing of balconies and extension to dissimulate it (Fig. 6.36c). A red frame surrounds the entrance to highlight the building renovation from the main street. Furthermore, a black steel sun-shading hides the four bathrooms windows, both for architectural reasons and energy-saving strategy because of the south exposition (Fig. 6.35).

Timber Technology

CLT walls were ground floor assembled (Fig. 6.36a) and then lifted by a crane using the steel beam predrilled for services distribution. The IPE steel profile is required because the only CLT slab could not support all the loadings from the crowding over the terrace, the green roof with the small tree and the jacuzzi water filling (Fig. 6.36b). Massive internal walls are also located under the bar perimetral walls. Due to the high loadings, CLT walls thickness is required in 5 layers of timber having 15 cm instead of the usual 9 cm of 3 layers.

Fig. 6.33 **a** Hotel Corte Ongaro after the renovation (© Hotel Corte Ongaro). **b** The original building before the vertical extension (© Wood Beton)

Fig. 6.34 Red marked access and the steel sun-shading system on the street front (© Wood Beton)

Fig. 6.35 The pitched roof is replaced by a single storey and a shared terrace with a bar, garden and jacuzzi. Services are set over the bar flat roof, accessible by a new internal stair. Black material characterises all the extension and refurbishment intervention (© Wood Beton)

Fig. 6.36 Mass timber plate (**a**) and slab (**b**) system. **b** The long span and the double floor elevation require a steel beam. It is predrilled for tubes passage. **c** Back front is extended with fibre cement finishing and fire escape external stair than closed by black finishing (© Wood Beton)

Pont Saint Martin Library

6.11 A+E

Location	Pont Saint Martin (AO), Italy
Project type	Vertical and horizontal extension
Use	Library
Client	Public: Municipal Administation
Design	**Architects** Enrica Quattrocchio, Eddy Cretaz; **Contractor** Gontier Massimo Srl; **Structural design and realization** Galloppini Legnami
Year	2011

Intro

Villa Michetti is built at the beginning of the nineteenth century in a liberty style with a flower decoration of the facades crowing. It is one of the relevant architecture of Pont Saint Martin in the Aosta province. Today the building is used as a public library for the community. A first horizontal extension was built with traditional brick-based technologies because of the necessity to augment the administration office spaces (Fig. 6.37b).

The Municipal Administration required a new reading hall to extend the common spaces and extend the administration offices. The project wants to contrast lightness, reflecting materials and moderns shapes to materiality, opaque finishing and historical building. The external skin guarantees the complex's unitarity, thanks to the red plaster over the insulation coat, while the big glass façade marked the facing the square and the garden, linking the new and the existing parts. The titanium zinc roofing covers the new volume and highlights the opaque south-east elevation's contemporary shape (Fig. 6.37a).

Interaction with the Existing Building

The extension can be considered both vertical and horizontal because it is built over the single floor masonry addition and laterally connected to the historic building. The new volume is projecting in the south-east and west elevation thanks to a steel structure connected to the concrete roof. A metal portal is required to sustain the full glass façade (Fig. 6.38a), protected by the overhang CLT from the intense sunlight coming from the south.

Timber Technology

CLT is the adapter technology for masonry preexistence thanks to the loading capacity of the brick walls. The natural material (spruce) brings to mind a wooden box, typical for the bookshelves (Fig. 6.38b). Wood is also used for the floor finishing to have a comfortable ambient during the book consultation. The natural and artificial lighting design is optimized for book consultation. Still, the glass façade also has a conceptual function to open the population's culture (Fig. 6.38c, d). The use of timber, however, is not evident from the external side, thanks to the use of a traditional finishing uniforming the existing building and the new volume (Fig. 6.39).

Fig. 6.37 **a** The CLT vertical extension characterized by the big window and the titanium zinc roofing, adding 40 m2 of office spaces (© Galloppini Legnami). **b** Villa Michetti, the existing library, with the one-floor brick addition (© Eddy Cretaz architect)

Fig. 6.38 **a** The steel portal hanging the south-west glass elevation. **b** The CLT box over the old terrace. **c** Vertical window of the north-east facade. **d** The inner view of the southern public square. **e** The insulation coat installation with scaffoldings (© Galloppini Legnami)

Fig. 6.39 The interaction of the existing building with the new volume is characterized by the opposition of traditional elements and materiality to contemporary shapes and lightness. The south and west elevations have a modern interpretation of lightness and reflection thanks to titanium zinc and glass. Simultaneously, the red plaster of the remaining part integrates the intervention to the existing building (© Galloppini Legnami)

Horizontal Extension in Borgosesia	**Location**	Borgosesia (VC), Italy	***6.12 E***
	Project type	Horizontal extension	
	Use	Residential	
	Client	Private	
	Design	**Architect** Fabrizio Zamboni; **Structural design and realisation** Galloppini Legnami	
	Year	2011	

Intro

Extending a building with a marked character is always a challenge in integration, avoiding copying the existing architecture. For this project, the architect decides to detach the yellow preexistence from the new essential volume. (Fig. 6.40).

Interaction with the Existing Building

The new volume added obliged to extend the connection spaces; thus, a lift shaft was provided in the existing building corner. It was horizontally transported in two pieces and lifted by a crane truck (Fig. 6.41a); the prefabricated roof completed this element (Fig. 6.41b). The choice to split the vertical connection was necessary to maintain a slim construction site, using a crane truck instead of a fixed crane. The use of CLT for the elevator shaft rather than the traditional concrete allows having a shorter onsite job, with only ten days of onsite work. This element's lightweight avoids the necessity to have a deep foundation (typical of the concrete elements) and also having a perfectly integrated solution to the new timber structure. The addition was too completed by a slim body next to the existing one, softening the transition to an L shape with different storey height and a pitched roof.

Timber Technology

All the external cladding is finished by horizontal spruce on the metal substructure, besides the existing façade was interested in refurbishment intervention (Fig. 6.41d). This kind of finishing requires to be set up element by element; for this reason, the scaffoldings are installed after the positioning of the structural elements (Fig. 6.42a): CLT loading walls, beams and slabs. Internally gypsum boards on drywalls are mounted over C and U metal profiles completed by insulation for thermal, acoustical and fire safety reasons (Fig. 6.42b). Short massive wooden slabs compose the BBS (Binderholtz BauSystem) Cross Laminated Timber; it is also used for tiny beams and lintels (Fig. 6.41c). Thanks to the artificial drying process, the humidity is 12%, avoiding parasites, fungi, and insects. The high dimensional stability of panels reduces to negligible values the phenomena of swelling and shrinkage of the board, increasing its static resistance.

All the timber elements were stored in the small courtyard in front of the building. Particular attention has been paid to the wind barrier behind the façade and the waterproof layer around the window and the door openings (Fig. 6.42d).

Fig. 6.40 The new timber structure is declared by the spruce horizontal strips of the facade. The existing building is detached by the essential new volume with large windows (© Galloppini Legnami)

Fig. 6.41 **a** The CLT elevator shaft was transported in two parts and assembled onsite. **b** The positioning of the lift shaft roof by crane. **c** The crane truck is hanging the second part of the elevator. **d** The horizontal spruce strips of the new volume facade over the metal substructure (© Galloppini Legnami)

Fig. 6.42 **a** The external cladding completion by scaffolding. **b** The inner metal substructure for gypsum boards. **c** The flying CLT slab panels over the laminated timber beams. **d** The waterproof membrane around door and windows (© Galloppini Legnami)

Horizontal Extension in Cambiago	**Location**	Cambiago (MI), Italy	***6.13 E***
	Project type	Horizontal extension	
	Use	Residential	
	Client	Private	
	Design	**Architect** Franco Colombo, **Structural design and realisation** Marlegno	
	Year	2011	

Intro

Flexibility and essentiality characterize the horizontal extension in Cambiago. The two floors squared plan with a simple pitched roof add a new housing unit beside the existing one. It was built over the yet existing underground floor but represents an entirely autonomous solution, as the grey and white finishing underlines in the contrast with the ancient brick one (Fig. 6.43).

Interaction with the Existing Building

The new volume is next to the existing one and over the yet existing housing unit's basement. The timber frame walls—chosen for their lightweight—are positioned over a concrete kerb, and a"sleeping" fir beam is punctually anchored to the concrete element every 60 cm (Fig. 6.44). The new perimetral wall is 2 cm distant from the existing structure, allowing the air conditioning tubes' services gap. It is finished with a breathable waterproofing membrane outside and a breathable sheet behind the internal OSB layer, plus a double plasterboard counter wall to control the mould growth (Fig. 6.45a, b).

Timber Technology

The timber frame solution is plated with OSB (Oriented Strain Boards) to provide the bracing resistance (Fig. 6.45c). These loading walls sustain an outer lamellar beam moulded to accommodate the white roof beams. The wheelbase of the roof beams is 60 cm to have a limited high of the structural elements (Fig. 6.45d) interrupted by two roof windows and a skylight. The presence of skylight requires particular attention to the waterproofing sheet flap (Fig. 6.45e). The intermediate slab is a patented solution called Tavego© (Fig. 6.45c): a juxtaposition of laminated timber beams connected only by nails without glue. This solution is an alternative to the CLT slab, offering a nice visible finish to avoid a continuous layer's smoothness. It has a better acoustic behaviour thanks to every beam's different geometry, and it does not require the plaster counter ceiling but shows the beauty of wood. The slab requires an OSB horizontal layer on the extrados, giving the whole structure the necessary box behaviour. The key point to guarantee the proper air resistance and avoid the linear thermal bridges losses is to perimeter all the single elements joints with an airtight expandable tape (Fig. 6.45f). The insulation layer is triple density rock wool: behind the internal double plaster counter board internal (40 kg/m^3); between the wooden

Fig. 6.43 The horizontal extension adding a new living unit also included a skylight on the roof (© Marlegno)

Fig. 6.44 A concrete kerb is laid over the existing basement. Over the "sleeping" fir element is set the timber frame structure in touch with the existing one (© Marlegno)

Fig. 6.45 **a** The timber frame wall to set next to the existing building. **b** The predrilled fir beam over the concrete kerb. **c** Tavego © floor installation. **d** Laminated timber beams positioning. **e** The breathable waterproofing sheet installation flap the skylight. **f** Airtight expandable tape boundary every joint (© Marlegno)

pillars of the timber frame (70 kg/m^3) and the outer coat in XPS and EPS (90 kg/m^3) (Fig. 6.46).

Ledro Museum			***6.14 E+O***
	Location	Ledro (TN), Italy	
	Project type	Horizontal extension and refurbishment	
	Use	Exposition and offices	
	Client	Autonomous Province of Trento	
	Design	**Architect** Studio BBS - Massimo Scartezzini; **Structural design and realization** Rilegno	
	Year	2019	

Intro

Trentino is one of the most relevant regions for timber construction in Italy, thanks to its ancient wooden construction tradition. The Lake Ledro Pile-dwelling Museum is a UNESCO World Heritage Site since 2011 and a local branch of the MuSe (Science Museum) for the Bronze Age daily life. Originally it was a seasonal museum, built in the'70 s by arch. Piovan, with a massive wooden structure and big aluminium frame windows (Fig. 6.47a). In 2017 the necessity to extend the exposition spaces and adapt the building to the four-season activity induce the committee to build a new volume (Fig. 6.47c) and refurbish the existing one (Fig. 6.47b).

Interaction with the Existing Building

Due to the aggressive climate agents, the central body's twenty columns were substituted with lamellar timber (Fig. 6.48a, b). The new volume is a transparent glass box with vertical structures in steel and horizontal glulam beams. The glazed building contrasts with the existing architecture, giving more importance to the lake thanks to its total transparency. The glass box results essential and minimal, hiding all the services and distribution under the roof structure. The horizontal lamellar beams are double Z shaped with a cutting-edge steel plate to accommodate machinery and tubes (Fig. 6.48c). The Z plates are fixed with 8 × 8 steel pins, while metal L elements support the roof slab. Structurally the new box is separated from the existing building, while CLT walls foreseen for horizontal loads and work as bracings (Fig. 6.49a).

Timber Technology

The museum renovation required the central body's substitution and the renovation of the spruce façade (Fig. 6.49a). The finishing renovation purpose is to have more coherence with the new lamellar portal frame. However, the light red spruce changes its colour over time, and it will become grey-brown as the previous one. The external fixed tent structure accommodates the outside activities during the hot season. It becomes an important meeting point for the community: a public square opened to visitors in front of the opaque headbox (Fig. 6.49c). The outside tent is removed during the winter season because of the high snow loading. The whole intervention

Fig. 6.46 **a** Services connection between the new and the pre-existing volume. **b** External insulation coat installation. **c** Ventilation slats on the roof and the skylight. **d** Grey aluminium corrugated sheet as roof finishing. **e** Lightweight concrete for services horizontal distribution. **f** Ceiling plants distribution. **g** Window positioning (© Marlegno)

Fig. 6.47 **a** The 70's timber-based volume. **b** The 120 m^2 extension with exposition rooms and didactical spaces. c The new glass box office (© Rilegno, photos by Miriam Tinto)

Fig. 6.48 **a** The timber frame structure after 47 years required a renovation. **b** The vertical element of the laminated timber portal frame substitution. **c** The construction of the new glass office volume with a particular double Z lamellar beam to allow the system's distribution in the central part (© Rilegno)

Fig. 6.49 **a** CLT walls are shaped to accommodate lintels and roof beams. **b** The new spruce facade finishing of the whole Museum. **c** The external structure beside the opaque box. **d** Internal finishing of the glass box. **e** The complete intervention and the lake (© Rilegno, photos by Miriam Tinto)

moves the Museum to a LEED Gold certification thanks to technological, energetical and plant engineering renovation, valorising also the natural elements as lake and the mountains (Fig. 6.49d, e).

Casa Longano	**Location**	Monopoli (BA), Italy	***6.15 E***
	Project type	Horizontal extension	
	Use	Residence	
	Client	Private	
	Design	**Architect** Francesco Longano; **Structural design and realisation** Rubner Haus	
	Year	2011	

Intro

Timber technology is a good solution for a hot climate, as Casa Longano, next to Bari, in Puglia, shows. The historical "Masseria" was refurbished by the demolition of the superfetation (the concrete blocks volume, Fig. 6.50a) and the addition of one floor with a porch beside it (Fig. 6.50b). Arch. Longano wants to recovery the right balance between human and natural elements, choosing the timber solution for its essentiality and sustainability (Fig. 6.50c). Great attention was also given to the external courtyard, gazebos and covered spaces.

Interaction with the Existing Building

By removing the concrete blocks superfetation, the project could enhance the simplicity of the Masseria's volume (Fig. 6.51a). The extension is laid over a concrete ventilated platform with igloo technology and a reinforced concrete structural ring (Fig. 6.51b). Three trucks transport the blocks, stocked onsite and positioned with numerical sequence over the red membrane separating the wood from concrete to avoid the dump raising from the ground up to the structure (Fig. 6.51c).

Timber Technology

The Blockbau technology consists of CLT beams overlapped by the cutting section with a protrusion in the downer element and a recess in the upper one. The beams are bird dovetail detail connected in the corner (Fig. 6.51c). Thanks to the slim elements and the low high, scaffoldings are not required for the construction (Fig. 6.51d). The structural system provides for loading walls and beams: 2 principals run to the long side, secondaries laid on the primaries and the perimetral wall (Fig. 6.52b). Pillars are required only for the porch beam that overhang the south glass façade (Fig. 6.52d). Rubner's Casablanca solution was chosen because of the excellent behaviour in a hot climate, thanks to the big inertial mass of the wall and the insulation, leading to low transmittance wall performance ($U = 0{,}29\ W/m^2K$). Over the solid glulam wood is provide a black breathable membrane (Fig. 6.52a), low-density wood fibre insulation for thermal performance, vapour control layer (allowing the damp passage from inside to outside and not the contrary), horizontal wood boards (providing

Fig. 6.50 **a** The ancient "Masseria" before the building extension. **b** The south porch of the new volume. **c** Timber material of the facade is perfectly integrated into the natural context with olive trees (© Rubner)

Fig. 6.51 **a** Demolition of the superfetation. **b** Igloo boots disposition for the ventilated foundation floor. **c** Blockbau elements storage onsite. **d** Massive listel blocks overlay (© Rubner)

standing air chambers), high-density wood fibre plaster (for the thermal delay) and plaster finishing. Inside the toilet services are anchored directly to the timber wall and a counter wall was provided for the acoustic performance. A ventilated roof completes the intervention moving the Masseria to an A + CasaClima certification (<2,5 kWh/m^2).

RenovActive			***6.16 I+E***
	Location	Anderlecht, Belgium	
	Project type	refurbishment	
	Use	social housing complex	
	Client	private company	
	Design	Antwerpbased **Architect** ONO architectuur, **Lighting Design** Le Foyer Anderlechtois and VELUX Group	
	Year	2017	

Intro
Model Home 2020 is a renovation project of the existing building asset across the world. The VELUX Group promotes it to demonstrate how to meet 2020 legislation without compromising sustainable living thanks to modern technologies and products. RenovActive is a design concept aiming to integrate Active House principles with a social house's tight budget framework. Modularity, flexibility, reproducibility, and scalability of the solution make this prototype a template for 86 similar renovation projects in the community (Fig. 6.53).

Project Description
Indoor visual and thermal comfort, the focus of this project, are provided by seven different strategies (Fig. 6.54). The attic is converted to a 12,5 m^2 of quality living space by inserting roof windows that give more daylight quality. Their disposition activates the stack effect reducing the energy consumption and the 3rd skin of dynamic sunscreen during middle seasons and summer. Thanks to passive strategies, the effort of mechanical ventilation is reduced, having a hybrid system. The new façade insulation, new windows, the new roof construction and the new floor heating of the ground floor with modern radiators improved the thermal envelope giving optimal indoor comfort and greater energy efficiency.

Interaction with the Existing Building
Two are the interaction typologies with the existing building. Building Inside (I) for the attic conversion from a facility € space to a high-quality living space (Fig. 6.55). While Building bEside is used to extend the ground floor by 15 m^2. Thanks to both these extensions strategies, the single-family house can host five people showing this kind of intervention's economic affordability because of the total construction cost including the real estate and the operational cost of re-evaluation (Fig. 6.55).

Fig. 6.52 **a** Airtight disposition on the wall; lamellar beams of the slow slope roof. **b** Primary and secondary roof beams disposition over the loading walls. **c** Bathroom services integration to the blockbau structure. **d** A snowing day at Casa Longano (© Rubner)

Fig. 6.53 RenovActive building intervention on the left of the double family house. The attic became a new bedroom, while the ground floor living room extension is characterized by the green painting and the green roof with the flatten window. (Ph. Adam Mørk)

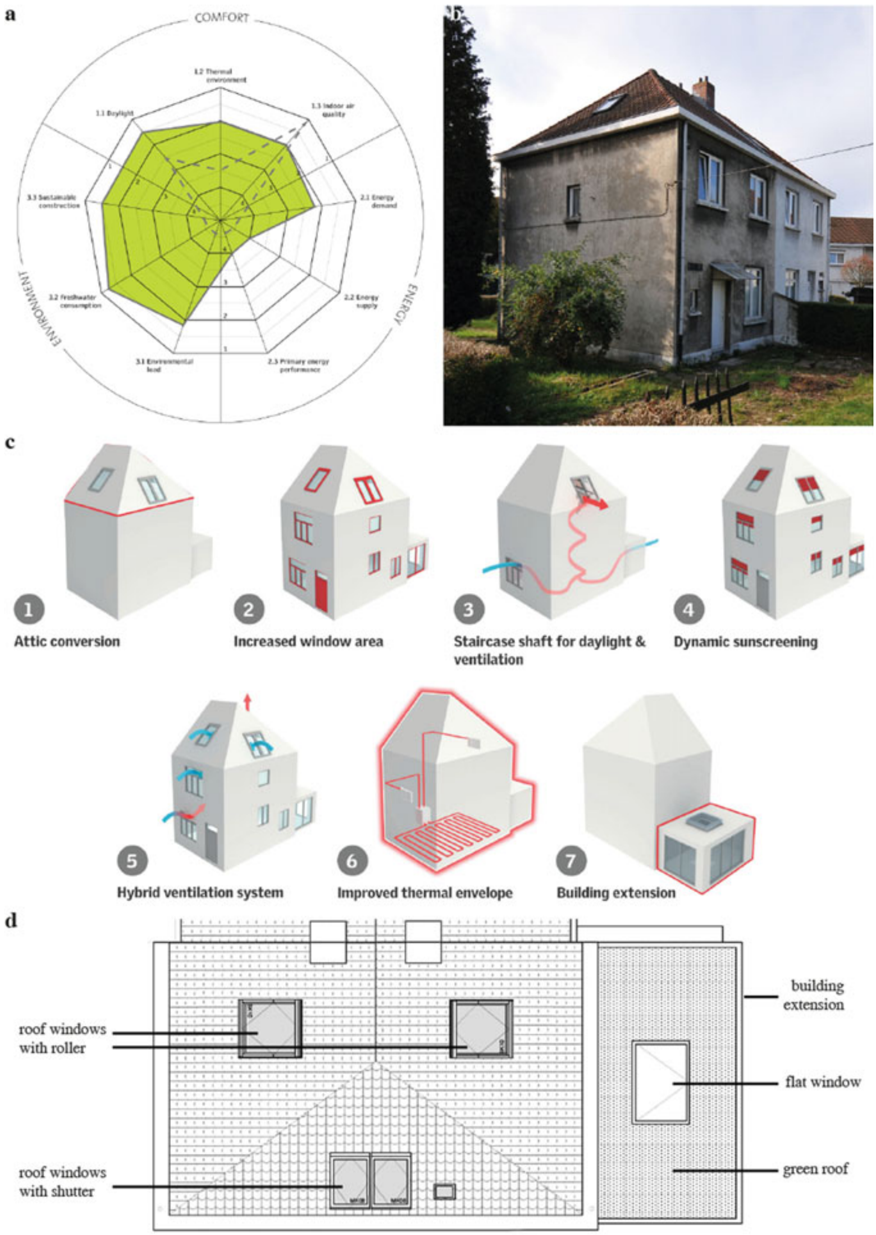

Fig. 6.54 **a** Active House Radar. **b** The existing building before the renovation. **c** The seven intervention strategies. **d** Roof plan after the renovation (© AH Alliance drawing)

Fig. 6.55 RenovActive before (© AH Alliance) and after (Ph. Adam Mørk) the renovation: outer side and attic conversion with the adding of new windows

Timber Technology

The timber roof structure is checked and restored in primary and secondary beams. The building extension is a post and beam timber structure with particular attention to the green roof and the flatten window's integration. The fixed window frames are in wood also.

Ex Fabbrica di Pomidoro Dagnino	**Location**	Palermo (PA)	***6.17 I***
	Project type	refurbishment	
	Use	Residences and hospitality	
	Client	private company	
	Design	**Architect** : Anna Patti **Planning and site supervision** Studio PL5; **Structural Engineering** Ing. Margherita Franzitta, Ing. Valentina Giacobbe; **Daylight planning** VELUX Italia s.p.a.; **Wooden structure and interior construction** Sarni Group	
	Year	2019	

Intro

Industrial archaeology has a lot of expressions in Italy. The "Ex Fabbrica di Salsa di Pomidoro e Conserve Alimentari Niccolò Dagnino" is a notable case for transforming a factory into residence and hospitality. The architectural memory of a production site is evident from the crass typing chosen for the main entrance (Fig. 6.56a). However, it is preserved thanks to the use of zenithal light crass typing selected for the main entrance (Fig. 6.56b–e), the essentiality of shapes and the chimney refurbishment.

Interaction with the Existing Building

The intervention consists of the demolition of the storage volumes superfetation, the structural preservation of the chimney, and the main blocks' refurbishment. Sala Stagnini and Sala Lavorazione Pomidoro are interested in a building inside transformation: internal partitions and the roof are removed, boundary loading walls and timber trusses are preserved (Fig. 6.57a). The inner space was divided into smaller commercial/offices spaces by light-frame timber partitions maintaining the characteristic zenithal light (Fig. 6.57b). The slim brick smokestack is structural consolidated by metal rims (Fig. 6.58a) and it is identified as the landmark of the project, viewable from every rooftop skylight (Fig. 6.58b).

Timber Technology

The pitched roofs are wholly renovated, except for the solid wood truss beams. Spruce secondary beams and purlins composed the roof stratigraphy, completed by shingles and flat windows on the ridge (Fig. 6.56b). Particular attention was given to daylighting design, flatten roof, treated as the fifth façade with a precise

Fig. 6.56. **a** Ex Fabbrica di Pomidoro Dagnino refurbishment. **b** Bathroom illumination and maioliche finishing. **c** The central hall roof skylight. **d** Steel reticular and timber roof structure. **e** Rooftop skylight around the characteristic brick industrial chimney (© Velux)

Fig. 6.57. **a** Demolition of the existing roof saving timber trusses and perimetral loading walls. **b** Internal view of the rooftop skylight and the new timber roof structure framing the refurbished brick chimney by metal rims (© Velux)

Fig. 6.58 **a** Chimney industrial memory. **b** Rooftop skylight access. **c** Aerial view showing the open air space importance and the fifth facade: the flat rooftop common terraces (© Velux)

furniture design. These shared terraces are accessible thanks to the skylight timber structures used to enlighten stairs and distribution spaces (Fig. 6.57a). This use of natural light, courtyard and common rooftop areas and the complete rehabilitation of an abandoned structure make this project a model for the intervention on ‘900 s industrial architectures using simple elements in south Italy.

Costa Volpino Renovation	**Location**	Costa Volpino (BS), Italy	***6.18 O***
	Project type	refurbishment	
	Use	residence	
	Client	private owner	
	Design	**Cladding Design** Ing. Ezio Rosa, **Wooden structure and realisation** Wood Beton	
	Year	2017	

Intro

The use of timber to improve both the seismic and energy behaviour of the medium size complex is an exciting opportunity for Italian residences, as the Costa Volpino Renovation shows (Fig. 6.59a). The RHINOCEROS WALL® is a patented technology by Wood Beton, an external “airbag” for the houses proving for time and cost savings, guaranty for the security of the workmen and few discomforts for inhabitants. It fulfils the requirements of Sismabonus and Ecobonus, two incentives from the Italian government for the seismic and energy renovation of the existing building stock.

Interaction with the Existing Building

Starting from the laser scanner survey (Fig. 6.59b), the project is 3D design developed (Fig. 6.54b) to adapt the exoskeleton to the existing geometry with all the skewness and projections. The recladding (Fig. 6.60b) is realized by CLT walls plus low-density insulation and plaster finishing (Fig. 6.60c). The panels are anchored to the existing structure (Fig. 6.60d) and the ground by a concrete kerb and shooting irons. The external skin became the primary structure, while the box behaviour reduces horizontal displacement (Fig. 6.60e) and has an implemented resistance to lateral forces thanks to the stell anchoring to the ground (Fig. 6.60f).

Timber Technology

Panels are positioned only by crane, without scaffoldings, reducing the onsite activities and avoiding demolitions, except for removing the existing roof. Balconies (Fig. 6.61b) and mixed timber-lightweight concrete elements of the pitched roof (Fig. 6.61c) complete the system. The two floors high panels are truck transported (Fig. 6.61d) from the factory to the site yet finished. The steel plates (Fig. 6.61e) are fixed to the existing concrete structure, and a joint panel is provided for services vertical distribution (Fig. 6.61f). Onsite operations are completed by a single workmen team (Fig. 6.61g). This technology represents a significant opportunity

Fig. 6.59 **a** Recladding of the Costa Volpino residence using the RHINOCEROS WALL®. **b** The existing building before the renovation (© Wood Beton)

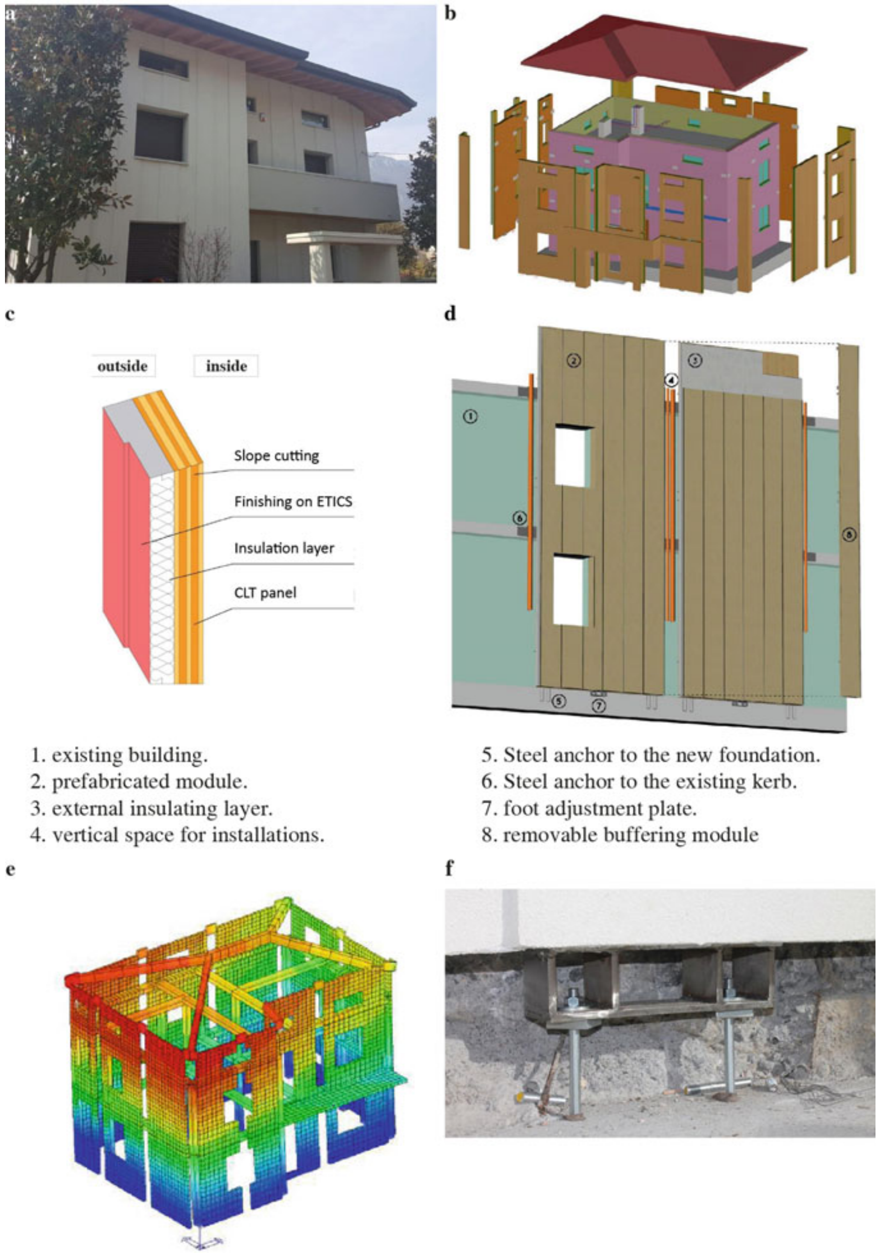

Fig. 6.60 **a** The East facade after the completed intervention. **b** Schematic design of the facades recladding including balconies and roof substitution. **c** RHINOCEROS WALL® timber-based technology. **d** The cladding application to the existing wall. **e** Structures displacement. **f** The steel anchoring to the ground (© Wood Beton)

for most of the two–three floors residential units to implement their quality with a flexible, reversible, aesthetic solution (it is possible to texturize the plaster with colours and drawings) that contribute to growing up the building economic value. It is an application example of the new generation of prefabricated elements, adapting themselves to every kind of shape and challenge.

Wood House	**Location**	Lodi (MI), Italy	***6.19 O+E***
	Project type	Refurbishment and horizontal extension	
	Use	residence	
	Client	private owner	
	Design	**Architects** ATelier2; **Interior Design** Studio Bellagamba; **Structural Design** Studio di Ingegneria G.P. Imperadori; **MEP Design** Forlani Impianti; **Contractor** Impresa A. Boaretto; Vanoncini S.p.A.	
	Year	2011	

Intro

The most common use of timber is the external temporary structure one; still it is possible to periodically transform a space from internal to external periodically, thanks to its flexibility and adaptability. Wood House is a horizontal extension of a single-family house (building bEside), including the outer walls' recladding (building Outside). A porch completed the squared plan in front of the swimming pool (Fig. 6.62a); furthermore, a one-room volume is added in the southern elevation (Fig. 6.62b).

Interaction with the Existing Building

The porch's fluid space periodically became a closing glasses volume looking to the swimming pool (Fig. 6.62c) and a simple cover area during the hot season by opening the full glass façade (Fig. 6.62d). Thanks to the intervention, the plan recovers symmetry by adding a new living space and a service one (Fig. 6.62e). The lateral extension continues the geometry of the existing pitched roof (Fig. 6.63a), while the essential paralepidid volume of the porch with the flatten roof results in a simple projection of the existing pergola (Fig. 6.63c).

Timber Technology

The porch's massive larch structure is laid over two new pillars sustaining two main beams and a frequent secondary structure (Fig. 6.63c) for the ventilated insulated system panels positioning (Fig. 6.63d). The lateral extension walls (Fig. 6.63e) have the same technology as the recladding (Fig. 6.63f): the existing timber finishing (Fig. 6.64a) is replaced by a thermal insulation system for ventilated facades by Isotec. A self-extinguishing rigid polyurethane foam (PIR) is covered by imperme-able aluminium foil at the intrados, and a fireproof mineral coating at the extrados

Fig. 6.61 **a** the crane installation of the two floors panels. **b** Balcony delivers from the truck. **c** Roof timber panels laying. **d** Truck delivering of the panels. **e** Stell plate fixing to the concrete slab. **f** Services integration in the system. **g** Joint panel positioning (© Wood Beton)

Fig. 6.62 **a** The porch addition in front of the swimming pool. **b** The lateral addition of a room and the complete recladding. **c** Opposite view of the porch. **d** Internal view of the lateral expansion. **e** The intervention plan (© Atelier2)

Fig. 6.63 **a** The existing building before the renovation. **b** Aerial view of the new intervention. **c** Porch timber structure. **d** Roof waterproofing barrier positioning. **e** Lateral addition cladding. **f** Recladding of the existing facade. **g** Contiguity of the new and the old roof (© Atelier2)

(Fig. 6.64b). The load-bearing panel has a ventilation chamber of 4 cm with a perforated steel stiffener. A double substructure provides the horizontal larch slats ventilation over the pre-shaped panels, substituting the existing ones (Fig. 6.64c, d). The same technology is also used for the roof and finished by purlins, while the inner partitions are drywalls (Fig. 6.63g). The structure's renovation gives a more integrated aesthetical finishing of the new timber light colour with the brick walls, faded by the sun (Fig. 6.64e, f). Still, overall, it provides for a better energy performance thanks to the new ventilated insulation system (Fig. 6.64g).

Tecnopolo Reggio Emilia

6.20 U+E

Location	Reggio Emilia (RE), Italy
Project type	Refurbishment and Horizontal Extension
Use	Offices
Client	Società di Trasformazione Urbana Reggiane
Design	**Architect** Andrea Oliva **General Contractor** : Impresa Allodi di Parma; Structural Design: Ing. Pierluigi Cigarini Wooden design, production and construction XLAM Dolomiti SRL
Year	2018

Intro

The 7.170 m^2 of the historical Officine Meccaniche Reggiane (Fig. 6.65a) are transformed into an innovation technopolis for research and start-ups in the industrial area of Reggio Emilia. The 1920's structure was preserved because of the beauty of the steel trusses and the Superintendence constraint (Fig. 6.65b). Andrea Oliva architect decides to have a double approach to the project: a concrete lateral extension—recalling the warehouse shape—for services and plants (Fig. 6.65c); plus a modular boxes addition under the primary structure, to provide to different sizes and dimensions of offices and shared spaces. The result is a contemporary space, maintaining its industrial memory, also including the technology innovation and comfort of a new construction (Fig. 6.65d).

Interaction with the Existing Building

New 3 floors structure is completed detached from the existing building, allowing a full offsite approach with 2D elements (walls and slabs) achieved by thermal and acoustical insulation, together with electrical, hydraulic, lightening and climatization plants and services (Fig. 6.54). The CLT elements are transported to the site and laid by the historical structure's existing crane (Fig. 6.55a, b), placing them in the central nave. The refurbishments interested the asbestos removal, the structural reinforcement of the ground soil and the shed substitution. The intervention is completed in four months and it is full removable because of its structure-envelope dry assembly approach (Fig. 6.66).

Fig. 6.64 **a** The previous timber cladding. **b** The ventilated insulation system with perforated steel stiffener. **c** The double sub-structure for timber slats. **d** The complete recladding of the volume. **e–f** Comparison before-after the recladding. **g** Thermal surface analysis of new finishing (© Atelier2)

Fig. 6.65 **a** The existing building before the renovation. **b** Strip-out phases and building bEside addition. **c** The completed intervention. **d** The industrial style of the internal spaces and CLT boxes built under the preserved steel truss structure (© Kai Uwe Schulte Bunert)

Timber Technology

The mixed structure includes loading CLT walls plus a slim steel structure for overhangs because of the three floors high (Fig. 6.67c, d). 722 m3 of Gluelam beams and 850 m3 of solid wood pillars sustain the most extensive span volumes, completed by a light OSB slab at the last floor because of the unloading roof element. Engineering woods' capability to be fully prefabricated and adapt itself to a complex worksite makes it the perfect choice for this intervention. The historical shape is preserved (Fig. 6.68a), and timber is perfectly integrated with steel structure and brick walls (Fig. 6.68b). The rhythm of volumes and boxes generate a dynamic space permeated by skylight illuminance (Fig. 6.68c), transforming the Tecnopolo into a landmark for the region (Fig. 6.68d).

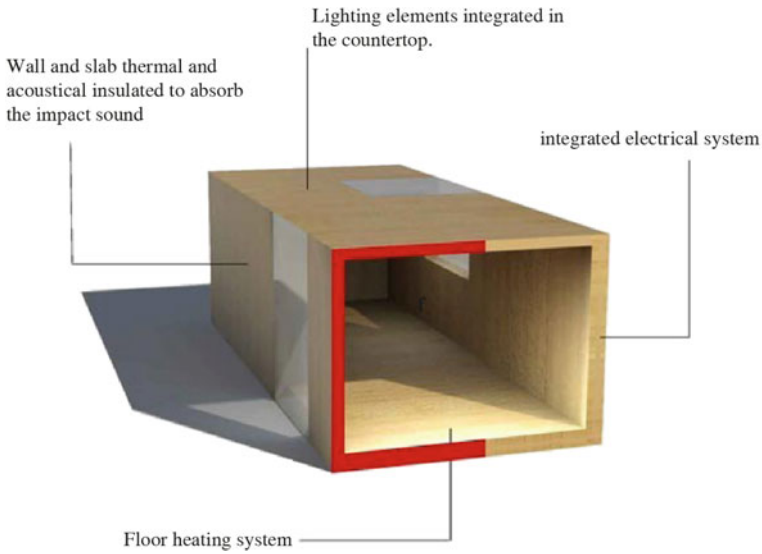

Fig. 6.66 The CLT boxes are autonomous elements thermally and acoustically insulated; all the services and plants, heating and cooling plus electrically, are complete offsite provided. The 848 m^3 of CLT elements plus the 722 m^3 of glulam store 1256 tons of CO_2 (© XLAM Dolomiti)

Fig. 6.67 **a** The hybrid structure of CLT and steel. **b** 2D elements are laid by the existing crane. **c** The distribution drywall volume. **d** Steel structure provides for the overhang of the third level. **e** Solid wood pillars, lamellar beams sustain the light timber frame slab OSB based (© XLAM Dolomiti SRL)

Fig. 6.68 **a** The external structure is also preserved in the graffito. **b** Industrial style perfectly combines timber, steel and concrete. **c** The modular boxes in the central nave. **d** Shed light makes the Tecnopolo a landmark torch also during the night (© Kai Uwe Schulte Bunert)

References

1. Italian Law DPR 412/93 (1993) Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n.10. (GU Serie Generale n.242 del 14-10-1993—Suppl. Ordinario n. 96). Retrieved from https://www.gazzettaufficiale.it/eli/id/1993/10/14/093G0451/sg
2. Italian Law DM 1444/68 (1968) Limiti inderogabili di densità edilizia, di altezza, di distanza fra i fabbricanti e rapporti massimi tra spazi destinati agli insediamenti residenziali e produttivi e spazi pubblici o riservati alle attività collettive, al verde pubblico o a parcheggi da osservare ai fini della formazione dei nuovi strumenti urbanistici o della revisione di quelli esistenti, ai sensi dell'art. 17 della legge 6 agosto 1967, n.765. (1288Q004) (GU Serie Generale n.97 del 16–04–1968) Retrieved from: https://www.gazzettaufficiale.it/eli/id/1968/04/16/1288Q004/sg
3. Unfinished, Spanish Pavillion Catologue at Biennale di Architettura 2016, La Biennale di Venezia. Available at: unfinished.es/en/ (accessed on 01/2020)
4. DATA LABAA. Laboratorio Architettura Ambiente. Università degli Studi di Firenze, DIDA, Dipartimento di Architettura. Available at: datalabaa.blogspot.it (accessed on 01/2020)
5. Costruire con il legno, Progetti e Tecnologie, Promo_legno di proHolz Austria. Available at: promolegno.com/materialegno (accessed on 01/2020)

Correction to: Timber-Based Transformations of the Built Environment: A Portfolio of Case Studies

Correction to:
Chapter 6 in: F. Brunone et al., *Wood Additive Technologies*, Springer Tracts in Civil Engineering,
https://doi.org/10.1007/978-3-030-78136-1_6

The original version of this book was inadvertently published with errors. The following corrections have been updated:

The captions and artworks of Figs. 6.2 and 6.3 have been modified;
The placement of 6 these figures has been changed accordingly;
The citation of Figs. 6.3a and 6.3b have been linked correctly;

The book and the chapter have been updated with these changes.

The updated version of this chapter can be found at
https://doi.org/10.1007/978-3-030-78136-1_6

F. Brunone et al., *Wood Additive Technologies*, Springer Tracts in Civil Engineering,
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