POLITECNICO DI MILANO

School of Architecture Urban Planning and Construction Engineering
Master Degree in Architecture - Build Environment - Interiors
Academic Year 2022-2023

DESIGNING ARCHITECTURAL TECHNOLOGY FOR *CIRCULARITY*

Holistic approach for bio-based materials towards a retrofit of the existing building stock

STUDENT	STUDENT NUMBER	SUPERVISOR (ABC department)	CO-SUPERVISOR (ABC department)
Federica Pradella	967943	Prof. Ingrid Maria Paoletti	Olga Beatrice Carcassi, Giorgio Castellano

Form must have a content, and that content must be linked with nature.

Alvar Aalto

Table of contents

Keywords

→ Sustainability

→ Construction industry

→ Supply chain

→ Circular build environment

→ Bio-based materials

→ Timber

→ Design for assembly

→ Design for disassembly

→ Prefabrication

→ Recycle

→ Re-use

Parole chiave

→ Sostenibilità

→ Industria delle costruzioni

→ Catena di approvvigionamento

→ Ambiente costruito circolare

→ Materiali bio-based

→ Legno

→ Progettazione per l’assemblaggio

→ Progettazione per il disassemblaggio

→ Prefabbricazione

→ Riciclo

→ Riutilizzo

Abstract (EN)

The aim of the research is to understand the supply chain's structure of sustainable materials used in the construction industry, comprehending the level of change needed for a large-scale application.
The notions of bio-based materials, supply chain, and construction industry are investigated together to fill the gap between the different area of interest. Starting from the idea to improve the green orientation of construction industry, the management side of the process is explored, understanding if the industry is currently able to produce these materials and run them into the market. Based on the collection of such data, the project of a prototype of building component is conducted, reflecting the concept of bio-based materials, Design for Assembly, Design for Disassembly, Reuse and Recycle.
The research has been conducted through literature review of the topic, qualitative research with interviews of the main actors of the wood supply chain, experimental project on a prototype of a building component for the retrofit of non-historical existing buildings, by using bio-based materials.

Research questions:

- Can the introduction of innovative bio-based building materials lead to a significant shift of the sector in terms of sustainability?
- Which is the level of change needed to move the construction industry towards a lower environmental impact, by implementing the use of sustainable building materials on a large scale?
- Which are the possible applications of these materials/technologies in the construction sector? At the same time, which are the difficulties in the shifting process and how can these be overcome in the future?

Abstract (IT)

L'obiettivo della ricerca è comprendere la struttura della catena di fornitura di materiali sostenibili utilizzati nell'industria delle costruzioni, intuendo l'entità del cambiamento necessario da apportare per un'applicazione su larga scala.
I concetti di materiali bio-based, catena di fornitura e industria delle costruzioni vengono analizzati insieme per colmare il divario tra le differenti aree di interesse. Partendo dall'idea di migliorare l'impatto dell'industria delle costruzioni, inizialmente viene esplorato l'aspetto gestionale del processo, cercando di capire se l'industria è attualmente in grado di produrre questi materiali e di immetterli sul mercato. Sulla base della raccolta di tali dati, la ricerca prevede la realizzazione di un prototipo di componente edilizio che rifletta i concetti di materiale bio-based, Design for Assembly, Design for Disassembly, riutilizzo e riciclo.
La ricerca è condotta attraverso una ricerca nella letteratura disponibile sull'argomento, una ricerca qualitativa con interviste ai principali attori della filiera del legno, un progetto sperimentale di un prototipo di componente edilizio per il retrofit di edifici esistenti non storici, utilizzando materiali bio-based.

Domande di ricerca:

- L'introduzione di materiali da costruzione innovativi, a base biogenica, può portare ad un cambiamento significativo del settore nell'ambito della sostenibilità?
- Qual è l'entità del cambiamento di paradigma necessario per portare il settore delle costruzioni verso un minor impatto ambientale, implementando l'utilizzo di materiali da costruzione sostenibili su larga scala?
- Quali sono le possibili applicazioni di questi materiali/tecnologie nel settore delle costruzioni? Al tempo stesso, quali sono le resistenze al cambiamento e come si possono superare tali problematiche in futuro?

Compendio (IT)

La ricerca, intitolata "*Designing architectural technology for circularity: holistic approach for bio-based materials towards a retrofit of the existing building stock*", si pone l'obiettivo di comprendere la struttura della catena di fornitura di nuovi materiali sostenibili utilizzati nell'industria delle costruzioni, proponendo una soluzione applicabile al patrimonio costruito esistente. Da qui, studiando le fasi che costituiscono tale processo, il fine è intuire l'entità del cambiamento necessario da apportare per un'applicazione di tali materiali su larga scala, considerando la possibilità che nuovi step saranno necessari.

Il lavoro è così articolato:

- Cap. 1: contesto teorico di riferimento;
- Cap. 2: ricerca sul campo;
- Cap. 3: progettazione di un sistema per il retrofit di edifici esistenti;
- Cap. 4: rappresentazione dei risultati;
- Cap. 5: discussione dei risultati ottenuti in una prospettiva futura, ponendo l'accento sui punti da implementare nelle prossime ricerche.

Il primo capitolo è rivolto alla revisione di articoli scientifici, libri, pagine web, documenti ufficiali, norme e schede tecniche, cercando di trovare un punto di collegamento tra l'area di ricerca maggiormente attinente ad aspetti architettonici/tecnici; con la componente più manageriale, che verte su aspetti prettamente economici/produttivi.

Questa prima parte di ricerca bibliografica è stata condotta nella letteratura disponibile sull'argomento, la quale è risultata carente di collegamenti tra i due ambiti di interesse: il management e l'architettura.
A seguito dell'introduzione dell'argomento, è stata delineata una panoramica delle principali direttive europee (Agenda 2030, Green Deal) e di come queste vengono applicate a livello di cambiamento climatico. Inoltre, l'accento è stato posto sul PNRR (Piano Nazionale di Ripresa e Resilienza), cercando di comprendere come a livello italiano si sta procedendo per contrastare le problematiche legate al surriscaldamento globale.
Successivamente, il problema da affrontare nella ricerca è stato delineato. Il settore delle costruzioni ha un pesante impatto sull'equilibrio del pianeta, sia per quanto riguarda l'emissione di gas serra, che per la quantità di energia necessaria per costruire, usare e mantenere un edificio.

In particolare:

- Uso di nuovi materiali;
- Elevato utilizzo del suolo;
- Impoverimento delle risorse;
- Surriscaldamento globale;
- Problemi di approvvigionamento di materie prime;
- Fine vita dei materiali e del ciclo di utilizzo;
- Questioni di rifiuti e riciclo.

La sfida è quella di pensare alla futura industria delle costruzioni in ottica bio-based. Per fare ciò, è stato necessario guardare al passato dell'architettura vernacolare, sia per quanto riguarda i materiali impiegati, sia per le tecniche costruttive, adattandoli alle questioni e ai processi del giorno d'oggi. Necessariamente, una panoramica di concetti chiave è stata realizzata per cercare di colmare il divario tra passato, presente e futuro. Economia circolare, Life Cycle Assessment (LCA), approccio Cradle to Cradle (C2C), Material passport, Design for Manufacture and Assembly (DfMA), Design for Disassembly (DfD), certificazioni sono alcuni di questi temi base.

Attraverso il secondo capitolo, dai concetti generali sopra citati, si passa all'inquadramento su una particolare area di mercato: il legno come materiale da costruzione. Infatti, tra i materiali bio-based e vernacolari, il legno ha una catena di fornitura più sviluppata rispetto a materiali come il micelio, essendo utilizzato già da molti decenni nel settore delle costruzioni sotto forma di componenti ingegnerizzati. Inoltre, per avere una visione più completa sul tema, in aggiunta alla letteratura esistente, sono state realizzate una serie di 19 interviste a specifiche categorie di attori della supply chain del legno, del contesto non solo italiano ma anche europeo. A tale scopo, sono stati coinvolti designer/ingegneri, primi trasformatori del materiale, produttori di componenti, imprese di costruzione ed enti di standardizzazione. I numerosi dati raccolti sono stati selezionati e interpretati attraverso un "coding frame", permettendo così di definire dei risultati parziali. Tali risultati sono serviti da punto di partenza della sperimentazione progettuale: la realizzazione di un prototipo di componente edilizio per il retrofit di edifici esistenti - non storici - che rifletta i concetti di materiale bio-based, Design for Assembly, Design for Disassembly, riutilizzo e riciclo.

Il terzo capitolo si pone come obiettivo la proposta di un sistema prefabbricato per il rimodernamento del patrimonio costruito che, in un continente "antico" come l'Europa, rappresenta la percentuale maggiore di edifici esistenti. Tale sistema rappresenta un'importante possibilità di retrofit strutturale, energetico e architettonico. L'attenzione viene data sia ai materiali a base biogenica, in particolare legno, usato come struttura e finitura esterna, insieme alla paglia di riso, impiegata come isolante. Inoltre, basandosi sul concetto di prefabbricazione, tecniche antiche come l'utilizzo di giunti ad incastro di collegamento tra diversi elementi, che non prevedono fissaggi con elementi metallici, vengono riscoperte e applicate dove possibile.

In questo modo, l'aspetto più tecnico della stratigrafia del pannello si affianca all'aspetto puramente architettonico, cercando di unire funzionalità ed estetica nel nodo marcapiano, progettando un elemento originale e riconoscibile.

Si tratta di una ricerca che prova a delineare una problematica e a proporre una soluzione, molti sono gli aspetti che in attività future potranno essere studiati in modo più approfondito.

1/ THEORETICAL BACKGROUND

Semantic literature analysis

The first step comprehends the topic consist of an unstructured reading on the main topics of the research: supply chain of bio-based materials and construction industry. The early-stage raw information is coming mainly from Businesses and Government documentation. The position paper of the COP26 and IUCN Global Standard are a first example of papers regarding Nature-based Solutions (NbSs). Moreover, online databases of materials have been used: Material connexion[1] , Material District[2] , Materially[3].

The second step includes a more structured reading. Herein, the search methodology has been set. It consists of a first framework definition to frame the boundaries of the research: main topic, area of application and keywords. The principal databased which have been used are Scopus, ResearchGate, Google Scholar, JSTOR, Politecnico di Milano online library.
The totality of scientific articles, books, online resources, conference papers have been found under the condition of open access. The period considered is mainly 2016-2022 since the research issues has exploded in these last years.

The search methodology of articles has been based on a series of keywords combined in different ways: bio-based materials, supply chain, value chain, construction industry, business model. First, the articles matching the topic have been collected in an Excel file, then in the Mendeley database.

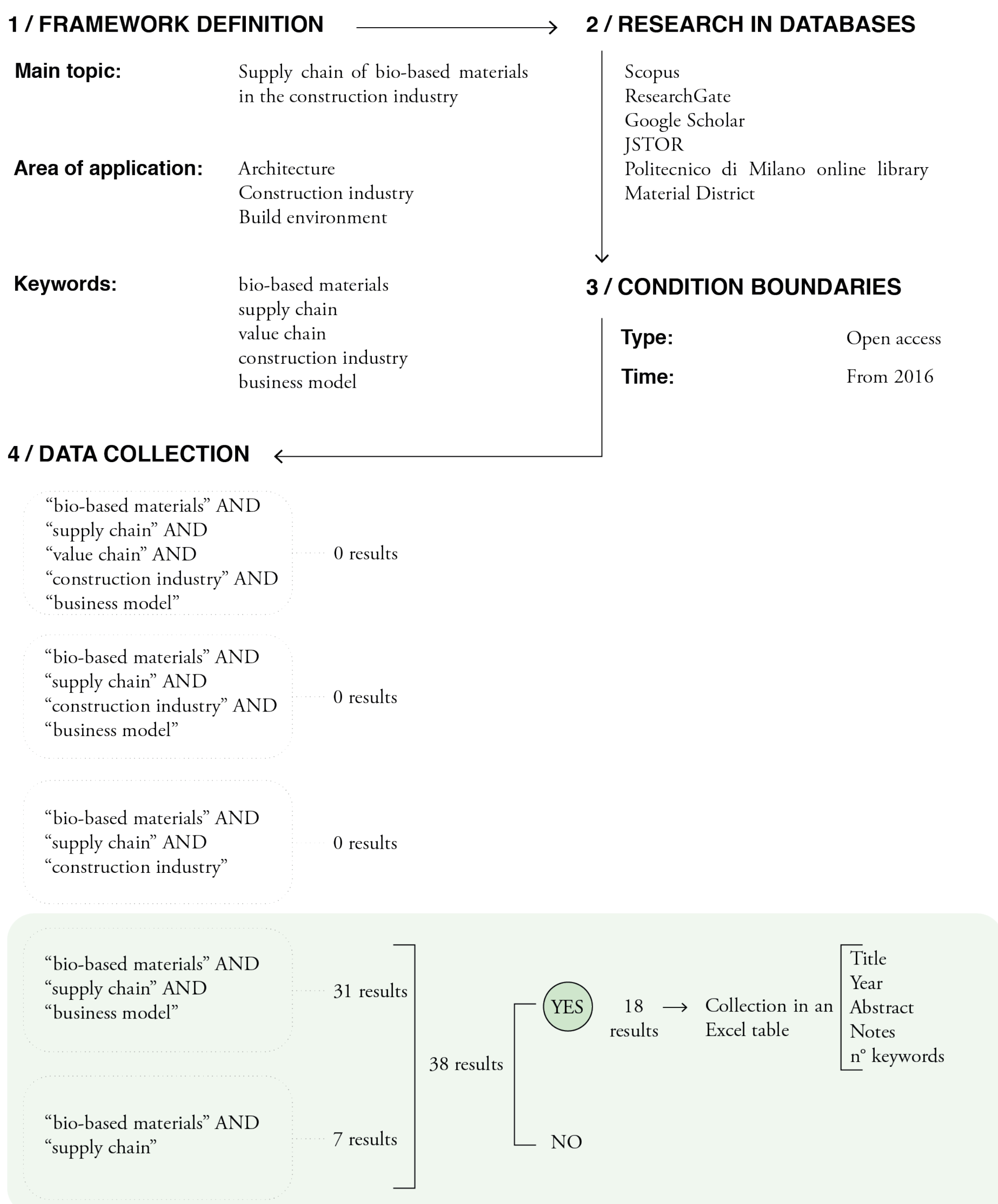
For each article has been summarized:
- Title;
- Year of publication;
- Abstract;
- Number of matching keywords;
- Notes of the content.

The very first result of the survey of references consist of a lack of shared information between the disciplines which has represented an important gap in the comprehension of the topic. Moreover, it has been difficult to find common ground between the main area of interests, the supply chain of bio-based materials used in the construction industry.

01 | https://materialconnexion.com/

02 | https://materialdistrict.com/

03 | https://www.materially.eu/it/



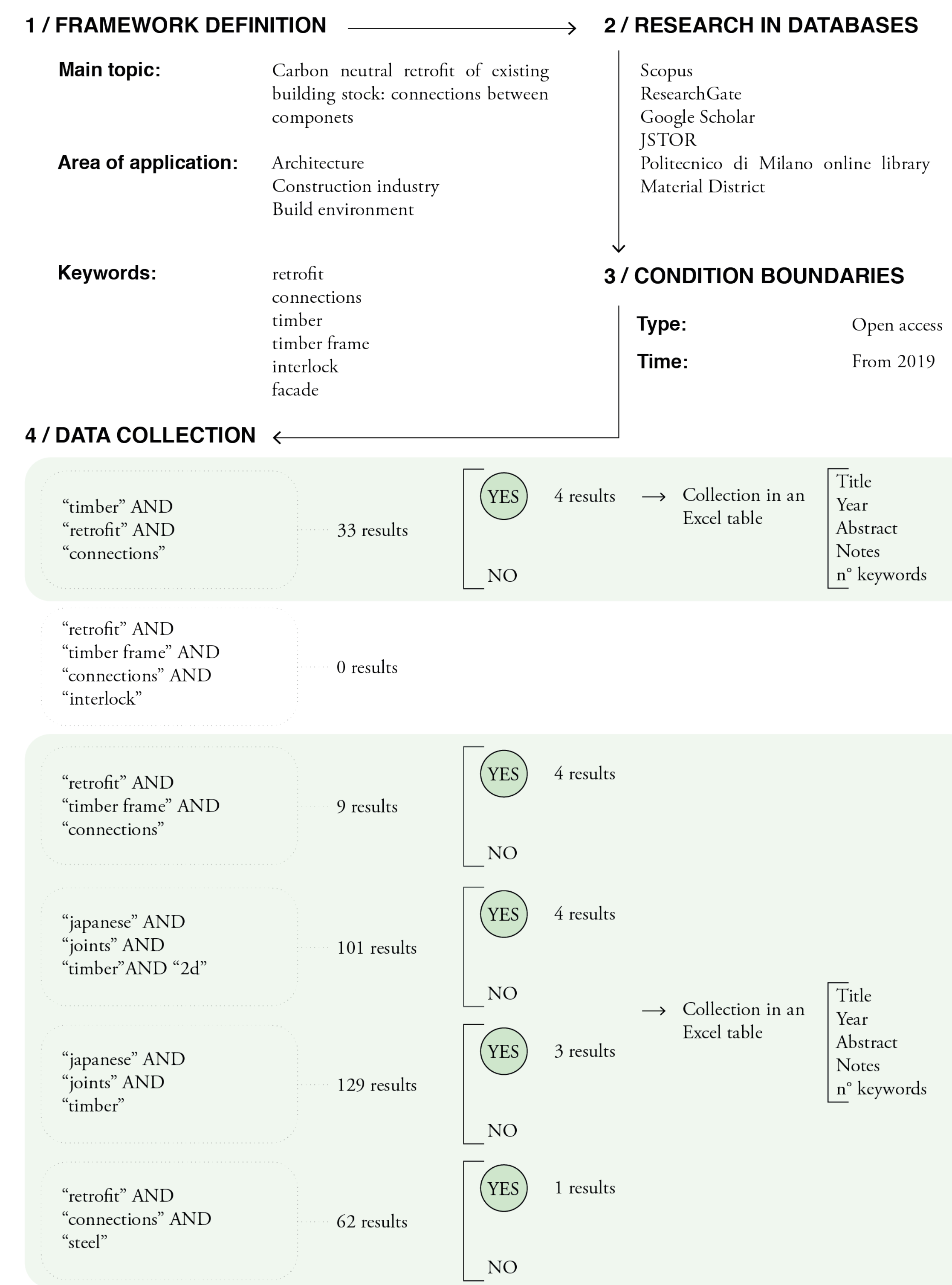


FIGURE 01 | Elaboration by the author of the search methodolgy applied for the introduction part.

FIGURE 02 | Elaboration by the author of the search methodolgy applied for the prototype part.

1.1 Introduction

Current impact of the construction sector

"Climate changes" are defined by the United Nations as long-term variations in temperature and weather patterns. These alterations can occur naturally; however, since the 19th century, human activities have been the main factor behind them.

The first point of the COP26 position paper by UN (2021) underlines how much this condition is in the present. Nowadays all the countries should mitigate the GHG emissions to limit the global warming to 1.5°C, under the Paris Agreement. In this context, the application of Nature-based solution could play an important role, contributing to mitigate around 30% temperature levels. Despite that, it is estimated that only about 3% of climate financing is currently directed towards Nature-Based Solutions. Investments need to at least triple in real terms by 2030. [1]

From the International Union for Conservation of Nature (IUCN) of 2016, Nature-based Solutions are defined as "*actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*". So far, with the increasing awareness around the topic of sustainability in every field of life, the Nature-based Solutions represent mandatory tools to be used to avoid crises related to biodiversity and climate change.

Going on through the second point, Nature-based Solutions are presented as "*[...] a critical contribution to both climate change mitigation and adaptation while also supporting biodiversity conservation, health, poverty eradication and other societal objectives agreed to under the Sustainable Development Goals (SDGs).*" [1]

The UN Agenda of 2030 for Sustainable Development sets 17 Goals that should be achieved in terms of environmental, social, economic, institutional initiatives. Between the 17 SDGs, the eleventh is related to "Sustainable cities and communities". That goal aim to make cities, and in general the human's settlements, safe, resilient, and sustainable.

General awareness of climate change issues is growing. The European Commission approved the Green Deal in 2020. This is a set of policy initiatives through which member countries commit to decrease greenhouse gas emissions by at least 55% by 2030 and pursue climate neutrality by 2050 [2].

One of the elements that constitutes this document concerns how to build and renovate the built environment in an energy and resource efficient way. In fact, the construction and use of building require both significant amounts of energy and material resources. Buildings currently account for 40% of total energy consumed and 36% of total GHG emissions. Moreover, it has produced over 923 million tonnes of waste in 2016.

1.5°C

Limit to the global warming under the Paris Agreement

30%

Expected mitigation of temperature levels by using Nature-based Solutions

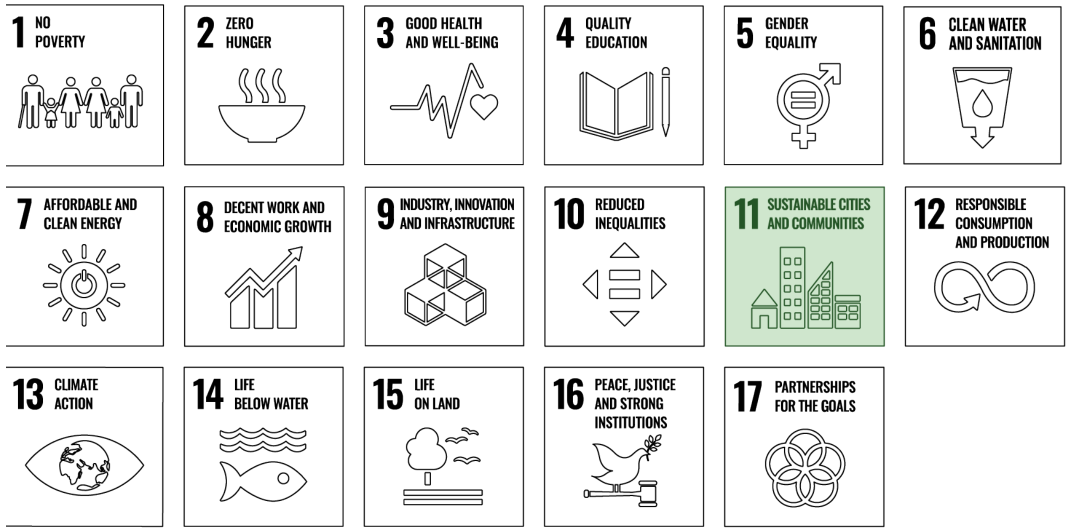
3%

Total economic financing to Nature-based Solutions

55%

Limit to the GHG emissions pursuing carbon neutrality by 2050

FIGURE 03 I
Adaptation by the author of the search European SDG's.



40%

Total energy consumed by construction sector

36%

Total GHG emitted by construction sector

923mln

Tonnes of waste generated by construction sector in 2016

25

Years needed to change an industrial sector

So far, the construction sector "*[..] (it) is still permeated by a number of detrimental factors such as the use of high impact materials, non-reversible building solutions, low efficiency processes and manufacturing*" [3]. In fact, the use of natural resources has generally been a linear model. The materials for construction were sourced, used in the built environment, dismissed generating waste which couldn't been used again. The larger part of wasting materials includes concrete, bricks, gypsum, wood, glass, metal, plastic, solvents, asbestos and excavated soil [4].

Hence the need for a "green transition" for the construction sector as well. In this context, bio-based materials can represent an alternative to the more traditionally used materials in architecture, engineering, and construction (AEC).

At the Italian level, the Presidency of the Council of Ministers has published the PNRR: Piano Nazionale di Ripresa e Resilienza (2021). Part of the document is addressed to energy efficiency and building upgrading. Italian buildings account for more than a third of the country's energy consumption and most of them were built before the adoption of energy-saving criteria and related legislation.

Therefore, systematic interventions represent a key point for the reduction of consumption and the abatement of CO2 emissions.

In particular, the programme concerns:
- Improving the efficiency and safety of the public and private building stock;
- Introduction of a temporary incentive for the energy requalification and anti-seismic adaptation of the private building stock and for social housing;
- Development of efficient district heating systems [5].

It will take at least 25 years to change an industrial sector and all value chains connected. Therefore, new technologies, sustainable solutions, straightforward strategies must be adopted in the following years to achieve a tangible shift to 2050, as per the European agenda [2].

1.2 Problem statement

Scale up a new supply chain for innovative construction materials

It is strongly established that the so-called "business as usual" scenario does not represent a viable option for a sustainable future. There's the necessity to identify new development models for our society to continue growing and prosper in the future. The construction industry must reflect this urgency of change [3].

The development of green procurements standards, certification schemes, publicly accessible databases of environmental data on products and building components enable the shift towards a "green" supply chain for the construction sector [6].

Construction is not an environmentally friendly industry. In such field sustainability implies a natural resources balance. Its core principle is described as a "meeting the needs of the current generation without compromising the ability of future generation to meet their needs" [7].

The idea to improve the green orientation of the industry should consider the application of new innovative materials in buildings, such as bio-based materials. In this sense, bio-based materials can be considered inside the wider approach of the Nature-based Solutions (NbS), promoted by UN.
A shift in the material used is connect to new technologies of production and thus, on a shift in the supply chain for the transformation and production of raw materials into construction materials.

The main reasons are:
- Use of new materials;
- High land use;
- Depletion of resources;
- Problems of global overheating;
- Problems with the supply of raw materials;
- Problems connected to the end of life of materials and use cycle;
- Problems of waste and recycle [7].

Moreover, construction is considered as a prototype production due to its temporary and no-repetitive nature. The low levels of repetition make continuous improvement difficult and subsequently limits innovation to projects. This is often presented as one reason for a lack of performance in the industry [8]. More work is needed to bridge this gap with more pragmatic methods that can be rapidly applied in day-to-day decision making [6].

In addition, a large-scale use of bio-based materials requires an industry that is able to produce them, a market where to buy, experts which are capable to use them in buildings construction. Herein, processing a new business model is fundamental. It is not sufficient to have a good material, to run in it in the market it is mandatory to have the possibility of large-scale production and use.

Such scaling can be achieved by integrating circular criteria into the standard situation. Circular criteria should become the core for both for public and private activities [9].

From an economic system perspective, almost all construction projects are divided into parts that are subcontracted to individual enterprises. This decomposition principle allows a production process constitutes by subprocesses [8].
"*A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves*" [10].

Its purpose is to create value for both the client and the end-user. If inside the supply chain there is a change in actors, the new actor will bring inside the supply chain a new culture and values, thanks to the different background and education, changing parts of such subprocesses. Accordingly, the new materials could bring into the supply chain a new culture and values [6].
Herein, the shift from the supply chain of traditional construction materials to the one of bio-based construction materials requires to be studied.

The construction of a building is seen as the production of a something, which comprise the transformation of inputs in outputs. It is characterized by multiple steps and, consequently, multiple stakeholders are involved in different parts of the system. Therefore, communication in such processes is complex. The information flow in the building process is fragmented because the building process itself is fragmented [11]. Decomposition enables the building to the pack in different parts which are constructed and managed by different professionals [8].
Accordingly, the need of collaboration within and across sectors is crucial for a more rapid progress [6]. Based on such requirements, this research aims to act as a collaborative and exploratory work between Architecture and Management Engineering.

The study of the current supply chain of traditional building materials is the base for understanding if a shift in the model is needed or if the actual one could support a large-scale production. For this purpose, methodical bibliographic research has been complemented by a series of interviews conducted with different categories of actors who have a role within the building construction process, to have a more complete and practical view to add to the bibliographic sources. The combination of these studies served the creation of a prototype of an architectural façade component, characterized using bio-based materials. The project is based on the prefabrication of the individual elements that compose the system, taking into account not only the production phase but also the assembly phase and planning for future disassembly, in the perspective of reusing the elements.

The problem of the construction sector is that building without considering the local boundaries, generates a relevant impact on the environment.

CONSTRUCTION PROCESS - actors and practices

	N°	STAKEHOLDERS	LIFE CYCLE PHASE	ACTIVITIES	CHARACTERISTICS
Stakeholders directly involved in the building life cycle:	1	CLIENT / INVESTOR	project development / design	**demand for construction**	The client require for a new building to be built with a specific technique or a specific material, in this case wood, more generally bio-based materials
	2	SUPPLIER	construction / deconstruction	**appoiting to procure the building**	Economic player who makes a tender, to select the most feasible project and contractors
	3	BANKS / FINANCIAL INSTITUTIONS	project development / capital	**provide economic capital**	Since Real Estate market is expensive, the investor require capital from banks, making debts
	4	MAIN CONTRACTOR	construction / deconstruction	**transformation of the raw materials**	The conversion of the raw materials into building products is one of the mos importa phases of the supply chain.
	5	Sub-contractors		resource extraction manufacturing transportation retail usage and consumption **construction**	In fact, according to the type of material, several features will change: - environmental property - technology - construction process - extected lifetime/maintenance - recycling/waste
	6	ARCHITECTS / ENGINEERS	project development / design / construction	**design of the building**	Digitalization is playing an important role in the construction sector. The main tool used is the BIM which integrates designing, modelling, planning
	7	USER / CLIENT	operation / maintenance	**occupancy**	Final consumer of the building exploitation
	8	PUBLIC AUTHORITIES	all the phases	**control / commissioning of the building**	Activity of control in the different stages of the supply chain
Stakeholders not directly involved in the project:	9 10 11 12 13	non-governamental organizations and civil society research and education media environment future generations	all the phases		Control of developing social equity and well-being to the users Access to technology and knowledge Access and sharing of information

FIGURE 04 I
Elaboration by the author of the construction process - actors and practices.

CONSTRUCTION PROCESS - circular approach

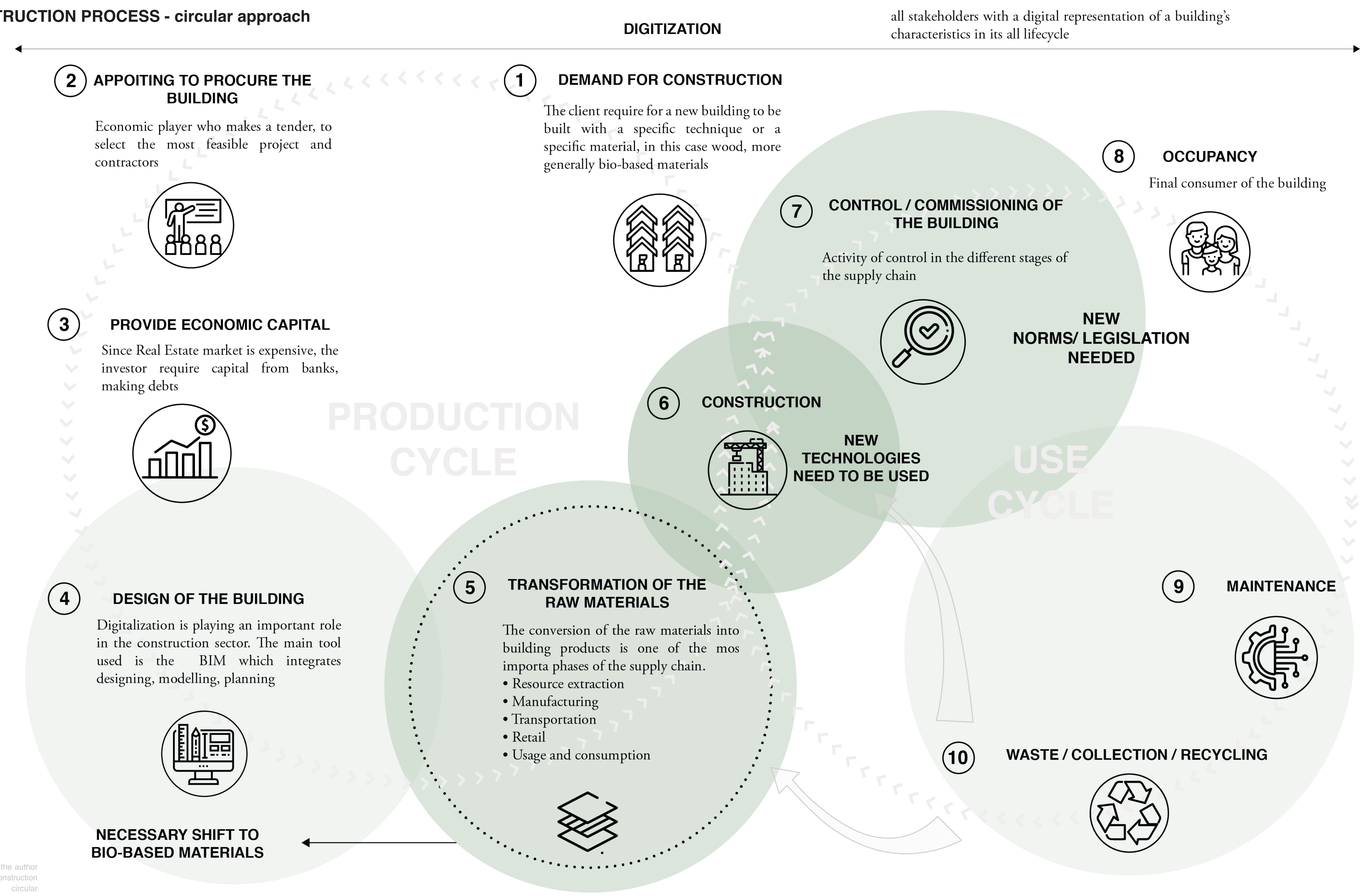


FIGURE 05 I
Elaboration by the author of the construction process - circular approach.

1.3 Main objectives of the research

Understand the future direction of the construction sector in a bio-based optic

Strategies and implementation steps to lower the impact of the construction sector are needed. The geological period named Anthropocene is the Earth's phase which is characterized by a negative impact of the human activities on the climate and the environment. This has started from the Industrial Revolution in the 1800s, with the shift in the production given by the mechanization and the advancement of new technologies. In more recent years, digitalization has brought further optimization. Globalization and modernism gave the possibility to construct alien and non-climate specific typologies, where concrete and iron have replaced natural and local materials. These copy-paste solutions can't no more be applied.

The hybridization of technologies of traditional materials and vernacular materials could become an answer to those issues. Accordingly, one of the research projects set for Paris Agreement, implies the adaptation of vernacular and indigenous technologies to a modern use, not just from a local level but to and international level. For a successful integration, new science, and technologies by using traditional materials should be combined [12].

Looking backward to go forward

A good example of "looking backward to go forward" principle is given by the book "HABITAT – Vernacular Architecture for a Chancing Planet" [12]. It explores the connection present between the natural environment and the build environment. The environment has been divided in 5 different climatic zones: tropical, dry, Temperate moist mid-latitude with mild winters, Continental moist mid-latitude with cold winters, Polar (based on the internationally recognized Koppen-Geiger system).
Each of these climatic zones is characterized by different technologies in construction, the use of different materials that a more suitable for a place than other, finding them in the local environment (zero-carbon solutions) embedded in local micro-economies.

The value of vernacular

A basic relationship established in the build environment is between user and constructor. The shift from vernacular ways of building and modern ways of building has signed a shift also in the relationship between these two stakeholders. In the first case, from local labour which produce buildings with local materials for its own community, then in the second case we've passed to more modular and less regional chains of production and constructions [12]. Such shift has been necessary living in a global economy and working in an international market.

In economic terms, the technical development can improve the supply side and the stimulation of the market can foster the demand. There's the need of a good strategy for both improve the supply and the demand [12]. As a matter of fact, while sustainability is the leading-edge goal everywhere in the world, the actions aimed at achieving such a goal are necessarily site dependent. For this reason, it results fundamental the study of a short supply chain, connected to the production-sale-use site [13].

Postulates such as off-site construction, modularity, disassembly should enable the reduction of waste amount and energy consumption. Consequently, components and materials can then be reused for other applications, remaining inside the construction sector or transferring for different uses, fostering recycle and avoiding primary material use. Refurbishment keeps building parts in use for longer, helping to reduce or lower waste [14].

Even though these concepts appear contemporary, are actually from the past. For example, the reuse of timber components from old construction has been a common practice in many parts of the world for centuries.

"*In medieval Europe, a scarcity of suitable construction timber led to the dismantling of old buildings to recover parts, such as beams and columns, that could be reused in new buildings. Historically in Denmark, half-timber construction is the most widespread system for building with timber. Such method allowed for easy disassembly thanks to modular components. This provided the possibility for easy extensions or removable building parts without changing the overall character of the building. This also resulted in many buildings being disassembled and reassembled in other places.*" [15] This has been reported by the Danish Architectural firm GXN, aiming at spreading ideas to improve construction sector.

Therefore, the knowledge of existing solutions is the key to improve future construction models.

1.3.1 Key concepts

Some key concepts need to be introduced for the comprehension of the research, to bridge the gap between Architecture notions and Management ones.

Here's the list of the notions analysed:

1. Circular economy and Circular build environment;
2. Life Cycle Assessment (LCA);
3. Cradle to Cradle approach (C2C);
4. Material passport;
5. Design for Manufacture and Assembly (DfMA);
6. Design for Disassembly;
7. Lean construction;
8. Certifications.

1 CIRCULAR ECONOMY AND CIRCULAR BUILD ENVIRONMENT

In the last years there has been a huge discussion about the shift from the linear approach to the circular approach, which is characterized by a more conscious use of natural resources in the built environment [9].
The circular economy is a model of production and consumption emerging in different sectors and seeking to reduce waste, emissions, and energy needs [16]. It is based on an economic model aiming at keeping materials and resources in use as long as possible, ideally forever, in a closed loop. It aims to be restorative and regenerative by design and aims to keep product, components, and materials at their highest utility and value all times [12]. Furthermore, it can be applied at different scales, from local to global. Opposite to the circular economy are single use, downcycling, and loss of value [9].
The circular economy is about preserving the added value of existing things, both materials and buildings. [9]
There are three stages of great importance when considering the adoption of circular strategies: material and component manufacture, design and planning, and end-of-life management. [17]
Considering the engineering and construction industry (AEC), it is the world's largest consumer of raw materials. It accounts for 50% of global steel production and consumes more than 3bn tonnes of raw materials. A circular approach could help the sector to reduce its environmental footprint. Some manufacturers, for example, are already designing products that can be reused or repurposed [14]. For the building sector, these principles are summarised in the ReSOLVE framework, elaborated by the Ellen MacArthur Foundation. This system identifies a set of six actions that companies and governments can take to transition to a circular economy (Regenerate, Share, Optimise, Link, Virtualise and Exchange) [17].

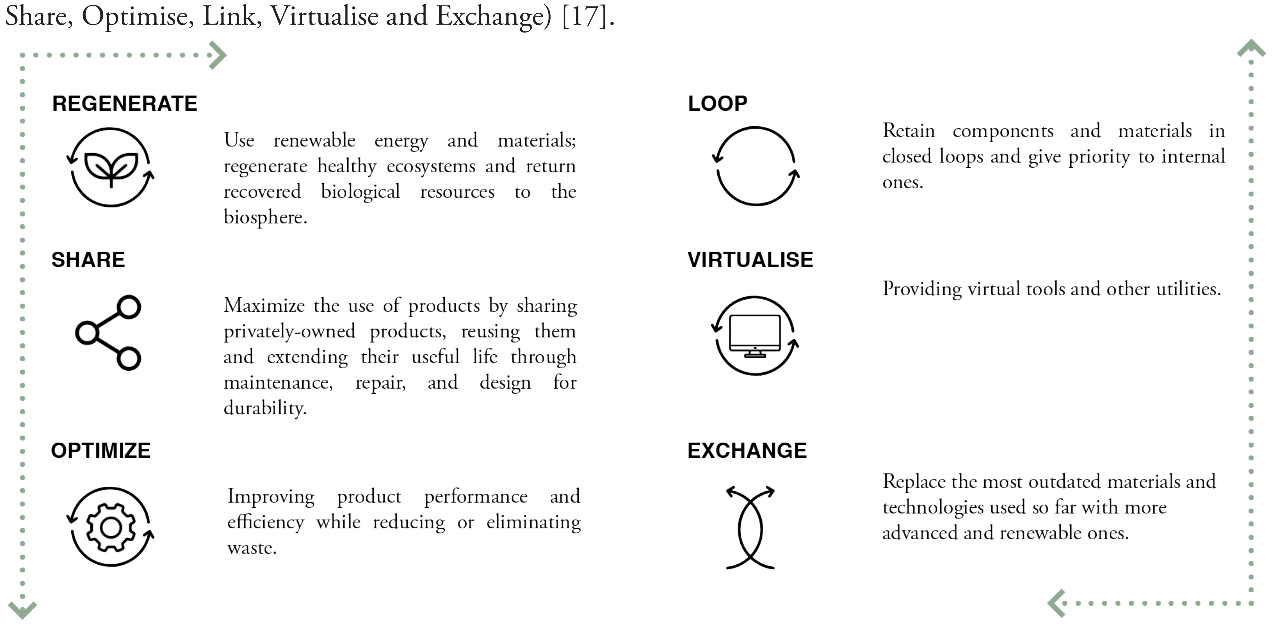


FIGURE 06 | Elaboration by the author of the ReSOLVE framework by Ellen McArthur Foundation.

Circular practices which can be adopted for the build environment:

- Modularity;
- Prefabrication;
- Off-site construction;
- Design for Assembly and Manufacturing DfAM;
- Design for Disassembly DfD;
- Reuse and recycle. [14]

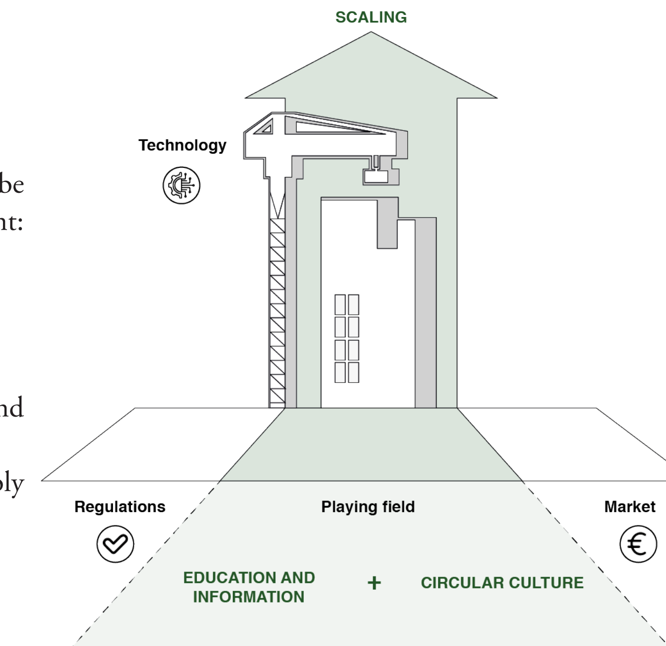


FIGURE 07 | Adaptation by the author of drivers to scale circularity in the build environment.

The transition from linear built environment, take-make dispose process that assumes no limit on the availability of resources (which are lost for future use) to circular built environment, keep materials and resources in use as long as possible.

2 LIFE CYCLE ASSESSMENT (LCA)

The definition of Life Cycle Assessment (ISO 14040 2006a-2006b) given by the European Environmental Agency is the following[4]:
"Life-cycle assessment (LCA) is a process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities. It can be used to study the environmental impact of either a product or the function the product is designed to perform. LCA is commonly referred to as a "cradle-to-grave" analysis.

LCA's key elements are:
1. identify and quantify the environmental loads involved (e.g. the energy and raw materials consumed, the emissions and wastes generated);
2. evaluate the potential environmental impacts of these loads;
3. assess the options available for reducing these environmental impacts."

It is a fundamental tool related to the management of a product, which provide the best framework for assessing its potential environmental impacts currently available[5].

04 | https://www.eea.europa.eu/help/glossary/eea-glossary/life-cycle-assessment

05 | https://ec.europa.eu/environment/ipp/lca.htm

LCA Life Cycle Assessment - general stages

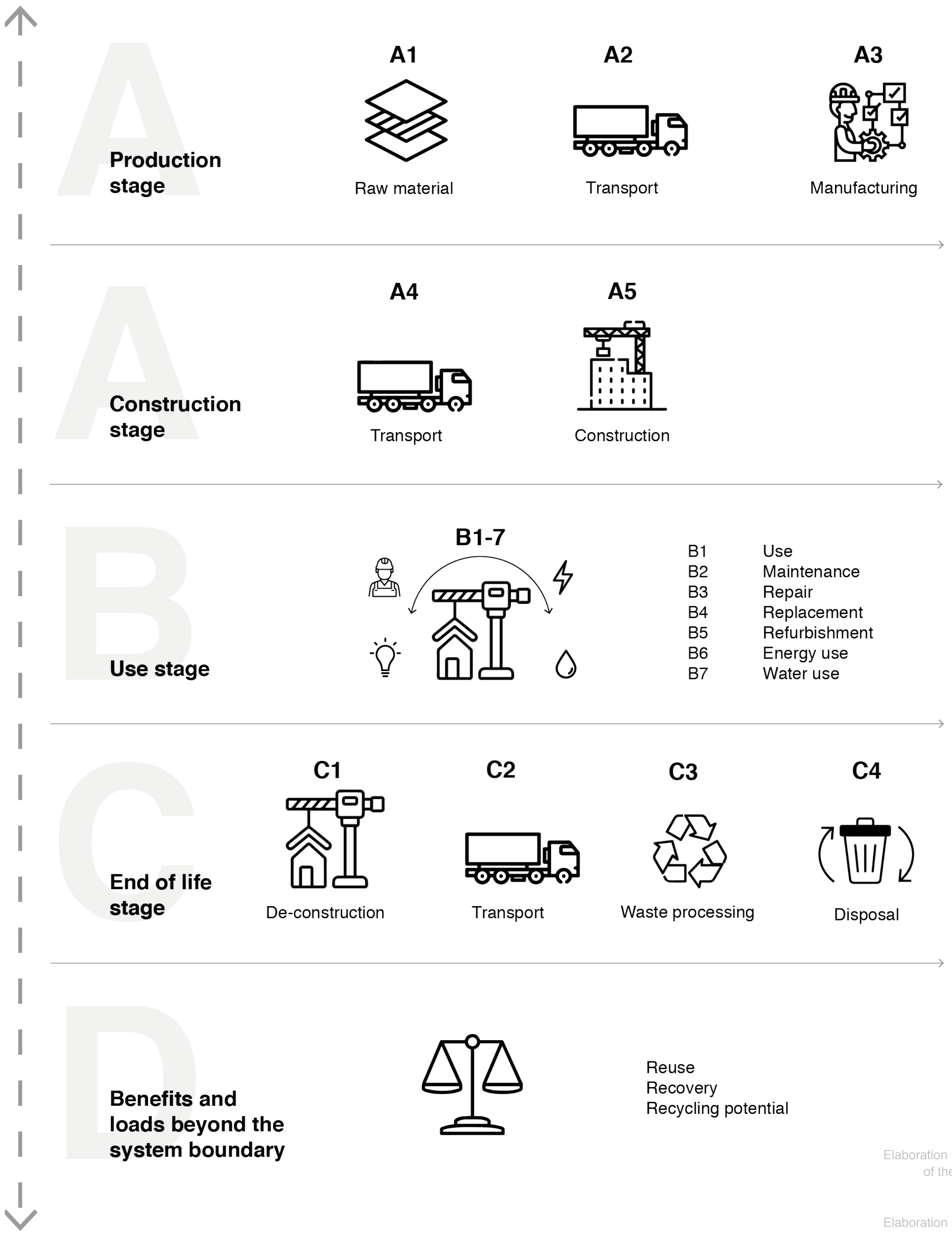


FIGURE 08 | Elaboration by the author of the LCA stages.

FIGURE 09 | Elaboration by the author of the LCA examples.

LCA Life Cycle Assessment - examples

Stage	Module		LCA concrete	LCA steel	LCA cross laminated timber CLT	LCA EPS
Production stage	A1	Raw material supply	x	x	x	x
	A2	Transport	x	x	x	x
	A3	Manufacturing	x	x	x	x
Construction stage	A4	Transport from the gate to the site	MND	MND	x	x
	A5	Assembly	MND	MND	x	MND
Use stage	B1	Use	MND	MND	x	MND
	B2	Maintenance	MND	MND	x	MND
	B3	Repair	MND	MND	x	MND
	B4	Replacement	MND	MND	x	MND
	B5	Refurbishment	MND	MND	x	MND
	B6	Operational energy use	MND	MND	x	MND
	B7	Operational water use	MND	MND	x	MND
End of life stage	C1	De-construction demolition	MND	MND	x	MND
	C2	Transport	MND	MND	x	x
	C3	Waste processing	MND	x	x	x
	C4	Disposal	MND	MND	x	x
Benefits and loads beyond the system boundaries	D	Reuse Recovery Recycling potential	MND	x	x	x

3 CRADLE TO CRADLE (C2C)

The C2C approach goes beyond the concept of cradle-to-grave and conforms more to the model of the circular economy. In such model products would be designed in a way that at the end of their initial life they can be readily reused, or recycled, and therefore avoid landfill altogether[6].
A cradle-to-grave system implies the use of a product once, so that it become then useless waste at the end of it life. On the contrary, the cradle-to-cradle approach foster the regenerative cycles of material and products, making them valuable after one use, prolonging their life. Certainly, at the basis of such way of thinking there is the reduction of natural resources waste and the minimization of toxic pollution. Nevertheless, it goes one step further, demanding that companies redesign industrial processes [18].

C2C is based on:

- Eco-effectiveness: it is aimed to improve the actual principle of the existing industrial system. Nevertheless, it requires creating a new system that do not generate pollution or deplete natural resources. Effectiveness is achieved in product cycles when the materials used are not just recycled but upcycled[7].
- Disassembly: the product should be easy to be divided in parts.
- Recyclability: the product should use materials that could be recycled, avoiding disposal and landfilling. In order to minimize its impact on virgin raw materials, the product should use as much recycled material [18].

The material passport is a document which enable the circularity of products and components.

4 MATERIAL PASSPORT

For example, the client/designer/developers who choose to select the material with this type of document, can comprehend that the product has an added value given by this business strategy. Moreover, it is easier to understand how the product can be disassembled, and reused/recycled, entering again in the loop.
BAMB (Building as Material Banks)[8] is a project founded by the European Union's Horizon 2020, aiming to enable the shift towards a circular building sector. In this context, a dataset of electronic material passports has been developed.

The goals are:

- Increase the value or keep the value of materials over time;
- Create incentives for suppliers to produce sustainable and circular materials;
- Make a simple system for for developers, managers and renovators to forster sustainable and circular building materials;
- Facilitate the withdrawal of used materials.

06 | https://knowledge4policy.ec.europa.eu/glossary-item/cradle-cradle

07 | transforming them into new materials or products of better quality or for better environmental value (https://cordis.europa.eu/programme/id/H2020)

08 | https://www.bamb2020.eu/topics/materials-passports/

Another example is given by Madaster[9], an international online platform established in 2017 and founded by the European Horizon 2020 programme framework in 2018. Its aim is to facilitate the circular construction and management of Real Estate and infrastructure, providing insights into the materials and products used, the CO_2 stored within them and the possibilities for disassembling them for reuse. By simply uploading IFC or Excel file of the project, its material passport is created automatically.

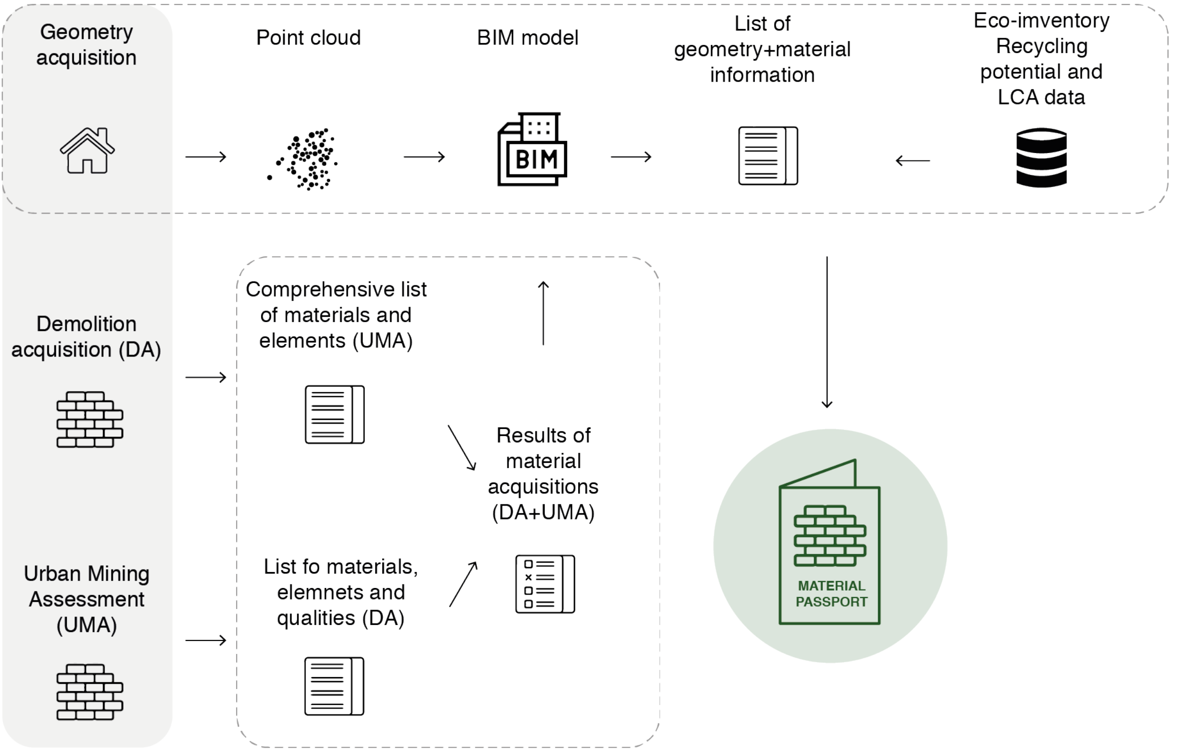


FIGURE 10 | Adaptation by the author of Material Passports for the End of Life stage of Buildings: Challenges and Potentials https://doi.org/10.1016/j.jclepro.2021.128702

5 DESIGN FOR MANUFACTURE AND ASSEMBLY DfMA

Design for Manufacture and Assembly is a holistic approach which synthetize 2 concepts.
The Design for Manufacture (DfM) involves the project of the building components and the construction systems depending on the manufacturing processes.
The Design for Assembly (DfA) involves the project for a simplification of the assembly, with a reduction of the working time and the possibility of error. It is related to the off-site construction and prefabrication of building components. Connected to the prefabrication there's the optimization of the material used, in terms of possible waste, which is reduced to the minimum. [19]

09 | https://madaster.com/our-purpose/

6 DESIGN FOR DISASSEMBLY

Design for Disassembly (DfD) is a holistic design approach since any given product should be easy to disassemble into all its individual components. To make a product suitable to be disassembled, the main thing to consider are the connections. They must be reversible without damaging the components. Accordingly, considering building components, screws, splits, and bolts are favoured over nails and glue which should be avoided. [15]

This practice was present already in the vernacular Architecture. From the disassembly of a building, the components can be used in 3 different ways:
- Upcycling: reuse the materials for a new product with higher value and quality than the original one;
- Downcycling: reuse the materials for a new product with lower value and quality than the original one;
- Recycling: reuse the materials for a new product with the same value and quality than the original one.

Such cascading use of components and materials allows different value streams and extracting, over time, stored energy [16].
For a conscious disassembly phase, it is necessary a project of DfM and DfA, especially for what concern the structure layer. Only if the connection between elements have been projected in order to be smart and reversible, it is possible to have a feasible disassembly phase in both economic, commercial and productive terms.

7 LEAN CONSTRUCTION

Lean Construction is a management practice applied to building processes, as a derivation of the Lean Manufacturing. The aim of that practice is to achieve the best result with the minimum cost, reducing waste. The construction of a building is seen as the production of a product. Decomposition enables the building to the pack in different parts which are constructed and managed by different professionals [8].

The building stages considered are:
- Project
- Construction
- Use/Maintenance
- Disposal
- Recycle.

8 CERTIFICATIONS

Regulations are crucial for sustainable development. Nowadays, a large number of tools for assessment and labelling are available on the market. They can be classified into different ranges of complexity and varying scopes of application. For instance, certifications can be related to entire city districts and buildings, building products and components, materials [20]. The major drawback of such analysis is the time consumed and the economic affordability, other than the inclination to greenwashing[10] [12].

Some examples:

LCA: cradle-to-grave analysis.

EPD: The Environmental Product Declaration[11] is suitable for construction materials/products. It does not guarantee the environmental worthiness of the material but ensure a more transparent choice between alternative materials. The parameters which are considered are:

- GWP Global Warming Potential: the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.
- ODP Ozone Depletion Potential: Destruction of the stratospheric ozone layer which shields the earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine and/or bromine containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules.
- AP Acidification Potential: has negative impacts on natural ecosystems and the man-made environment included buildings. The main source of emission of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating, and transport.
- EP Eutrophication Potential: Excessive enrichment of waters and continental surfaces with nutrients, and the associated adverse biological effects.
- POPC Formation Potential of Tropospheric Ozone: Chemical reactions brought about by the light energy of the sun.
- ADP Abiotic Depletion Potential: Consumption of non-renewable resources, thereby lowering their availability for future generations.

LEED[12]: Leadership in Energy and Environmental Design is the most-widely recognize label for buildings. Currently, it is used for practically all building (commercial or residential) and project types, new construction, refurbishment activities, and maintenance upgrades. If the materials and product used for the construction of a building are certified with EPD, it will be more probable that the building will be certified with the LEED.
BREEAM[13]: It has a wider application than LEED, since it is suitable both for planning project, infrastructures, and buildings.

10 | Companies' attitude which can give a false impression of their environmental impacts or benefits. With a proposed new law on green claims, the EU is taking action to address greenwashing, and protect consumers and the environment. (https://environment.ec.europa.eu/)

11 | https://www.environdec.com/about-us/global-house-of-epd

12 | https://www.rts.com/resources/guides/what-is-leed-certification/

13 | https://www.breeam.com/

WELL: It is a voluntary certification. Differently from the above-mentioned tools, the objective of the certification is to evaluate the property, measuring the social, environmental, and economic sustainability of a property, according to the user well-being. The analysis approach evaluates the satisfaction of 10 parameters: air, water, nourishment, light, fitness, comfort, sound, materials, mind, community.

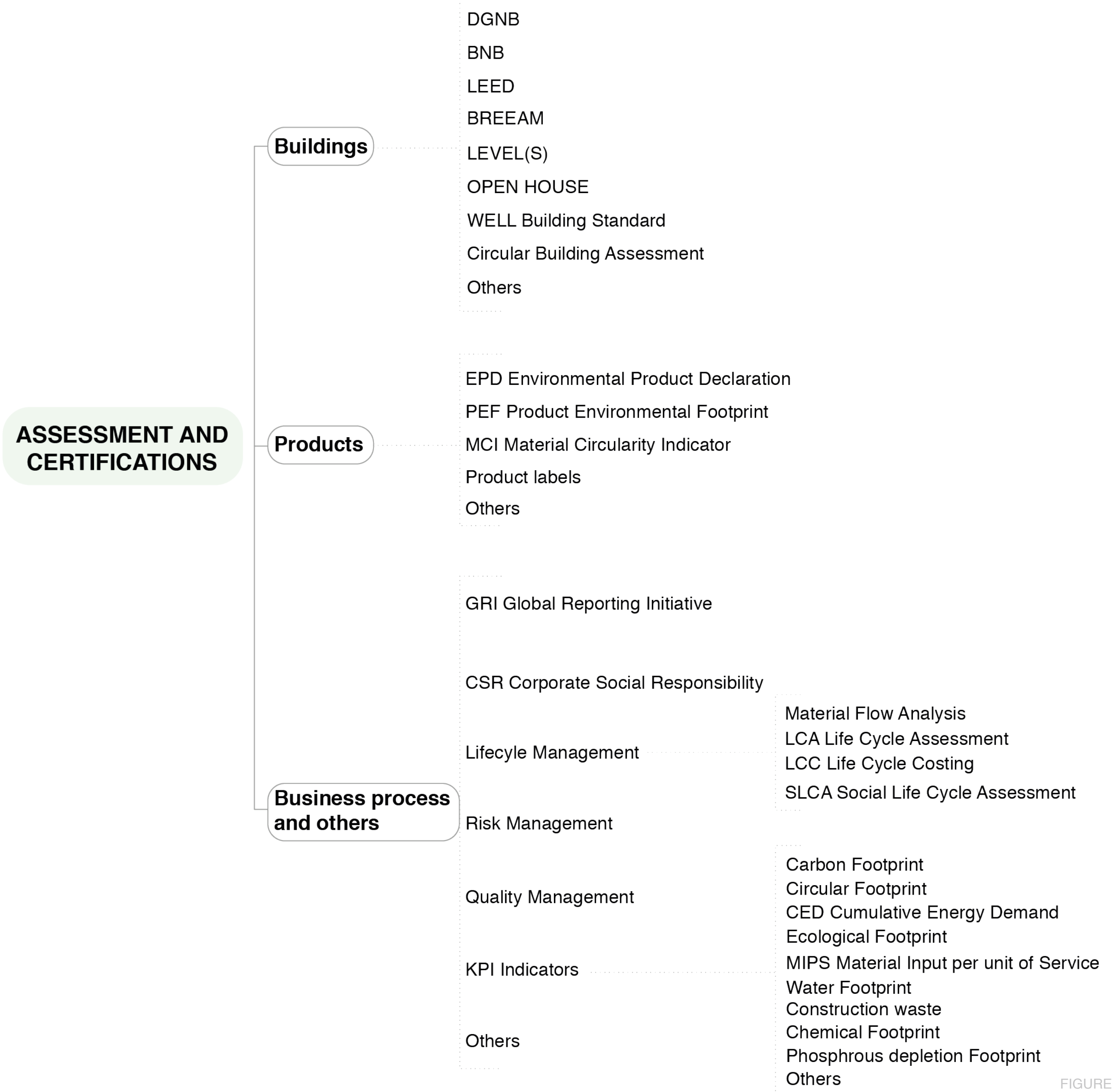


FIGURE 11 | Elaboration by the author of hierarcy levels of certification types.

1.3.2 Introduction to bio-based materials and building applications

The unique properties of bio-based materials make them suitable for various applications, including the construction field. The choice of innovative building materials to reduce energy consumption and emissions is the focus of contemporary research.

For definition, bio-based products are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations or fossilized[14]. The terms "bio-based material," “natural material," "bio-construction material," "biogenic material" are all synonyms referring to a material that is processed or engineered to obtain a product that derives partially or fully from bio-based resources.

According to the European specifications, a product is considered as bio-based if at least 25% of the composition is from biogenic source [21].
New materials need new technologies of production, that should be tested for understand if the production will be feasible on an economic, environmental, and social perspective [22].

Before start using bio-based materials, it is important to understand which are the benefits and the drawbacks, compared with the traditional materials for construction purposes. Moreover, it results fundamental to understand not just the physical and environmental performances, but also the economic performance, related with the impact on costumers and the supply chain. [12]

CARBON CAPTURE OFF AND STORED ON-SITE: summary

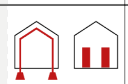
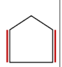
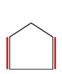
Approach	Application to construction	Carbon content [kgC/kg]	Carbon dioxide content [$kgCO_2/kg$]
Wood	Load-bearing structures Surfaces, Cladding, Insulation, Furnitures	0.5 (range 0.42 - 0.61)	1.84 (range 1.54 -2.24)
Cellulose Fibre	Insulation	0.39 - 0.41	1.42 - 1.50
Cardboard and construction paper	Vapour barriers, Insulation Engineered products	0.41	1.5
Bamboo	Load-bearing structures Surfaces, Cladding, Insulation, Enginnered products	0.55 - 0.67	2.02 - 2.46
Hemp	Insulation, Composites	0.55 - 0.57	2.02 - 2.09
Cork	Flooring, Insulation, Composites, Engineered products	0.56	2.06
Straw	Insulation, Composites	0.48	1.76

FIGURE 12 | Elaboration by the author of carbon captured on-site by bio-based materials.

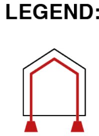
14 | ec.europa.eu/growth/sectors/biotechnology/bio-based-products_en

Such new materials solutions are gaining importance. In fact, bio-based solutions have a very low or even positive impact on the environment, in terms of renewable resource, CO2 storage, and reduction of GHG emissions [23]. In fact, during the production stage they required less energy compared to traditional construction materials. On the economic side, since such materials are locally grown, transportation costs are reduced. Some are also characterized by excellent multi-physical properties as heat insulation, sound absorption, transmission loss and do not require high resource production techniques [24]. In addition, by lowering embodied carbon, they can also create healthier buildings in terms of environmental performance, both regarding the production process and the capability to preserve a healthy indoor environment during their lifetime [25]. Moreover, bio-based materials have a higher potential to act as a carbon sink for the GWP-global warming potential (EN 15804:2020) [26].

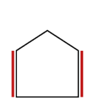
APPLICATION INSIDE A BUILDING TABLE

Inside a building		Properties				Environmental parameter
Material	Application	Density ρ [kg/m³]	Thermal conductivity λ [W/mK]	Water vapour diffusion resistance index μ	Fire resistance class [EN 13501]	Carbon content CC [%]
Sawn wood		440 - 470	0.14 - 0.22	-	-	35 - 50
CLT		420	0.12	20 - 50	D - d0	50
Glulam		445	0.12	20 - 50	D - d0	50
Wood fibres		150 - 250	0.040 - 0.081	2 - 5	E	50
Wood wool boards		60 - 600	0.080 - 0.100	2 - 5	E	50
Flax		20 - 50	0.038 - 0.045	1 - 2	E	-
Hemp		20 - 50	0.038 - 0.045	1 - 2	E	45
Cork		100 -120	0.038 - 0.050	10 - 18	E	64.6
Reeds		150	0.040 - 0.065	2	E	47
Cellulose		25 - 66	0.040 - 0.045	1 - 2	E	44.4
Rice straw		25 - 66	0.040 - 0.045	1 - 2	E	44.4

LEGEND:

 structure

 insulation

 cladding

 interior com floor, roof, fi

FIGURE 13 I Elaboration by the author of material properties, applications.

Furthermore, bio-based products possess the potential to hold carbon, acting as carbon storage. The longer the carbon remains stored in a product, the greater become its climate benefits. Ideally, buildings once erected should not be demolished but adapted through refurbishment activities for new uses over time. If this process prevails, captured carbon never reverts to CO_2 [12]. However, if the product is disposed or decomposes at its end-of-life, the carbon is released back into the atmosphere. This is why is fundamental extend materials' lifecycle into next lives, by reusing and recycling. The amount of carbon storage in buildings depends on the size of the building and the bio-based materials used. It can vary from 109–300 $kgCO_2/m^2$. In general, the highest amount can be found in buildings made with massive CLT [27].

For instance, bio-based material includes plant materials. Plants materials are characterized by grown fibres as timber, bamboo, which can become also engineered elements such as fibre boards or GLT. To use them for construction in and engineered way, it is fundamental test the mechanical properties, establishing basic behaviour that can be foreseen. Another issue is the connection between elements. Steel beams and columns can be bolted or welded together, different is the case of timber and bamboo. Another drawback to be considered are the limitation in size and geometry [12].

Six main fields of applications for bio-based materials have been identified: [3]

- Interior partitions and finishes: low specific weight flat boards, easy to handle, sufficiently stiff to ensure appropriate resistance to impacts.
- Furniture: natural fibres can be shaped in complex forms for chairs, tables and more generally for any interior application for various aesthetic appeals.
- Acoustic absorption: fibres of different types can be combined to create insulation material with good sound absorption properties.
- Thermal insulation: natural fibres obtained from agricultural harvesting can be used, providing low thermal conductivity, good fire performance, water repellent such as potato peelings and cork. For instance, thermal conductivity of flax and hemp panel is comparable to the one of glass fibre and rockwool, the advantage is that they are user-friendly and non-irritant. In addition, they can store more heat than traditional materials (damping effect). They absorb CO_2, hemp, straw, and timber can remove carbon in the air [12].
- Carpets and moquette: obtained from residue of bananas or pineapple harvesting, and other flexible, strong and lightweight fibres.
- Envelope systems: natural fibres can be combined with biopolymers to obtain products that can be employed for both interior and exterior applications. The use of fabrics and membrane as envelope for building systems characterized the evolution of the human beings. Nowadays, the evolution is represented using textiles derived from cotton, sisal, silk, coconut, and more traditionally by hemp, flax, and jute. The fibres are tested in order to improve tensile performance and exterior applications. Another evolution is represented by the biopolymers combined with natural fabrics [12].

APPLICATION INSIDE A BUILDING scheme

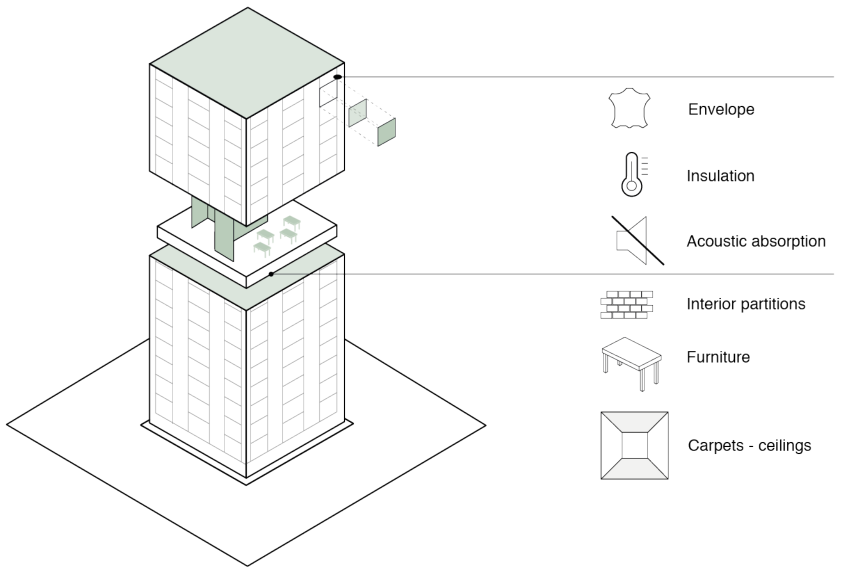


FIGURE 14 | Elaboration by the author of bio-based materials applications.

Bio-based materials can be employed for different building application. Following the theory of the "sharing layers", different parts of building components can be changed in different moments.

The theory was firstly proposed in the 1970s by the architect Frank Duffy and further developed in the 90s by Brand. The fact that building is composed by separated layers but connect one to each other, means that those layers can be easily removed and replaced, since each of them is characterized by a different lifespan. The outside layers could be replaced or refurbished without touching the inner ones, increasing the flexibility and the lifespan of the building. Accordingly, the lifespan of the inner layers should take into account those of the outer layers. When an inner layer needs replacement, it will be subject to limitations of the outer layers. The site should be integrated, the structure should last as long as possible, the skin and services should be accessible and replaceable, the space plan should be flexible, the stuff should be reusable, and the social setting should be good for the people living or working in the building [9].

The six layers involve all the scales of the building:

- Site: Site is the fixed location of the building. It is the geographical and physical environment LIFESPAN: eternal
- Structure: Structure is the building's skeleton including the foundation and load-bearing elements - LIFESPAN: 30-300 years
- Skin: Skin is the façade and exterior - LIFESPAN: 20 years
- Services: Services are the pipes, wires, energy, and heating systems - LIFESPAN: 15 years
- Space: Space is the solid internal fit-out including walls and floors - LIFESPAN: 3-30 years (according to the function, if it is residential or commercial)
- Stuff: Stuff is the rest of the internal fit-out including the furniture, lighting - LIFESPAN: daily/monthly duration.

More in detail, the research will focus on two layers, structure and skin.

STRUCTURE: set of technological units which aim is to sustain vertical and horizontal loads acting on a building and connect statically the building's parts. There are different types of structure, it can be continuous or discontinuous.

SKIN: Set of technological units which aim is to divide and create the interior spaces of a building, in respect to the exterior environment.

Considering the building as a combination of layers enable to understand deeply how circularity should be enhanced. Different stakeholders are involved in each layer. For example, architects, engineers and construction companies determine the structure, whereas installation companies determine to a large extend the services, users and owners deals with maintenance [9].

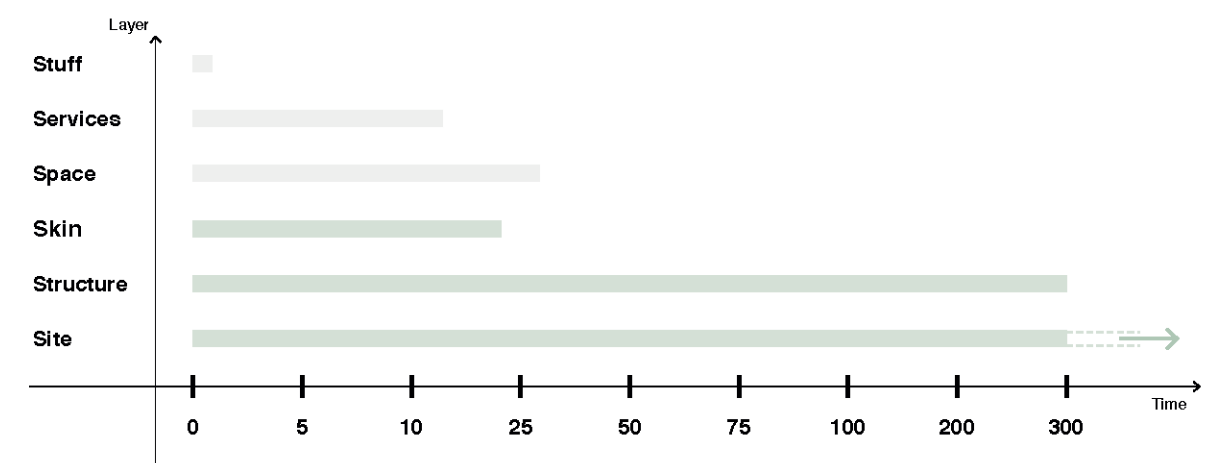
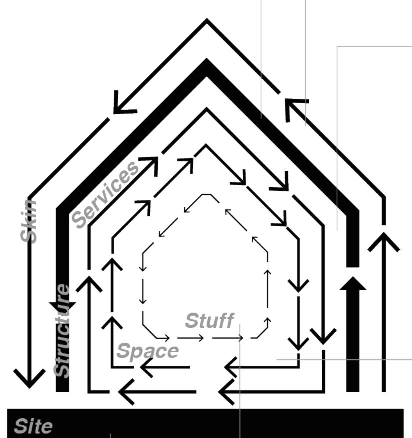


FIGURE 15 | Elaboration by the author of Brand's shearing layers lifespan.

A building is considered as a combination of "several layers of longevity of building components." (Duffy, F. 1990)

Shearing layers of Change (Brand, S. 1994)



Structure

Structure is the building's skeleton including the foundation and load-bearing elements.

LIFESPAN: 30-300 years

Skin

Skin is the façade and exterior, cladding system.

LIFESPAN: 20 years

Services

Services are the pipes, wires, energy, and heating systems.

LIFESPAN: 15 years

Space

Space is the solid internal fit-out including walls and floors.

LIFESPAN: 3-30 years

Stuff

Stuff is the rest of the internal fit-out including the furniture, lighting, and ICT.

LIFESPAN: daily/monthly duration

Site

Site is the fixed location of the building. It's the geographical and physical environment.

LIFESPAN: eternal

FIGURE 16 | Elaboration by the author of Brand's shearing layers.

1.3.3 Digital tools

More than others, the construction sector need this shift, due to its intrinsic complex structure. Herein, numerous multidisciplinary construction firms and professional services providers are rarely integrated with each other. Furthermore, it is geographically fragmented and its supply chain members are based in numerous different locations [6].

Here's the necessity of digital tools. According to the Institute of Civil Engineers (ICE, 2017) digital transformation is defined as the application of digital technologies to all aspects of human life. Since the projects are becoming more and more complex, a managerial approach focused on the "final product" could help in the supply chain management. The use of BIM methodologies and the supply chain management could allow small and medium enterprises fare alongside the large organizations of the construction sector, by equalizing the opportunities. [6]

Building information modelling (BIM) communicates information relating to all phases of an asset's lifecycle. [14]

These tools were initially designed for optimizing the design and construction phases, but over the years they have been developed to be able to support the data for future recycling of components, in a circular economy optic.
In fact, BIM technology is not a simple 3d visualization of the project. Indeed, every single construction part is identified with exact dimensions and characteristics. This gives access to detailed information about the entire project with respect to the final design, constructability [15].
It can be used by stakeholders throughout the supply chain, including designers, contractors and building operators. BIM collates data to facilitate monitoring processes, enable preventative maintenance and allow for upgrades. The process allows multiple stakeholders to collaborate more efficiently on the design, construction, and operation of buildings. [14].

The intelligent linking of software tools, such as automated tools, with industrialized fabrication methods leads to significant economic benefits [29].
The advantage of parametric tools is the iteration of the design processes and return-optimized information quickly through the definition of constraints and variables. The potential of the parametric software is permitted to manage the modularity of the panel. Changes can be made directly without having to restart the project, with time and cost savings.

2/ SURVEY: research field analysis

2.1 Wood industry: market to investigate

The theoretical background research has shown a knowledge gap between bio-based materials in building application and actual business models. Therefore, since the current supply chains for bio-based materials in the construction industry are still at an early stage in their lifecycle, wood supply chain has taken as main example. This supply chain is the most globally spread and hence the research field analysis here and then extends the results by analogy.
Wood is a bio-based material already in the market since several years, with a wide application in different construction components, from structure to envelope and cladding systems. Wood is a natural composite material, basically constituted by:

- cellulose fibres (40-50%);
- hemicellulose (25-35%);
- lignin (20-30%);
- extractives (up to 10%).

It is organized in long thin tubular cells. Most cells are oriented in the direction of the axis of the trunk, but there also cells, known as rays, which run radially across the trunk. Three directions in the wood trunk can be recognized:

- axial direction, related to the trunk;
- radial direction;
- tangential direction.

An important biological concept is the distinction between hardwood and softwood. The difference stays on the microscale structure of the tree, with consequences on its macroscale.

Structural properties:
It is an anisotropic materials, its properties change according to the direction. It is a hygroscopic material, meaning that its behaviour depends on the moisture content MC, as it has the ability to gain or lose moisture from the surroundings air. In fact, moisture content is calculated as the difference between weight and over dry weight, subdivided by dry weight. The result can be transformed in percentage value by multiplying per one hundred. The MC of wood tends to stabilize at a value that is commensurate with the surrounding moisture air, with consequences on the mechanical properties [12].

Thermal properties[15]:
The thermal conductivity of wood is a function of the MC and density. Moreover, it is independent from the species. Wood heat capacity is 1.76 J/g°C, two times greater than concrete heat capacity which is 0.88 J/g°C.

Carbon capture and storage:
Since the CO2 emitted today will affect the global climate in the future; the sequestration of this gas will minimize its impact. A tonne of wood can capture and convert by photosynthesis 1.4 tonnes of CO2, lowering the global warming. To achieve this goal, the use of more wood,

15 | https://www2.chem.wisc.edu/

harvested from sustainably managed forests in ways that will preserve the timber thus procured as a long-term carbon store [12].

Benefits of wood:
- Minimum treatment required;
- Minimum energy consumption in the life cycle;
- Possible short supply chain [7].

Wood can be transformed into several components. Below the most relevant types of engineered wood have been listed:

Plywood:
It is cheap, common, manufacture from veneers, bonded under heat and pressure. The sheets are orthogonal to increase the strength. The panel manufactured from sheets of cross-laminated veneer, bonded under heat and pressure using durable, moisture-resistant adhesives. By alternating the grain direction of the veneers from layer to layer, named cross-orienting, panel strength and stiffness in both directions are maximized.

Oriented strand board OSB:
Panel manufactured from rectangular-shaped strands of wood that are oriented lengthwise and then arranged in layers, laid up into mats, and bonded together with moisture-resistant, heat-cured adhesives. The individual layers are cross-oriented to provide strength and stiffness to the panel.

Laminated veneer lumber LVL:
It is produced by bonding thin wood veneers together in a large billet. The grain of all veneers in the LVL billet is parallel to the long direction. The resulting product features enhanced mechanical properties and dimensional stability.

Glued laminated timber (glulam):
It is composed of several timber laminates glued together with moisture-resistant adhesives, creating a large, strong, structural member (beam, column, etc.).

Cross-laminated timber CLT:
It is a versatile multi-layered panel made of lumber. Each layer of boards is placed crosswise to adjacent layers for increased rigidity and strength. CLT can be used for long spans and all assemblies, e.g. floors, walls or roofs.

Life cycle stages of wood production [7]:
- Planting: activity related to the selection of the site to the seeding.
- Growing: activity which is depended on the variable of time, differing from each wood specie. It can take several years.
- Wood harvesting: it includes felling wood, skidding wood to landing area, debarking. Just a small amount of energy is needed.
- Manufacturing wood in sawmill: both electrical energy and thermal energy are required. Electrical energy is used for sawmilling, chipping, planning, peeling. Thermal energy is used for processes as: drying, gluing, pressing.
- Transformation: it depends in which supply chains the manufacture wood enter.

The Total Embodied Environmental Impacts of life cycle stages has been calculating by summing the impacts of harvesting, transportation, and manufacturing. There's the necessity to underline that using locally found wood is important to avoid energy expenditures for transportation.

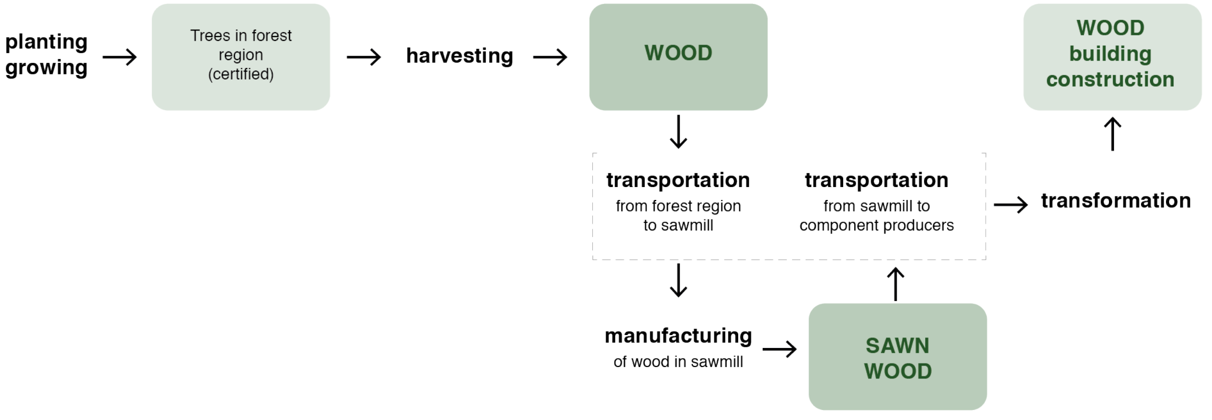


FIGURE 17 I
Adaptation by the author of wood lifecycle stages.

Nevertheless, wood is still considered an underutilized resource, even in those countries where forests area is really important for the economy and the people's jobs involved in the production sector. "Sweden is often held up as an example internationally for the steps it has taken to realise the potential of wood in the construction supply chain, while developing local bio-economies and cutting carbon emissions. This has been enabled by a pro-wood policy landscape over many years, but wood could still play a greater role [..]." [30]

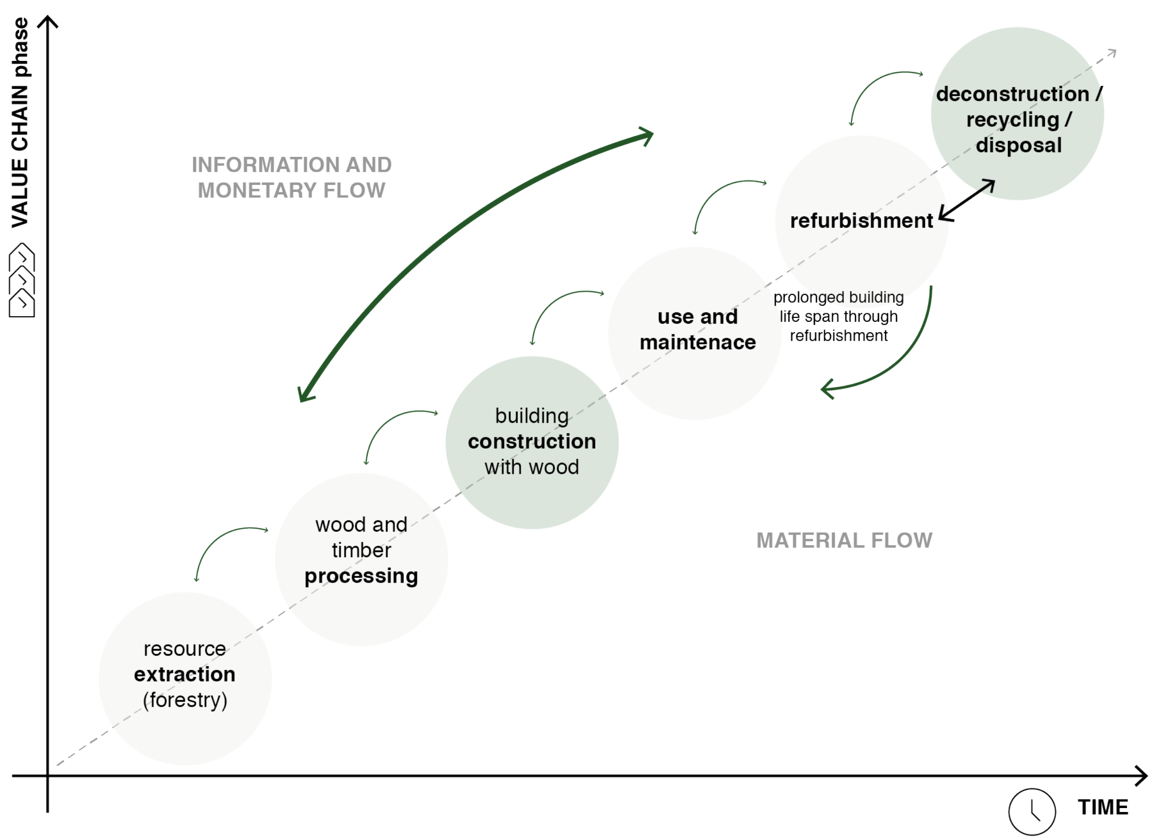
It is important to look at the Nordic countries because sustainability is one of the main topics, the large presence of forests, but they have been capable to use those resources. For example, Norway has recently introduced the NS 3720 standard to bring a common way of working with climate assessment of buildings, even though local authorities can act flexibly within the wood construction industry and requirements [30].

The topic of requirements is extremely relevant for this material. In fact, one big issue of building

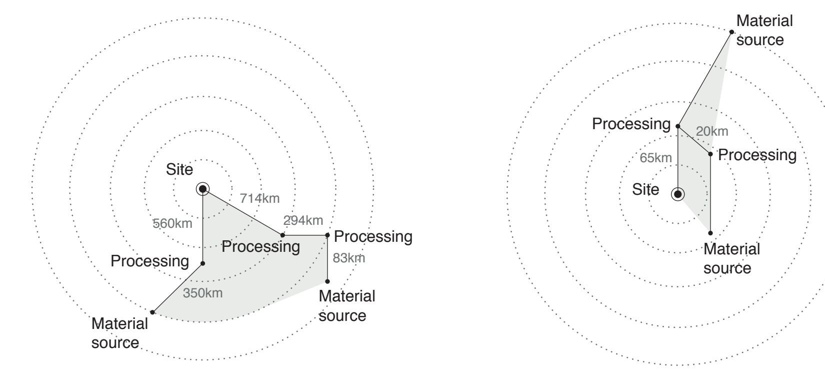
in wood is the floor height limit of the projects, due to fire regulations. It is necessary to scaling-up the process since there's the request of more projects in wood. It should be also considered the local production of wood, to ensure sustainability in all the steps of the supply chain [30].
In Sweden, the limits of floor-height have been lifted, allowing a larger study for architect and designers in that way. This shows an important example in which industry, academia, and local authorities collaborated for developing competencies through the supply chain [30].

Another problem is related to the fact that not all the countries in the world have the same mass area of forests. In those cases, sustainable performance should be considered before entering wood production. Sustainable performance is related to both energy consumption and CO2 emissions. Since in many countries there is not a sufficient resource of wood, therefore, these countries need to import wood from overseas. This means that it needs to be considered the impact of harvesting, manufacture, and transportation, understanding if the process is feasible under a sustainability and economic point of view. So that, the sustainability performance of wood imported will change according to wood production processes, energy structure, type, and length of transportation, involving different supply systems [7].

FIGURE 18 I
Adaptation by the author of material and monetary flow.



The benefits of the short chain are both on macroeconomic and environmental side, thanks to the reduce distance between the processes. Wood can be produced locally, with minimum transportation costs and in an ecological manner. For example, in Italy wood chain is considered as a short chain to exploit local productivity, in fact the length of the route considered is just 53 km, instead in general, where the forests are more likely to be widespread, is 600 km [31].



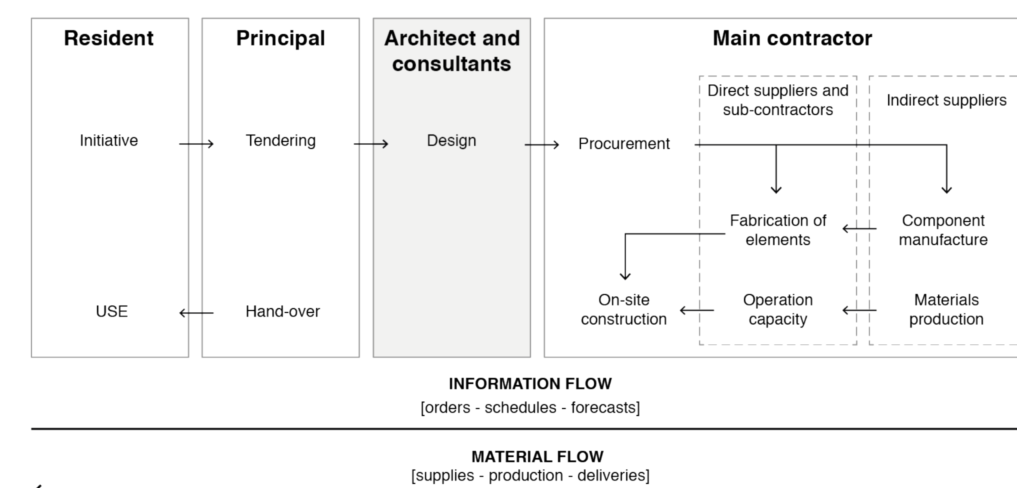


FIGURE 19 I
Adaptation by the author of wood supply chain distances.

FIGURE 20 I
Adaptation by the author of supply chain in residential buildings.

In addition, forest certification is a recent approach ensuring that forest products are produced sustainably. The European Union Timber Regulation (EUTR) prohibits placing on the EU market wood harvested in contravention of the applicable legislation in the country of origin, as well as wood products derived from it.
Frequently used Conformité Européene (CE) indicates that the product conforms to all applicable European legislation related to safety, health, energy efficiency, and environmental concerns.
Forest Stewardship Council (FSC) is an international organization that provides a system for voluntary accreditation and independent third-party certification. The system permits certificate holders to mark their products and services along the production chain. It confirms that wood

products are coming from well-managed forests that provide environmental, social, and economic benefits.
The Programme for the Endorsement of Forest Certification (PEFC) is an international non-profit, non-governmental organization endorsing sustainable forest management. It ensures that timber and non-timber forest products are produced by respecting ecological, social, and ethical standards [34].
Despite the different policies regarding wood construction, digitalization is a fundamental key in the supply chain [30]. Through digital tools, all the actors accounting in the supply chain of a wood-based component, can trace information and check them in specific steps of the process, from harvesting to production, transportation, assembly and disposal.

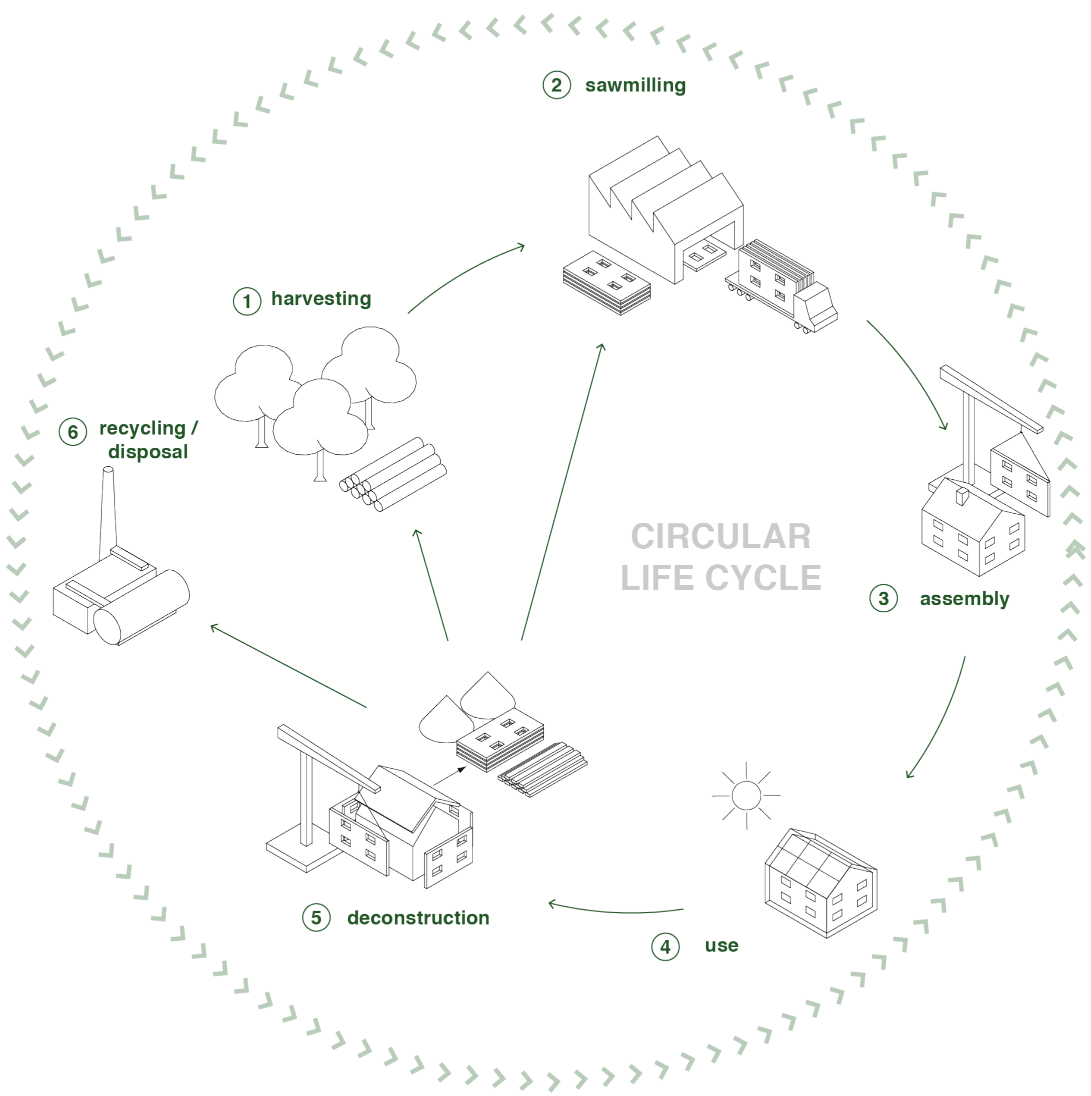


FIGURE 21 | Adaptation by the author of circular wood stages.

2.2 Qualitative research method explanation

The understanding of the current situation of the construction market, in relation to bio-based materials, in particular wood, is the aim of the interviews. Such investigation needs to be performed in a structured and rigorous way through a qualitative content analysis. Since the interpretation of inductive research has often been criticized, a systemic approach is presented [36].

Qualitative content analysis is a method for describing the meaning of qualitative material in a systematic way. It is done by classifying material as instances for the categories of a coding frame [37]. The aim is to gain deeper knowledge of the phenomenon studied, understanding its essence [36], transforming raw data into communicative data [38]. Moreover, this type of research is context-specific, influencing the final interpretations of the data [37].

The phases of the qualitative content analysis are:
- Research design;
- Data collection;
- Data analysis;
- Grounded theory simulation. [36]

Importance is given both on how the data are acquired but also in the way those data are analysed. Multiple data sources have been employed, such as scientific articles, data sheets, books, field notes, on which base the structured interview. The aim is to obtain a real-time experience of the phenomenon investigated. It is fundamental to note that during the interviews, the research question must change, through progressively better knowledge on the subject.

Regarding the data acquisition, Gioia et al. [36] have elaborated an approach based on a first order analysis, and a second order analysis. One is based on informant-centric terms and codes, the other uses research-centric concepts and themes. The duality of the system of both voices, informant and researcher, allows high quality research which balance the two perspectives.
The goal is to produce a clear and transparent connection between research question, categories and interview data.

The data analysis is conducted by using a coding frame. Coding frame is defined as a way of structuring the material, acting like a filter. It consists of main categories specifying relevant aspects and of subcategories for each main category specifying relevant meanings concerning this aspect [37].

Phases of coding [37]:
- Selecting;
- Structuring and generating;
- Defining;
- Revising and expanding.

The selection of the material is fundamental for starting to make choices, to reduce and to structure the material investigated. Accordingly, the distinction between relevant and irrelevant material is performed: all material that has a bearing upon research question counts as relevant, and all material that does not can be considered irrelevant.

Afterwards, the data selected needs to be described by labels, helping to fit into categories parts of the interviews. The methodology allowed could be concept-driven, based on prior knowledge about the task, or data-driven, letting the categories emerge from the materials. The two ways could also be combined, allowing an in-depth description of the materials. By coding, it is necessary to look at each individual sentence and paragraph in the data and make a judgement about its meaning. Thus, coding is an approach which makes revisit all aspects of the data collected, including those which may not have been noticed during the actual data collection [38].

The defining phase is necessary to assign a meaning for each category. It is a way of ruling for coding the material. This is a crucial step in qualitative content analysis: making explicit the meaning of each label and assigning it to data segments, allows the understanding of the material to all, not only to the researcher, and the study reliable. “Name”, “description”, “examples” define those categories.

Lastly, revision of the categories is made to avoid overlapping labels with same meanings but with different names. This step represents a more mechanical application of labels to segmented data. The goal is to start with interpretation, which is not a mechanical activity, to let emerge repetitive patters [38].

Once the coding phase is accomplished, the data collected should be interpretate to extrapolate meanings and knowledge. Hence, the results are prepared and then described in a qualitative or quantitative style. For example, merging categories definition and frequencies.

2.3 Construction of the interview guide

The actual conduct of the interviews has been preceded by the drafting of an interview guide, which differed according to the role of the interviewee within the wood industry supply chain. In fact, to capture as much cross-cutting information as possible regarding occurrences within that market, five professional categories have been selected:

- Architectural and Engineering firms;
- First material transformation companies;
- Component producer companies;
- Construction companies;
- Standardization institutes.

These categories have been selected based on the analysis of the stakeholder loop involved in the transition from linear to circular build environment.

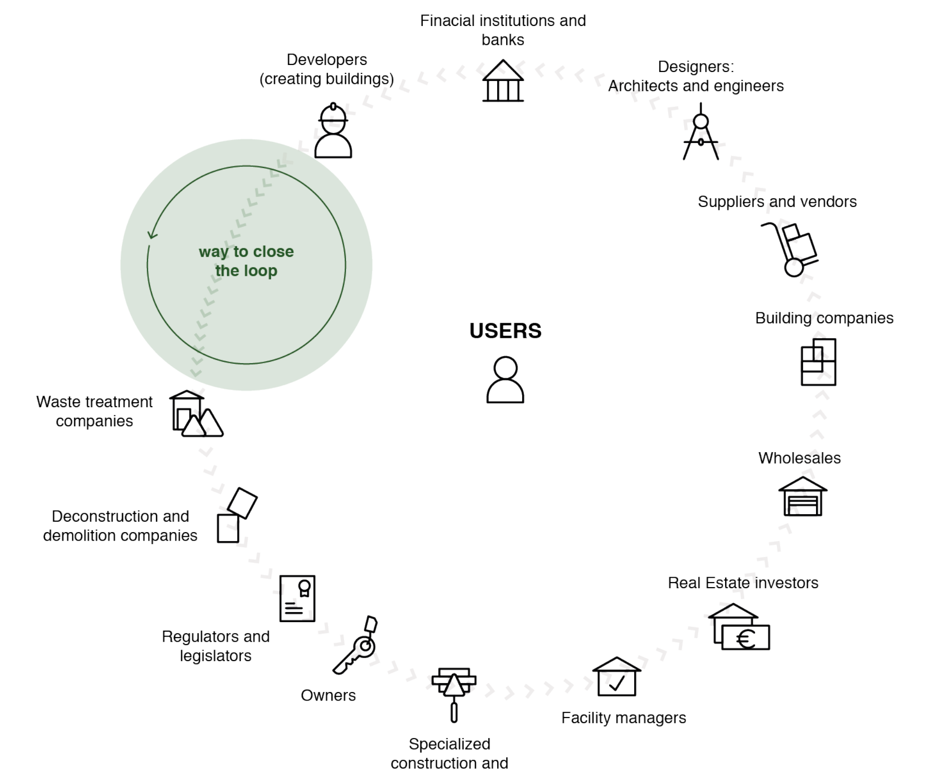


FIGURE 22 | Adaptation by the author of stakeholders loop.

For each category of actor, a different interview guide was created. In order to be flexible and adaptable, the interview guide consists of a more static part with general questions and a more detailed and specific part for each actor category.

The basic format of the interview guide is as follows.

1. General overview of the interviewed company
2. Potentials and Benefits of the use of Timber/Bio-Based materials
3. Challenges of the use of Timber/Bio-Based materials technical aspects
    - Economical aspects
    - Environmental aspects
    - Social political aspects
    - Specific aspects for each actor
4. Supply Chain adaptations to accommodate more wood/Bio-Based materials
5. Business model
6. Certification
7. Future perspectives.

The interview guides used for each actor in the supply chain may be consulted in the Appendix A.

The choice of actors to be interviewed was made trying to achieve a certain level of variety among small, medium and large firms. In fact, depending on the size of the architectural firm or enterprise, the problems and issues to be addressed are different. In addition, the actors interviewed operate both in Italy and abroad. This made possible to get a more complete overview of this market segment, exchanging ideas and information and comparing the practices in place in Italy with those in other European countries that are more advanced in the field.
Data were collected from the information procured during 19 interviews, divided as follows:

Architecture and Engineering firms: n°4

- **Bollinger+Grohmann:** German company which have had a strong expansion throughout the European market in the last 20 years. The firm does mainly structural engineering, façade and building physics. They are specialized in innovative structures.
- **Lombardini22:** Architecture firm born in 2007 in Milan from the cooperation between 7 partners. It is one of the most important offices in Italy. Thinking about the future, the ESG business unit is born. Its role is to integrate the environmental, social and governance criteria in the project model, which is highly request from great market since the European taxonomy[16] was issued.
- **Robertson Timber Engineering:** It is a UK based construction, infrastructure, and support services business born in 1966. They deal with constructions throughout their life cycle, from design, construction, maintenance, disassembly, and re-use.

16 | Common classification system for sustainable economic activities. It could play an important role helping the EU scale up sustainable investment and implement the European green deal. The EU taxonomy would provide companies, investors and policymakers with appropriate definitions for which economic activities can be considered environmentally sustainable. In this way, it should create security for investors, protect private investors from greenwashing, help companies to become more climate-friendly, mitigate market fragmentation and help shift investments where they are most needed. (https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

LEGEND:

Architecture and Engineering firms

First material transformation companies

Component producer companies

Construction companies

Standardization institutes

Indipendent experts

- **Ergodomus Timber Engineering:** Engineering office founded in 2007, thanks to the passion for wood. Wood engineering is not just a technical matter, but involves expertise, experience, and creativity. They build worldwide and they can be considered as a reference in the field.

First material transformation companies: n°1

- **Pfeifer:** Pfeifer is a leading company in the European wood industry. It was founded in 1948 as a sawmill business. The first step into construction was the start of the production of shuttering boards and formwork beams. The stepping into timber construction started in the mid-1980s by starting a glulam production and the CLT production. The big change into engineered timber was in 2019.

Component producer companies: n°4

- **Edilcanapa:** The company was founded in 2014, with the aim to try to improve the quality of life and interior comfort of the build environment using bio-based materials, in particular hemp wood and hemp fibre.
- **KLH:** The company was founded in 1997 based on the manufacture of CLT. The production involves all building components for wall, ceiling, and roof elements in structural timber construction. They operate worldwide.
- **Stora Enso:** Stora Enso is the oldest multinational company in Europe. It is the largest producer of CLT panels in Europe. The company goal is to convert everything that is now derived from fossil materials into biodegradable materials. This not only applies to construction, but also to biomaterials, plastics, paper, and everything derived from wood processing and sustainable forest management.
- **XLam Dolomiti:** XLam Dolomiti is a company born as supplier of raw material wood. In 2010 they opened the largest production facility in Italy. Right now, the company is much more oriented to the construction phase, covering all the stages from the production of the panel to engineering and on-site installation.

Construction companies: n°7

- **Colombo Costruzioni:** Colombo costruzioni has been founded in 1905 near Milan. It is a five-generation business. They are specialized in tall buildings. Some examples are "Torre Allianz", "Torre Unicredit", "Bosco Verticale", "Torre Gioia22".
- **Huf Haus:** The company existed for 110 years. The core building typologies are single family house, two family houses, office buildings, flats, and rooftops renovations. The big markets where they work on are mainly Germany, Austria, Switzerland, and UK. At the same time, they deliver buildings in the US, Russia, China, Africa.
- **LignoAlp:** The LignoAlp brand exists since 2010, by the merging of two companies from

South Tyrol. They are a modern timber builder combining craftsmanship know-how with modern design and production technology for the realisation of complex timber projects.

- **Marlegno:** Malegno has been working in the field of wooden structures and houses for 20 years. They design and build prefabricated wooden houses, customised on the customer's needs. Their offer starts from the architectural design to the executive design, detailed design, prefabrication phase in the factory, up to the completion, then the installation on site and the realisation of all finishes.
- **One Haus:** One Haus' aim is to make the passive house affordable. Good design and technology are considered together to build a better future. The offer is both of tailor-made building and catalogue houses.
- **Riko Hise:** The company was founded in 1997, devoted to the production of prefabricated timber elements. Riko Hise now deals with the construction of prefabricated wooden houses, exclusively on a project basis, without catalogue houses.
- **MAK Building:** MAK building is part of the MAK Holtz Group. The company has the exclusive right to use Stora Enso's CLT panel since 2008. The offer is composed by the managing of the design interface with the costumers or designers, the production discourse and logistics. The goal is to achieve a high level of optimisation of the project based on their production size standards, giving advice to the designers on how to set up the design part to avoid waste.

Standardization institutes: n°1

- **Agenzia CasaClima:** The CasaClima agency is a public body since 2002. It is an instrumental body of the province of Bolzano but recognized all over Italy and internationally. It deals on one hand with the energy certification of buildings and in production from renewable sources, but also with the concept of sustainability through its certification quality label "CasaClima".

Independent experts: n°2

- **Andrea dell'Orto and Maria Chiara Voci:** They are journalist, marketing and communication consultant working in the field of sustainability in the construction industry. During the occasion of Klimahouse[17] 2022 , they were the presenters of the Wood Summit Networking Party, in which designers and components producers explained their contribution to the sector through real prototypes on the market.

The interviews have been conducted after an e-mail request for research collaboration was sent, specifying topic and timing. Depending on the availability on the interviewer side, interviews were conducted in-person at the SAPERLab of the Politecnico di Milano (Via Ampère 2, 20133 Milan, Campus Bonardi, Building 11) or at the headquarters of the company. In other cases, interviews were conducted via Microsoft Teams and Zoom platforms.

17 | Klimahouse is an exhibition event dedicated to energy efficiency and sustainability in construction, within which it is possible to discover innovative solutions and to participate to conferences, seminars, workshops.

The following Table contain the specifics for each interview (date and place), regarding the company, its role in the SC, the person interviewed.

n°	Company	Country	Employee interviewed	Role in the company	Interview date	Interview place
			Designers/Architectural and Engineering firms			
1	Bollinger+Grohmann	Italy	Tommaso Pagnacco	Structural engineer	13/05/2022	SAPERLab, Politecnico di Milano (MI)
2	Lombardini22	Italy	Elena Stoppioni	Engineer ESG Senior Consultant	17/05/2022	Lombardini22, Milano (MI)
3	Robertson Timber Engineering	Scotland	Nicola Jackson	Architect Technical Manager	10/06/2022	Online
4	Ergodomus Timber Engineering	Italy	Franco Piva	Engineer Director	16/06/2022	Online
			First material transformation companies			
5	Pferifer	Austria	Bernd Gusinde	Product Manager	01/07/2022	Online
			Component producer companies			
6	Edilcanapa	Italy	Mariaelena Alessandrini	Sales Manager	01/06/2022	Online
7	KLH	Austria	Alberto Schiavinato	Sales Manager south and south-east Europe	14/06/2022	Online
8	Stora Enso	Italy	Maria Milita	Business Development Manager – Division Wood Products	04/07/2022	Online
9	XLam Dolomiti	Italy	Giacomo Del Bianco	Sales manager Italy	27/06/2022	Online
			Construction companies			
10	Colombo Costruzioni	Italy	Carlo Berardi	CEO	21/06/2022	Online
11	Huf Haus	Germany	Christoph Schmidt	Managing Director	24/06/2022	Online
12	LignoAlp	Italy	Christoph Mahlknecht	Marketing Manager	20/06/2022	Online
13	Marlegno	Italy	Alessandro Greppi	R&D Manager	20/06/2022	Online
14	One Haus	Italy	Andrea Tornaghi	Architect, CEO	01/06/2022	OneHaus srl, Seveso (MB)
15	Riko Hise	Slovenia	Peter Pucer	Project Manager Head of Sales for Italian market	01/07/2022	Online
16	MAK Building	Italy	Federico Marino	CEO	07/07/2022	Online
			Standardization Institutes			
17	Agenzia CasaClima	Italy	Ulrich Klammsteiner	Technical Manager	29/06/2022	Online
18	Independent expert	Italy	Andrea Dell'Orto	Marketing and communication consultant	18/07/2022	Online
19	Independent expert	Italy	Maria Chiara Voci	Journalist (Sole24Ore; CasaItaliaRadio; CasaNaturale; Home Health & High-Tech)	18/07/2022	Online

TABLE 01 | Interviewees list by role in the supply chain.

2.4 Coding frame of the transcripts' information

Once the interviews were conducted, they were integrally transcribed, allowing for a systematic analysis. In order to make use of such information, it was necessary to sort them by following an initial coding and labelling scheme, which were fundamental to subdivide the large number of scattered examples and testimonies into a more orderly and scientific framework.
The coding frame is a way of structure the material collected, subdividing it in categories, meanings and small descriptions [37].

The core operation of coding involves examining a portion of the transcript and labelling it with a word or short phrase that summarizes its content. Doing so, coding reduces large amounts of empirical material and makes the data readily accessible for analysis, while at the same time increasing the quality of the analysis and findings.
While coding, judgements have been made about each individual element in the data to decide whether it is relevant or not. This reduces the amount of data considered into the final analysis and makes the analytical tasks easier. In this case, coding provides with a structure that allows comparison of specific dimensions of interest [38].

RAW MATERIAL (interview transcript) → **CODING FRAME** → **RESULTS / OUTCOMES**

The coding frame has been set as follow:

- Name categories with labels providing a small description of what the category refers to;
- Revise the coding frame, stepping back to check the categories;
- Divide the data into units so that each unit fits into one category of the coding frame.

The quality of the analysis and findings it is strictly dependant from the accuracy of the coding phase. Findings and results do not emerge from transcripts and documents by themselves but require deliberate work to identify the most important elements [38].

Firstly, the questions of the interview guide have been standardized. This step is fundamental for a correct interpretation of the specific answers. Nevertheless, it is possible to lose some minor and distinctive details.

n°	Standardized questions	Count of quotes
1	How long have you been in the business? Which is your core business?	221
2	With whom do you interact the most during your business operations?	101
3	How do you deal with sustainability requests from the market?	44
4	How widespread are prefabricated timber solutions used in the construction industry?	76
5	How much is wood used in the construction industry?	32
6	Who will push for a larger adoption of wood during the construction process?	80
7	Will the use of wood in the construction industry create new opportunities?	23
8	Which is the most challenging problem related to wood?	120
9	Which is the most critical drawback during the lifecycle of a building?	70
10	How does maintenance have to be performed in a wood-based house?	85
11	Is the sustainability perceived as an added value or only as a cost?	126
12	Which is your cost structure?	38
13	Which are your top-selling products?	25
14	How are you lowering your environmental impact?	53
15	Do you know design paradigms such as Cradle 2 Cradle or Design for Disassembly?	108
16	Will the presence of wood in the building ever be a key choice factor?	35
17	What should governments do to foster the use of wood?	86
18	Are you using BIM technology?	134
19	Which certifications have you adopted?	89
20	Could your supply chain handle a sudden increase in demand?	34
21	Are customers willing to pay for more environmentally friendly solutions?	24
22	Which is your vision for the future of the construction industry in Europe?	94
	TOT quotes	1698

TABLE 02 | Standardised question list.

Then, a database dependent on the transcription of the 19 interviews has been set, identifying each phrase of the transcripts with one or more level of labels, according to its content. As Gioia et al. [36] pointed out, after the first analysis phase, the number of labels tends to explode. Since such step is characterized by the use of informant terms, 203 labels have been defined to structure the analysis on the interviews. Accordingly, to filter these data, the research focus on 43 main labels, which are the most appropriate for the study based on the guiding research questions set at the beginning, more connected to the architectural/technical side.
The labels are subdivided by topics:
- general information about the company/work;
- economic aspects;
- technical aspects regarding the material and the way of building;
- climate change;
- future perspectives.

Below the list of labels considered and the related meanings.

1. Adaptation

Such label refers to the changing needed in the construction industry, related to the possible shift to more prefabrication and off-site working. This is particularly true when dealing with timber components.

2. Fire proofing

Strictly fire safety requirements are shown to be an issue when dealing with bio-based materials.

3. Ground connection

Technical aspect related to connection between wood structure and foundation structures, aiming to avoid the phenomenon of rising damp.

4. Sustainability report

Voluntary, not compulsory, information document in which all the main relationships between the company and the environment are described.

5. Construction site

It refers to all the construction activities involved in a specific space. For wood structures it is mainly related to the possibility of assembly on site the prefabricated elements, so that all the works connected are faster, easier, cheaper, cleaner than they are used to be with traditional construction materials.

6. Carbon credits

A carbon credit is a generic term for any tradable certificate representing the right to emit one tonne of carbon dioxide. In other words, by exchanging carbon credits, resources should be invested to increase the sustainability of the planet.

7. Carbon footprint

It measures the impact of the material on the environment. Regarding bio-based materials (wood in particular), there's already an original advantage thanks to its CO2 storing capacity.

8. Carbon tax

It is an example of an eco-tax. It is connected to the emission of CO2 by certain construction materials. It is an ongoing political discussion.

9. Certifications

Certifications. It consists of a wide range of mandatory/voluntary policies at European or country level. Certifications are fundamental to enter in the market and to be competitive. There's an ongoing shift in the actual people's mindset. Higher quality, both technological component and entire building, of the final product is pursued.
Certifications are both related to the material process of production but also to the building in its entirety. So that, according to the role of the actors in the supply chain, different types of documents are required. For wood production, to trace the material origin from the raw tree to the finite component, FSC and PEFC certifications are requested. FSC aimed at prescribing correct forest management and traceability of derived products. In the vision of the Chain of Custody it is a mandatory document to have to sell a product as certified. PEFC is a voluntary certification. LEED, BREEAM, WELL are example of certifications related to the entire building. The risk is to adhere to such procedures not out of intimate conviction but for purely marketing reasons. There is also a dependency from what the client asks for.

10. Lifecycle

It embraces all the activities related to the building's entire life, considering design, construction, operation, deconstruction if designed, demolition and waste treatment eventually.

11. CLT

Type of engineered wood used for building structures.

12. Material combination

The building stratigraphy is composed by several layers made of different materials. This means that combination is the key factor. It is possible to use mainly wood but not only wood, it is always arranged with other materials.

13. Foreign policies

Distinction has been made between governmental regulations in different countries, mainly considering Europe. In this way it has been possible to compare the level of progress of different countries in relation to the production, maintenance, and encouragement of the use of bio-based materials.

14. Italian policies

Specific focus has been given on the Italian regulation in matter of bio-based materials, often compared to a better advancement of other European countries such as Germany, France, UK.

15. Connections

Connections. This topic is related to the more sensitive parts of buildings: the joints. It has been important to underline how different companies deal with such problems, trying to optimize the solutions. Thus, regarding the possible future structure's disassembly and disposal, making the process as much circular as possible.

16. Correct design

Wood structures, and more in general the application of bio-based materials, involve a new understanding of the design process, which is characterized by prefabrication, standardization, off-site construction, and on-site assembly. Architectural and Engineering firms need to know these changes in the processes, spending much more time in the design phase.

17. Proper use of resources

Europe has set a roadmap to a competitive low-carbon economy, making secure energy supply, sustainable growth, and employment. Practices as energy saving, recycling, substitution, repurposing, valorisation should ensure the proper use of resources.

18. Cradle2Cradle

Model of production designed in a way that at the end of their initial life they can be readily reused, or recycled, and therefore avoid landfill altogether. Importance is given to the knowledge and consciousness of such topic by the different actors of the supply chain.

19. Deconstruction plan

It is related to a design activity aimed to implement the circularity of the construction process.

20. Design for Assembly

It refers to the general approach involving prefabrication, off-site construction, reduction of on-site working activities and waste.

21. Design for Deconstruction

Connected to the definition of Deconstruction plan, it implies a holistic design approach for building, ensuring recovering and recycling of resources.

22. Design for Disassembly

Connected to the definition of Design of Deconstruction, it implies a holistic design approach which consider any product to be easy disassembled into all its individual components, promoting upcycle, downcycle and recycle of parts.

23. Digitalization

Process of dealing with information coming from different sources in a smart way, from the early design phase to the end-of-life stage. Moreover, BIM technology is intended to connect easily architect and engineers, component producers, construction companies.

24. Pre-existing buildings

Categories of building stock which need more attention in terms of use of resources and energy savings.

25. Embodied carbon

Especially in relation to timber components, it is considered a fundamental feature in the optic of reduction of GHG emissions.

26. End-of-life management

It underlines the necessity of higher degree of circularity in the construction sector, closing the loop from design to construction and disposal.

27. Building management

It is mainly related to the understanding of the application of digital tools, as BIM technology, which can facilitate several aspects of the building management, from the early design phase to the end-of-life.

28. Integrated management

Holistic system aimed at the management of the connected activities between different actors involved in the building's supply chain.

29. Material hybridization

It is related to the concept of material combination. In this case it has been stressed the bonding of bio-based materials with traditional ones as concrete or steel.

30. Innovation initiatives

Understanding of new proposals coming from companies in different branches of construction sector.

31. Sustainability initiatives

Understanding of new proposals coming from companies in different branches of construction sector aimed to the improvement of their sustainability.

32. Application limits

Understand whether there are limits to the use of certain bio-based materials and technologies.

33. Maintenance

Relevant topic for the building's management, in relation to the end-of-life, disposal and reuse.

34. Design model

Design model. Such topic is connected to the mandatory shift needed from the building design with traditional materials, to the building design with bio-based materials. The design phase is important to foresee and prevent possible problematics in a faster and less expensive way.

35. Prefabrication

It is intended as a shift in the way of building, which need to be connected to a change in the mindset of all the actors of the supply chain, from the early design stage to the transformation and production of components and the construction.

36. Pre-manufactured value

Value of the works carried off-site, aimed to the reduction of energy resources and carbon emissions.

37. Building issues

General understanding of the problematics which can occur in the different life stages of a building.

38. Future perspective

General insight on programs and expectation trends of the construction sector in a bio-based optic.

39. Recycle

General view regarding the reuse of materials and components in the different stages of the building's life.

40. Building upgrading

Connected to the thematic of pre-existing buildings, the focus is on the application of timber and bio-based materials for this purpose.

41. Standardization

Concept connected to the prefabrication of components, allowing flexibility in the design process.

42. Stratigraphy

Combination of layer composing building's walls.

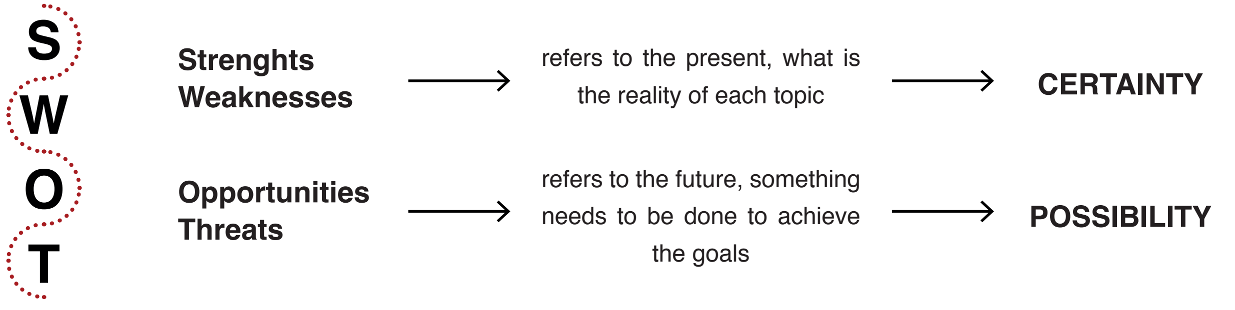
43. Material drawbacks

Material drawbacks. Understanding of the main disadvantages of bio-based materials in order to overcome possible problematics in every stage of the construction process. The focus is on handling the material in the best way possible.

Data related to the above-mentioned concepts have been elaborated through an Excel Pivot table, allowing to navigate and to exploit the set of databases created in a structured manner.

The variables considered inside this considerable database are:
- role in the SC;
- country of the company;
- company;
- labels;
- quotes.

In fact, the typology of actor, the country in which it acts, the dimension of the firm are all variables which determine different perspectives for the study of wood industry dynamics.
Once all the data have been collected, they needed to be processed. Such step has been performed by a SWOT analysis[18] , which evaluates strengths, weaknesses, opportunities, and threats for a given phenomenon/situation.



The quotes, subdivided by typology of actor and company, have been labelled according to the SWOT's four points. This step allowed to organize the data coming from the interviewees, revealing the topic stressed more by the stakeholders in the optic of identifying which are positive aspects of the sector and what could be implemented in the future.

18 | a study undertaken by an organization to identify its internal strengths and weaknesses, as well as its external opportunities and threats. (https://languages.oup.com/)

Labels	Architecture/Engineering firms			
	Bollinger+Grohmann	Lombardini22	Robertson Timber Engineering	TOT
S	10	3	5	18
Building site	1			1
Certifications		2	1	3
Lifecycle	1			1
Foreign policies	2			2
Italian policies	2			2
Design for Deconstruction			2	2
Digitalization		1	1	2
End-of-life Management	1			1
Sustainability initiatives	1			1
Design model	1			1
Pre-manufacture value			1	1
Building issues	1			1
W	5	10	20	35
Certifications		4	1	5
Lifecycle		1	1	2
Foreign policies	1		2	3
Italian policies	1	1		2
Proper use of resources			4	4
Cradle2Cradle		1	1	2
Deconstruction plan			2	2
Design for Deconstruction			2	2
Digitalization			1	1
Embodied carbon			2	2
End-of-life Management	1	1		2
Material hybridization		1		1
Sustainability initiatives		1		1
Maintenance	1			1
Design model	1			1
Future perspectives			1	1
Re-use			1	1
Material drawbacks			2	2
O	8	7	18	33
Adaptation			1	1
Certifications		1		1
Lifecycle	1		1	2
Foreign policies	1		1	2
Italian policies		1		1
Proper use of resources			1	1
Design for Deconstruction			1	1
Digitalization	2	1		3
Pre-existing buildings	1			1
Embodied carbon			2	2
End-of-life Management	1	2		3
Sustainability initiatives		2	1	3
Maintenance			2	2
Future perspectives	2		4	6
Re-use			4	4
T	6	11	1	18
Carbon credits		1		1
Certifications		3		3
Lifecycle	1		1	2
Italian policies		1		1
Proper use of resources		2		2
Digitalization	2	1		3
Pre-existing buildings		2		2
End-of-life Management	2			2
Design model		1		1
Future perspectives	1			1
TOT quotes	29	31	44	104

Labels	Component producer companies				
	Stora Enso	Edilcanapa	KLH	Xlam Dolomiti	TOT
S	13	4	2	19	38
Certifications	2		1	6	9
Building site	3			2	5
Material hybridization				3	3
Design model				3	3
Lifecycle		3			3
Correct design	3				3
CLT	2				2
Carbon footprint				2	2
Maintenance				2	2
Building upgrading		1			1
Standardization			1		1
Design for Disassmbly	1				1
Recycle				1	1
Re-use	1				1
Building Management	1				1
W	4	4	6	6	20
Material hybridization				3	3
Maintenance	1	1		1	3
Italian policies		1	2		3
Building site	2				2
Design model			2		2
Digitalization		1			1
End-of-life Management			1		1
Future perspectives			1		1
Connections				1	1
Prefabrication		1			1
Correct design	1				1
Cradle2Cradle				1	1
O	6	5	8	11	30
Digitalization	1	2		4	6
Certifications	1		1	3	4
Foreign policies	1			2	2
Italian policies		3		1	4
Future perspectives	1		2		2
Standardization	1		1		1
End-of-life Management			1		1
Lifecycle				1	1
Maintenance			1		1
Building site	1				0
Design model			1		1
Sustainability initiatives			1		1
T	6	7	9	6	28
Maintenace	4		4		4
Design model		6			6
Certifications				3	3
Digitalization			1	2	3
Foreign policies				1	1
Italian policies		1	1		2
Re-use			2		2
Material hybridization			1		1
Correct Design	1				0
Building site	1				0
TOT quotes	29	20	25	42	116

TABLE 03 | SWOT analysis: architecture/engineering firms.

TABLE 04 | SWOT analysis: component producers companies.

Labels	First material transformation companies
	Pfeifer
S	**7**
Certifications	4
Foreign policies	2
Prefabrication	1
W	**10**
Certifications	1
Cradle2Cradle	1
Standardization	1
Material drawbacks	7
O	**14**
Fire proofing	1
Certifications	1
Cradle2Cradle	1
Digitalization	3
Material hybridization	1
Innovation initiatives	2
Maintenance	1
Future perspectives	1
Standardization	2
Material drawbacks	1
T	**8**
Certifications	2
Cradle2Cradle	2
Future perspectives	1
Material drawbacks	3
TOT quotes	**39**

TABLE 05 I
SWOT analysis:
first material
transformation
companies.

Labels	Costruction companies							
	Colombo Costruzioni	Huf Haus	LignoAlp	Marlegno	One Haus	Riko Hise	MAK Building	TOT
S	**10**	**17**			**14**	**20**	**17**	**92**
Material combination	1	3			5	8	5	22
Lifecycle	2					2	2	6
Adaptation								
Building upgrading								
Construction site	4	4			2	2	2	14
Standardization						1	1	2
End-of-life Management							3	3
Maintenace	2				2			4
Digitalization		3			2	1		6
Design model		4			3	3	2	12
Proper use of resources		3					2	5
Certifications	1					3		4
W	**5**	**4**			**16**	**8**	**14**	**47**
Material combination	1	2			1	3	5	12
Design model		2			1	2	3	8
Initiatives for innovation	1				2		1	4
Digitalization					4	1	2	7
Material drawbacks					1			1
Proper use of resources	3				4	2	3	12
Connections					2			2
Maintenance					1			1
O	**7**	**11**			**1**	**7**	**11**	**37**
Foreign policies						1	4	5
Italian policies						1	2	3
Proper use of resources	1	3				1		4
Embodied carbon		3						3
Maintenace		3						3
Adaptation								
Building upgrading	1							1
Digitalization	1				1	1	1	4
Initiatives for innovation		2				1	1	4
Certifications	2					2		4
Construction site	2						3	5
T	**8**	**9**			**3**	**11**	**3**	**34**
Italian policies	3	2			2	2		9
Design model	5	3			1	3	1	13
Material drawbacks		2				4		6
Digitalization		2				1	2	5
Connections						1		1
TOT quotes	**30**	**41**			**34**	**46**	**45**	**210**

TABLE 06 I
SWOT analysis:
construction
companies.

Labels	Standardization instutues		
	Agenzia Casaclima	Indipendent experts	TOT
S	**9**	**6**	**15**
Digitalization	4	2	6
Design model	1	2	3
Certifications	2		2
Material combination		1	1
Foreign policies			
Maintenace	1	1	2
Standardization			
Material hybridization			
Correct design	1		1
W	**15**	**15**	**30**
Correct design	2	3	5
Material hybridization	7	2	9
Maintenace	1	4	5
Lifecyle	3	3	6
Certifications		2	2
Digitalization	2	1	3
O	**17**	**22**	**39**
Lifecycle	3	9	12
Material hybridization	2	2	4
Correct design	1	3	4
Material combination	2		2
End-of-life management	1	4	5
Carbon footprint	1	1	2
Building upgrading	3	2	5
Certifications	2		2
Foreign policies	2	1	3
T	**13**	**6**	**19**
Material hybridization	1	2	3
Correct design	3	1	4
Lifecycle	4	1	5
End-of-life management	3		3
Maintenace	2	2	4
TOT quotes	**54**	**49**	**103**

TABLE 07 | SWOT analysis: standardization institutes.

2.5 Outcomes

The elaboration of the interviews focuses on several themes which have been stressed by interviewees. The SWOT analysis has been a key comprehension tool, since it permits to evaluate in a quantitative and qualitative manner the importance of the concepts and how each actors deal with it. For instance, certain themes could be considered points of strengths for some stakeholders, on the contrary the same theme is view as a weakness or a future opportunity.

Topics, deeply discussed, according to the number of quotes connected and with implication on the design phase are underlined below.

- Issue of pre-existing building stock;
- Digitalization and prefabrication;
- Hybridization and material combination;
- New building paradigm for bio-based materials;
- Circular processes;
- Certifications;
- Maintenance.

The results are subdivided and reported accordingly.

Issue of pre-existing building stock

From the interviews arise how much the concepts of pre-existing building stock, pre-manufactured value, adaptation, and upgrading are all linked one to the other. Upgrading and adaptation are considered as opportunities, in the optic of future direction of the construction sector.

In general, outside the Italian border, "[The demand] is particularly growing for buildings with increased pre-manufactured value with more done off-site". Pre-manufactured value has been defined as "[…] the value of the works that are carried out off-site, like how much do you do in the factory, and then how much is done on the site". The implication of this definition is "If we can increase the pre-manufactured value percentage, that will help to reduce embodied carbon, because you're reducing waste, and you're reducing transport emissions, and you're building things more efficiently with less energy in the factory."

This explanation has come from an Engineering firm, demonstrating how much this is emblematic, showing that there is a lack of awareness regarding such topic, which could become relevant in the perspective of climate change mitigation.

"So, I actually think it should be mandatory for all new buildings that are delivered to have a deconstruction plan." This is related to the design part, so it should come firstly from Architecture and Engineering firms. Again, this is something far from the Italian situation. Right now, since the wood industry in Italy is not mature yet, it is difficult to know about Deconstruction plans.

Seeing that the SC is still at an early stage, the Design for Deconstruction both for new buildings and existing ones is omitted.

The concept of Design for Deconstruction has been categorized both as a strength, from the firm which already deal with it in their design process, but also as a weakness since it's in its early stage of development and an opportunity to be further implement in the future.

Another step to proceed in a more sustainable direction is related to the current state of the Italian, and in general European, building stock. Gathering all the data from the interviews, the future vision has become clear: "the mission is to get new generations to build in wood, upgrading a building stock that is now old". In fact, all the incentive policies are aimed at improving the existing building stock because it wastes a large amount of energy and resources. Renovation is becoming the future for the construction industry. For example, in Germany, in order to avoid land occupation, the idea is to focus on rooftops exploitation.

"[…] We go on the rooftops, where the wooden construction is very excellent, the weight is low. [...] We have about 800,000 free plots of land in Germany, which are the rooftops." Again, "So everybody looks at the at the environment to find a new plot for a house, and usually it has to be green with grass, but it hasn't to be. The rooftops are plots for houses as well, and if you see it with this mindset, you do not have this problem that nobody finds a plot to live. This is quite the most challenging thing here in Germany, to find the plots to live." In Italy, in the downtown of Milan, plenty of vertical extension on existing buildings works have been done for the same reason.

Digitalization and prefabrication

In this context, standardization, prefabrication, and digitalization play a key role. Understand how to handle the material is fundamental to exploit its properties, without damaging it and making it durable. "But I think one key to use bio-based materials is that you have to prefabricate them because they are very sensitive" have been said by a constructor which need to deal with those materials during the on-site assembly.
Standardization is considered also from the digital point of view. Homogenization of file formats will help in processing faster the design data, starting from the side of the first material transformation company. "Every day we are fighting with 10 to 15 different file formats right now, IFC, DWG, 3D, whatever, which is a bit of a nightmare".
Moreover, here's some data from the side of construction companies: "Certainly the use of prefabricated wood solutions for the renovation of existing buildings has been steadily growing since the first crisis in 2008, the only part of construction that has been growing. However, I think we are still talking about low percentages of prefabricated houses compared to classic construction, we are around 20% compared to 80% of traditional construction. That's also because cement is very strong in the world, they are big companies that have big capital in it anyway and they eventually lead in various markets."
Digitalization is considered both as a strength which allow to take trace of changes developing faster designs but also as a weakness, since especially for mid and small companies in all the SC, digitalization represent a big cost in economic and time-consuming terms. On the other hand, if digital formats will be not homogenised between the different stakeholders, it will be challenging to exploit the possible advantages, as a future-oriented opportunity.

Hybridization and material combination

The importance of combination and hybridization of different materials has been underlined as a strength and an opportunity to be discovered. "You can use mainly wood, but not only wood. This is for the renovation as well as for the new builds." This concept has been mentioned by a construction company, as well as from component producers and first material transformation companies: "Structural wood will never replace all concrete or even all steel, it will be side by side, they will support each other". "Staying that, I personally believe that you know a hybrid approach, like timber including concrete, steel, whatever, even combinations out of engineered wood and for example, concrete, that makes probably the most sense on these projects and it is always a project-by-project approach."

New building paradigm for bio-based materials

Rising from the data of the interviews, another important issue to deal with prefabrication, considered for bio-based materials, is the change in the mindset, requiring a shift in the design model. So, a correct design phase needs to be performed. Going for bio-based materials, which require a high level of prefabrication and standardization, the time dedicated to the early design stage is higher than for traditional building technologies. On the other hand, there are savings during the construction phase "where the conditions are more difficult to deal with". A good design phase should overcome since the beginning possible problematics within the building.

The integration of BIM technology is another step forward, allowing to reach a higher level of prefabrication and a control on every stage of the building lifecycle management. Nevertheless, changes in materials and relative technologies are always considered as an obstacle. For technicians and people involved in the project is difficult to acquire knowledge different from what has been done before. Special attention should be given on details and connections. In fact, as component producers have said, "[…] then it is the designer who has to combine our material with all the other materials in the stratigraphy, so the insulation, the plaster, the cladding, the fixtures, and be able to have a satisfactory result."
End-of-life management at the actual state of the art is a threat with the possibility to become an opportunity with proper changes.

Circular processes

Circular processes, sustainability initiatives, common rules seem to be the key approaches for a shift toward carbon reduction for all the stakeholders involved.

“Years ago, there was only the statics, the design, the money. And now there’s somebody who talks about sustainability, and this is quite good development in the last years”. “I think the tax will increase the mindset for sustainability and I think it would be a thing you want to talk about with your friends, with colleagues. So, in the past two years, it increased very high because in Germany there is a political discussion about a CO_2 tax. So, it is all about the money at the end. And now they are thinking: what happens if a tax for CO_2 footprint comes? And then I must be sustainable?”. The debate on carbon tax is far from Italy. Some European countries, such as Germany, are beginning to discuss about it. The idea would be to make sustainability part of the project, not just the last step of the design.

For improving circularity, the disassembly phase should be considered from the early stage of the design, but then another perspective arises: “The real question that everyone should ask itself and to which there is actually no answer yet because we are still living at the beginning of this phase is: What do we do with the wood afterwards? Disassembly is a matter of design that one can manage already now and that is the Design for Disassembly. What happens next with the wood material? How do you know? It is difficult.” Indeed, there’s not yet a proper consciousness and regulations about this issue.

From the designers’ vision: “I think in the future we will have a better digitalized and more connected and collaborative industry and it will be doing more with digital twin, using digital systems to manage the progress in the factory and other assembled demanded buildings that are used on site and having all of that information there as how to deconstruct these buildings.”

Certifications

To help companies to collaborate, a common standard for circular materials should be considered. Standardization relates to the nature, composition and dimensioning of materials and products. To allow companies to take back materials that are produced by another company, it would be beneficial for products to be developed according to a standard range of specifications that all companies comply with [9]. Some of the interviewed companies have already established partnership with other actors in the supply chain to overcome such problems, enhancing collaboration and cooperation.
The topic of certification has been strongly debated among all actors due to a dissimilar perception, connected to the high risk of speculation. In fact, while on the one hand certifications are a useful tool to strictly control that products and buildings are made in such a way to reduce the impact on the environment, on the other hand there is a tendency for them to become a brand to sell at higher prices, without having a positive effect on the environment.

It’s interesting to list the number of quotes in which certifications are considered as a strength, a weakness, an opportunity, and a threat.

A shared ground based on certifications could be useful to avoid the marketing side taking advantage of the technical one, amplifying green washing issues. Even though there is an increasing demand from clients and customers requesting for certifications, which underline a greater awareness on those thematic, the implication is simple: not to aim for the score achieved through the certification system but to look for the effectiveness of the transition transformation process.
The correct design should also avoid the question of maintenance. Several times, the use of bio-

Maintenance

based materials for construction has been seen as a vernacular and unsafe practice. The practice is true especially in the Italian context. Bio-based materials do not require a different ordinary maintenance than traditional ones. Herein, “the maintenance issue is a non-problem, it is a problem of proper design”, going back to the correct design issue.

Regarding the maintenance of timber building there are different opinions, related mainly to the country in which the company is based, minor relation is given by the role in the supply chain. In Italy, for example, the topic of maintenance is neglected.

“In my opinion, the biggest threat, in our industry, as we are moving toward larger and larger buildings, multi-story residential apartment buildings, especially for the Italian model, which is to sell them for ownership, while in other European countries the most popular model is built-to-rent, we know very well that maintenance is neglected.”

In Italy, maintenance is considered as a big issue in general terms. Maintenance concerns all types of building, both concrete buildings, steel structures, brick walls, wood ones. Hence it can be deducted that the problematics are different according to each material. All the supply chain’s actor agrees on one point: the control of humidity inside timber structures and the attack of environmental agents.

As a representative of Architecture/Engineering firm: “The technical problem is that you must protect them [bio-based materials] from the point of view of environmental agents as fungi, parasites; you must prevent wood from going from wet to dry all the time because that is where it can break. If wood is protected behind a glass facade, for example, or behind any facade, it behaves exactly like reinforced concrete or like steel, it is a protected material that performs its structural function.”
“And therefore, I think the typical maintenance work will change.” Periodical checks need to be performed but no extraordinary maintenance is needed. “Maintenance is a lifetime thing.”

Summarising the key outcomes for a more sustainable future perspectives of the sector:

- Importance of the retrofit of the existing buildings. Old buildings that have low or null value: they should be restructured or rebuilt.
- More standardization of components and design. Always use the same types of connections and of links between the different components.
- Greater attention given to the design phase. Improving the circularity of the construction sector, bridging the gap between construction-deconstruction.

3/

EXPERIMENTAL PROJECT

3.1 The retrofit issue

Both the analysis of the existing literature and the survey has shown the relevance of the retrofit topic.

Europe's housing stock is as unique and heterogeneous as it is old [17]. The European Green Deal document, as multiple surveys on the existing building stock (for example Tabula Episcope [39]), have underlined the need of retrofit requirements. Even though building renovation was declared a key point for sustainable development, however, the renovation rate of residential buildings in the European Union is insufficient to meet the climate and energy targets set. More than 220 million buildings are over 21 years old of which up to 95% will still be standing in 2050, and none of them are energy efficient. This is due, among other reasons, to the fact that they are dependent on fossil fuels for heating and cooling, which means that there is considerable potential for energy savings [17]. Currently, the annual renovation rate in EU varies from 0.4 to 1.2% [2]. This rate will need at least to double (average 3% [17]) to reach the EU's energy efficiency and climate objectives, improving the performance of the building stock by lowering bills and energy costs.

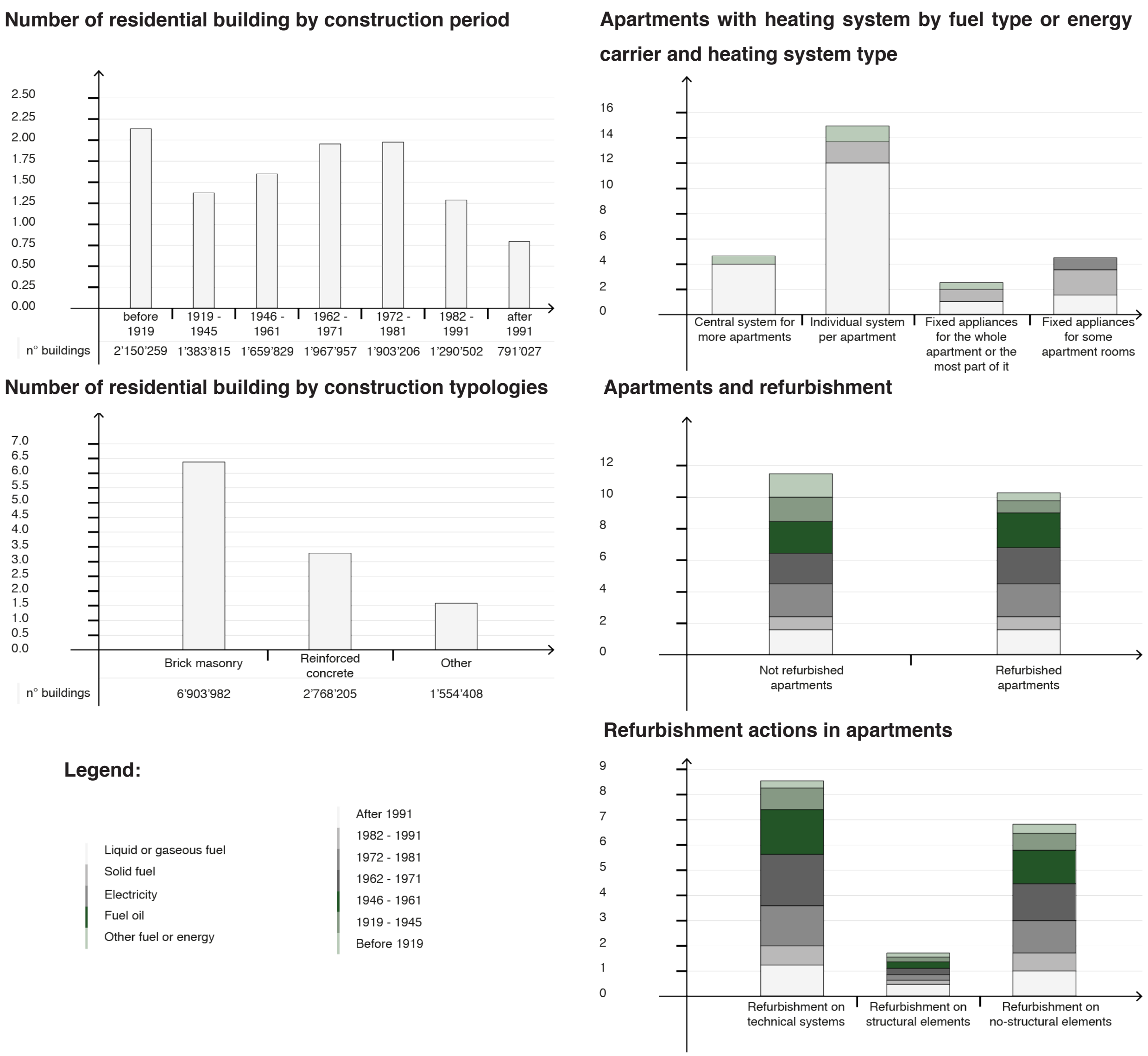
Renovation becomes a challenge when the structure and design of old buildings does not support refurbishment, reuse, or selective deconstruction [9]. Approximately 61% of all construction projects are retrofit projects (U.S. Green Building Council 2015).

For this purpose, the European-funded-project Tabula Episcope aims to classify the existing building typologies, to highlight the need for new technologies and new materials to act on the build environment.

The overall strategic objective of the Tabula project was to make the energy refurbishment processes in the European housing sector transparent and effective. This would help to ensure that the climate protection targets will actually be attained, and that corrective or enhancement actions can be taken in due time, if necessary.

The main outcome is a set of energy performance indicators which shall enable key actors and stakeholders to ensure a high quality of energy refurbishments, the compliance with regulations, to track the refurbishment processes in a cost-efficient way and to evaluate the actually achieved energy savings.

From the data taken from the Tabula research, it' possible to assume that most of the existing European residential buildings are reinforced concrete from the post-war years [39].
Hence, the necessity of retrofit action is ensured.



Italian building stock data (taken from Tabula Episcope, source ISTAT 2004):

- The Italian residential building stock counts 11 226 595 buildings;
- The number of apartments is 27 291 993;
- The average floor area for dwellings is 96 m².

FIGURE 23 | Adaptation of the results coming from the European Funded project Tabula Episcope [39]

Per definition, retrofit means recovering and improving some of the features of a building [40]. There are multiple types of possible measures that we can take on existing buildings. The following categories have been identified [41]:

- Seismic retrofit: improvement of the structural behaviour of the building under earthquake actions.
- Energetic retrofit: improvement of the thermal capacity of the building, reducing the carbon emissions and improving the quality of life for the inhabitants.
- Architectural retrofit: improvement of the general aspects of the building, including the protection of the building from agents of deterioration and usury.

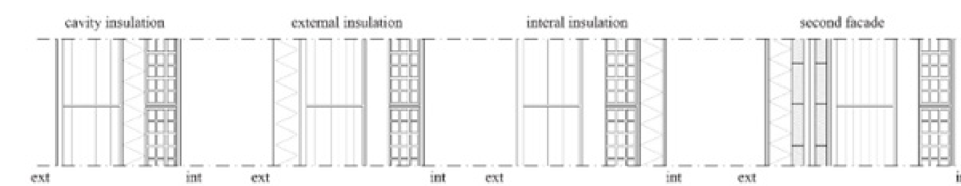


FIGURE 24 | Stratigraphy of the retrofit typologies currently available.

Currently, the retrofit approach is conceived more as a general holistic method that can improve different aspects of the build environment, including all the three categories mentioned above. Moreover, other than the technical aspects, the economic perspective should be considered. In fact, the conservation and refurbishment of the existing asset has a positive impact on the future value of the asset itself. Structure strengthening, good thermal insulation and durability of the façade are all improvements which minimize the lifecycle costs [35].

Retrofit legislation

At the European Union level, the Energy Performance Building Directives include retrofit legislation. The Directive 2002/91/EC and Directive 2010/31/EC have appointed to the building sector a set of policies, including energy performance strategies for the reduction of greenhouse gas emissions, fire safety and seismic risks.

The EPBD defines "major renovation" (Directive, 2010/31/EU) the retrofit which include minimum requirements. The significant renovation of an existing building is reached when the total cost of the renovation of the envelope or the technical building system is higher than 25% of the value of the building, or more than 25% of the surface of the building envelope undergoes renovations.

Since EPBD only specify the amount of surface refurbishment, without considering the value of energy savings, implementation is needed. The BPIE[19] Building Performance Institute Europe report relates the refurbishment depth with the level of energy or greenhouse gas emission savings achieved when refurbishing a building, specifying as deep the renovation achieves 60-90% energy-saving.

19 | https://www.bpie.eu/

The European insulation manufacturer association (Eurima) has issued a report of deep renovation on and economic perspective [42]. By increasing the rate and depth of renovation, both the operational carbon and embodied carbon of building are considered. The operational carbon is defined as the emission emitted during the use of the building. Instead, the embodied carbon is the emission associated with construction materials and products as well as the processes carried out prior and after the use of buildings. The primary energies associated with the construction sector are [40]:

- Embodied energy: energy required to extract, process, and transport material to the point of use or application.
- Operational energy: energy required to maintain the building and its comfort conditions.
- End of life energy: energy associated with the refurbishment/demolition of a building.

In addition to such general EU regulations, national governments and local institutions can set up specific policies which may vary to the European ones or implement them.

3.2 Bio-based material applications

The application of bio-based materials for the retrofit is essential due to their positive impact on the build environment: renewable resources, CO2 storage, reduction of GHG, behaving as a carbon sink [43]. Moreover, by lowering embodied carbon, they can also create healthier buildings and they can preserve a healthy indoor environment during the lifetime [44].

The main advantages of biomaterials are the low environmental impact due to their renewability and cascade use, low resource production techniques, possibility of prefabrication and fast installation, providing an innovative paradigm compared to traditional building materials [45]. Some are also characterized by excellent multi-physical properties (heat insulation, sound absorption, transmission loss) and require very low resource production techniques.
On the contrary, they have the disadvantage of being combustible, limiting their use because of Fire Safety Regulations [34].

From an architectural retrofit perspective, bio-based materials are used for two main applications: structure and skin, with particular focus on insulation [46].

Structure

Concerning the structural retrofit, the bio-based solutions are mostly in wood. Wood is the most promising in terms of space efficiency: relatively highest carbon storage in buildings while occupying the smallest land, low production energy required. The production of wood as a building material involves only about 10% of the energy consumption required to produce equivalent amount of steel [34].

The amount of land currently available for growing wood is sufficient to fulfil the whole material demand for construction in the EU [47]. Moreover, an advanced infrastructure network is already developed for timber supply. Wood has a vast application since it can be used either in form of timber slats, boards, and poles, or can become an engineered product as cross-laminated timber (CLT), glued-laminated timber (GLT), plywood, after industrial transformation [48].
The current research is concentrated on promoting the use of wood and investigating new forms of engineered wood, which, in addition to its ancient tradition, enters the contemporary construction logic with technological improvements that allow to overcome size or length limits [48].

As an external retrofit methodology, preassembled timber components have multiple advantages for building constructions. The seriality and modularity of the production can decrease manufacturing costs by optimizing processes and reducing fossil-carbon emissions during the assembly phase [49]. The rapidity of assembly ensures a short on-site construction duration minimizing the construction site-related discomfort for the occupants, without reducing the structural stiffness and the technical performance. The modular timber construction, primarily based on wooden elements allows for storing a significant amount of carbon in the structure (50% of the mass) [50].

Skin (non-structural application)

The main non-structural application is for the insulation material. There is a wide variety of bio-based materials used for insulation and façade component purposes: hemp, cotton, wood fibres [51]–[54].

An important distinction is needed. Bio-based insulation materials can be subdivided into two main classes: natural and recycled. Non-renewable materials can cause substantial environmental issues due to disposal and end-of-life [55]. Even though, considering the definition of bio-based materials, it is not mandatory that the renewable content is 100%, thus may causing problems to the environment when disposed. This research's focus is on bio-based materials.

Among the different options of biomasses, the interesting ones for insulation are those with a porous structure as corn cob with honeycomb structure, corn stalks. At the same time, those with long fibre show good mechanical properties and can improve the tensile strength of many materials [44].

Thermal insulations made of biomasses come mainly from [51]:
- agricultural waste (corn/wheat/rice straw, hemp, rice husk, linseed, kenaf, flax, jute, olive fibre, corn stalk, reed, sunflower);
- forest residues (wood, bark, coniferous residues, bamboo, coconut fibres, cork);
- farming (sheep wool);
- living organism (mycelium).

Straw can be strongly recommended for large-scale construction and renovation since it has the highest cumulative carbon storage potential [56]. Using it for construction should not change the amount of land used or the intensity of wheat production. RiceHouse s.r.l. Società Benefit[20] is an Italian company developing new building materials based on rice straw from this loss of rice cultivation and enhancing the organization of its whole supply chain.

Hemp is not sufficiently available. The land needed for hemp production covers only 2% of the demand, and the legislation limits its future development in many countries. Cork is only available in dry southern regions; only 4% of cork can be supplied for building insulation, which leads to slight potential carbon storage in the building stock [57].

Materials derived from animals or living organisms (sheep wool or mycelium) are more inclined to have durability and degradation problems, including ageing, weathering, mould and algae growth, decay, waterlogging, and insect infestation [58].

20 | https://www.ricehouse.it/en-home

→ TABLE 08 | Review summary of the retrofit technologies currently available.

3.3 Existing bio-based retrofit solutions

The following Table contain an extended review summary of the retrofit technologies available nowadays.

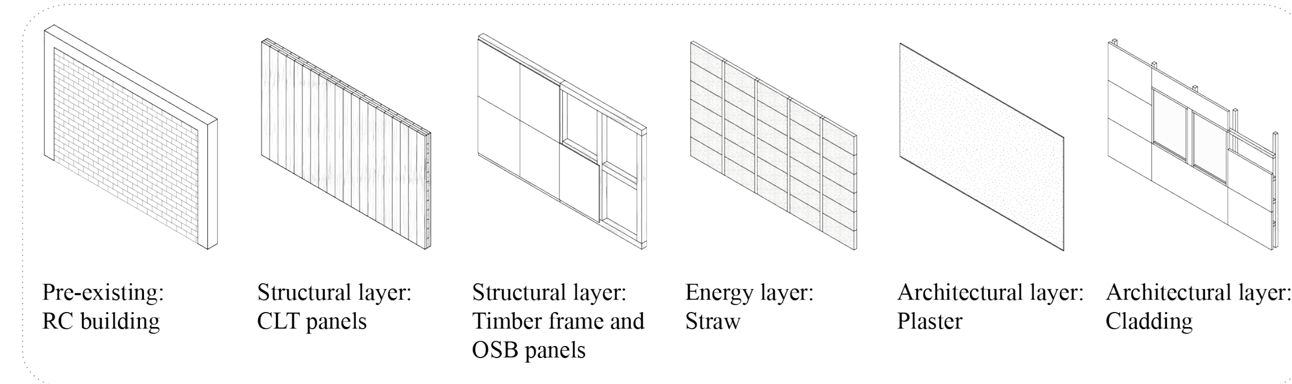
Existing building technology	Retrofit technology	Description	Bio-based solution	Reference
URM (unreinforced masonry walls)	CLT panel external and internal	New seismic retrofit technique for masonry walls using CLT panels fastened on the existing wall. CLT also provide thermal and acoustic insulation. It is a dry and removable technology that can be used externally and internally.	The internal shell of CLT walls is used for performing experimental tests on masonry examples of seismic retrofit.	[59]
RC (reinforced concrete) framed building	CLT panels	AdESA project is a holistic retrofit technique that consists of a dry, modular, and flexible shell exoskeleton. CLT panels for the structural retrofit, thermal insulation panels for energy efficiency, and claddings for the architectural restyling. The solution is designed to be easily mountable by adopting macro-prefabricated dry components and standardized connections.	The use of CLT as a structural layer and the presence of an alternative to EPS insulation layers: cork. Cellulose. They allow for the reuse-recycling of components at the end of their life.	[13]
RC framed buildings	CLT panels	Seismic and energy retrofit for RC frame using CLT panels. The strengthening of the RC frame system allows lower drift values and higher peak load.	CLT shear walls as a replacement for existing masonry infill walls	[60]
RC framed buildings	CLT elements	Example of seismic retrofit using CLT panels connected externally to RC frame structure by friction dampers. The system is named e-CLT. Friction dampers partially dissipate earthquake's energy and limit the internal force transmitted by CLT panel, avoiding possible failure.	CLT panels prove the strength and lateral stiffness	[61]
RC framed buildings	Timber cladding	NATURWALL is a façade system for both energy and architectural retrofit. It is a prefabricated, modular, lightweight, cost-effective solution. It is positioned in the existing envelope between structural beams fixed to the floors.	It is made of external stratified glazing, ventilated cavity, honeycomb cardboard, and an insulated sandwich panel.	[62], [63]
Concrete masonry-clad buildings	Insulated timber cladding	Energy and architectural retrofit with TRADA system. Timber cladding is fixed to timber battens and nailed to the existing structure. On-site construction, not prefabricated.	TRADA Technology: Timber cladding systems of three types. Hanging on the existing wall or self-supporting.	[64]
RC framed buildings	Timber cladding	Evaluation of the energy savings of wooden prefabricated façade elements with a simple assembly process. The advantages are the dry production process, on-site assembly, and reduced number of thermal bridge's external applications.	Timber-based cladding system. Use of recyclable materials	[65]

Timber, concrete, or brick structure	CLT wood panel, exterior	Energy and architectural retrofit are studied with prefabricated timber elements to provide environmentally friendly, energy- and cost-efficient solutions. The system is flexible. It can be applied to pre-existing timber, concrete, or brick structures.	"Modular wall system": consists of two outer multilayer solid wood panels with insulation in between connected to each other by wooden rods.	[66]
RC framed buildings	Timber Frame	The Ri.Fa.Re project consists of an innovative timber-based panel for energy and seismic retrofit. The study aims to provide a new process based on parametric design and lean construction principles. The process is composed of design, development, and testing.	Timber-based solution: wall panels are placed on timber beams (called console beams) directly anchored on the main concrete structure.	[67]
RC framed building	Textile reinforced concrete with EPS core. Timber panel for pitched roofs.	Example of energy and architectural retrofit of a multi-story residential building. For the façade a preassembled insulated panel based on two textile-reinforced concrete thin precast layers rigidly connected to an EPS core has been installed on the outer side. Instead, the existing pitched roof has been refurbished with preassembled timber panels.	Preassembled timber panel	[68]
RC framed building	Precast multilayer panel	EASEE project: envelope approach to improve sustainability and energy efficiency in existing multi-owner residential buildings. The system proposes both energy and architectural retrofit. Fundamental characteristics are prefabrication and quick installation. The system is a multi-layer panel made of two textile-reinforced concrete thin precast layers rigidly connected to an EPS core.	x	[68]–[70]
RC framed building – roof system	Preassembled timber Panel	The work aims to develop a prefabricated retrofit solution. The base version for the roof system is the non-load bearing panel "HABITAT". "Evo-HABITAT" is the optimized panel. The roof's primary timber structure was integrated into the preassembled panel, with significant benefits in terms of structural performance and optimization of the construction process.	HABITAT panel: preassembled timber panel with eco-friendly materials and wood-based product: multi-cell box by OSB panels. Evo-Habitat is a structural version whit a GLT structure that allows covering bigger spans.	[68]–[70]
RC framed building	Bio-based panels Sustainable adhesive	An energy retrofit solution is proposed by comparing different bio-based insulating materials. The insulating panels are directly attached to the existing façade through a sustainable adhesive. Experimental energy performance and solutions comparison between various insulating materials and changing thickness.	Bio-based panel for insulation Case studies: 5cm hemp insulation, 5cm straw insulation, 10cm hemp insulation, 10cm straw insulation, 12cm hemp insulation	[71]
RC framed concrete	Timber frame for façade system	The aim is to test a new integrated façade system to improve the overall energy performance: It consists of both energy and architectural retrofit. The system is prefabricated, well-insulated, cost-effective, flexible, and equipped with HVAC.	BERTIM: Building Energy Renovation Through Timber Prefabricated Module. Hephaestus system: off-site manufactured curtain wall module	[72]
RC frame building	Prefabricated timber-based panels CLT Timber frame	Seismic, energy and architectural retrofit is proposed as a new innovative holistic approach. It is based on the addition of CLT panels to the outer walls able to strengthen the existing building for seismic action through friction dampers (e-CLT system), in combination with wooden-framed panels for insulation and architectural renovation (e-PANEL design), hosting high-performing windows.	CLT panels Wooden-frame panels Wood screws Wood fibre thermal insulation	[41], [73]
RC building	Bio-based insulation materials Timber frame	Different energy retrofits for existing façade are proposed to test the best solution acting as carbon storage. Five alternative construction solutions are compared. Fast-growing bio-based materials have a higher potential for carbon storage than timber.	Materials inventory: I-joist frame with pressed straw, preassembled frame with injected hempcrete, timber frame, Hempcrete blocks, EPS.	[74]
RC building	Prefabricated panel systems: Timber frame panels RC panels. Steel panels for seismic retrofit	Energy and architectural retrofit systems are proposed. The three renovation models are made of façade panels. Structural framing, insulation, windows, doors, and air sealing are all included in a unitized panel nailed with hooks to the existing building.	Timber-based panel with wood, cellulose, recycled paper, and mineral wool. Insulation is then blown into gaps between the existing and new facades.	[75]
Light-framed wood building	Zero-carbon Bio-based wall panel	An energy retrofit solution is proposed to reduce carbon emissions. A bio-based retrofit panel system is optimally sized, efficient for installation with net-zero embodied carbon and a low-cost installation process, fabricated from a low-density wood-based substrate of three-ply cross-laminated timber (CLT) technology supporting the bio-based insulation in wood fibers.	CLT Wood fibre insulation systems are compared with different bio-based insulating materials with different thicknesses, according to climatic zones.	[76]
URM buildings RC buildings	Panel with a timber frame with bio-based thermal insulation	A seismic and energy retrofit solution is proposed combining timber mechanical properties and bio-based material's thermal insulation properties. Timber frame and insulation material are attached to the existing façade, internally or externally. Three retrofitting systems are investigated.	Timber frame for seismic retrofit. Two bio-based thermal insulation layers are used: cork boards and pressed grass panels.	[77]

URM buildings RC buildings	Panel with a timber frame with bio-based thermal insulation	A seismic and energy retrofit solution is proposed combining timber mechanical properties and bio-based material's thermal insulation properties. Timber frame and insulation material are attached to the existing façade, internally or externally. Three retrofitting systems are investigated.	Timber frame for seismic retrofit. Two bio-based thermal insulation layers are used: cork boards and pressed grass panels.	[77]
Concrete wall	Laminated wood panels	The main contribution of this paper is to propose a new business model with standardized products, logistics and project management, discussing different aspects of efficient business models considering prefabricated wooden elements. It can be achieved only with façade standardized elements.	Termowood system solution: Laminated wood panels connected with wooden dowels and insulation. It can come in two versions: structural and no structural.	[78]
URM walls	Internal and external CLT/LVL panels and timber strongbacks	The system proposes structural and energy retrofit. The structural retrofit consists of timber-based components (panels and strong-backs) connected to the masonry walls. Instead, the energetic performance is guaranteed by the installation of insulation layers.	Seismic retrofit with CLT/LVL panels and timber strong backs: the best solution is obtained with a CLT panel of 60 mm thickness, insulation layer and coating.	[47]
URM cavity-wall, precast RC panels	Internal timber frame connected to the URM through steel profiles.	The aim is to provide a large-scale application of timber retrofit for the URM walls. The system discussed is lightweight, reversible, cost-effective, and bio-based. The seismic performance of an empty building and a retrofitted building have been compared, demonstrating the benefit of the timber frame retrofit.	Seismic retrofit with timber frames (80x60mm): vertical timber posts, horizontal nogging (spacing 60 mm) connected to the masonry and floor systems and OSB panels nailed to them.	[79]

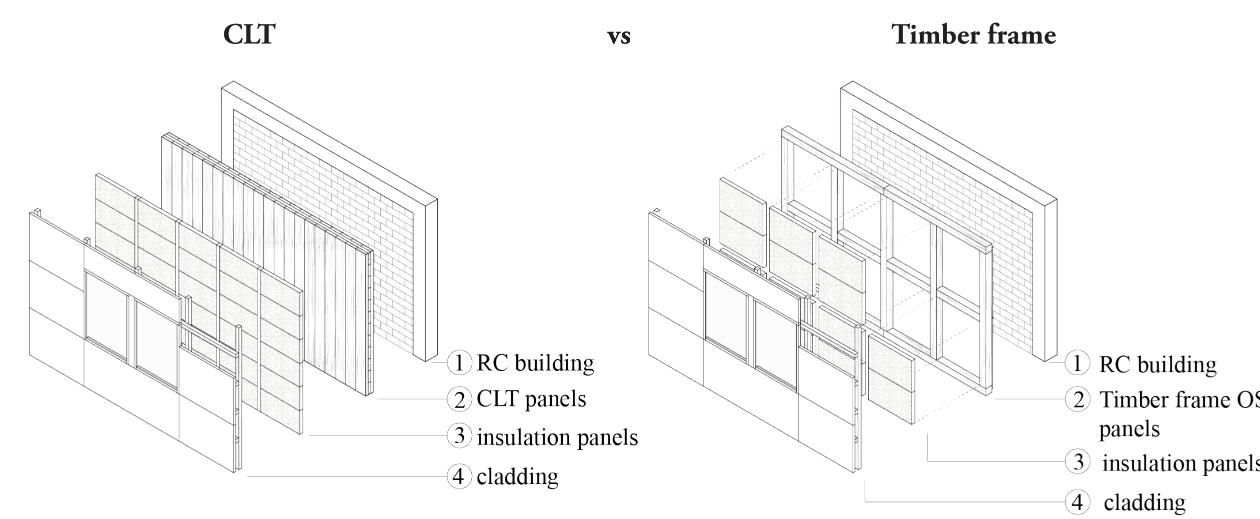
The following diagram explain how the different retrofit techniques are subdivided, focusing on which layer of the building is included in the retrofit. Few holistic approaches currently available have been found.

Hollistic approach	Structural layer	Energy layer	Architectural layer
• AdESA [13] • Naturwall [62, 63] • e-SAFE [41, 73] • BERTIM [72]	• CLT panels [13, 47,62, 59, 60, 73, 76] • LVL panels [47] • Timber frame [47, 50, 64, 65, 66, 75, 77, 79]	• cork [13, 77] • cellulose [13, 75] • cardboard [62, 63] • wood fiber [41, 73, 76] • hemp [71] • hempcrete [56] • recycled paper [75] • pressed grass panels [77] • straw [56, 71]	• curtain wall modules [62, 63, 72, 78] • timber cladding system with timber battens [64]



The two main retrofit systems described by the examples are constituted as follow:

- Structural layer: CLT panels or timber frames with OSB/fibreboards panels
- Energy layer: bio-based insulation made of straw, hemp, cork, cellulose etc.
- Architectural layer: simple coating with plaster or cladding system.



Such study has been necessary to set up the basis for the panel design and its further optimization.

The features which could be implemented in the project could be:

- **Modularity and dimensioning:** the modularity of the components has an essential role in the reversible connections of the components (disassembly and reassembly).
- **Connections:** the internal joints of the wooden frame may be studied for dry assembly. The connection with the existing building must face the irregular geometry of the existing building's uneven surfaces, which meant that the steel connectors of the façade module needed to be calibrated and adjusted to the façade geometry and its variations.
- **Assembly/Disassembly:** system interchangeability and reversibility of components (replacement with a similar element), flexibility (ability to adapt to different situations or needs), also through dry assembled connections.

TABLE 09 I ← Subdivision of the retrofit technologies currently available.

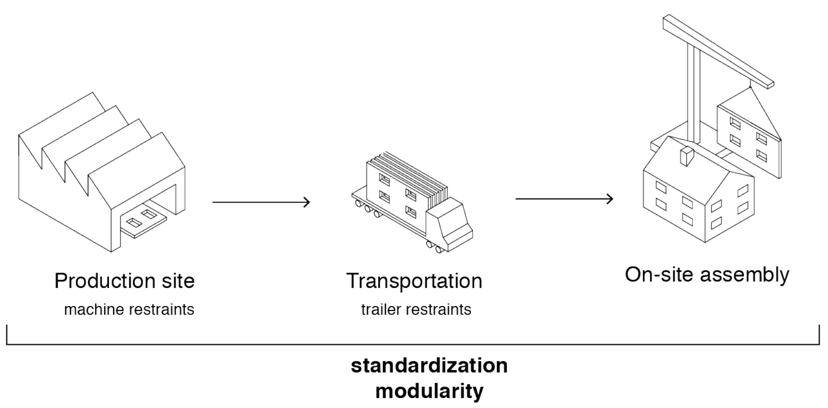
FIGURE 25 I Functional layer s considered for the retrofit.

FIGURE 26 I Representation of the 2 main approches of timber retrofit : CLT and timber frame.

3.4 System design and optimization

According to multiple sources [80], on-site renovation looks problematic due to the high number of technicians and craftsmen involved, complex coordination on-site, low-quality production level, and inefficient construction process. On the contrary, prefabricated components involve fewer companies, enabling easier coordination, better quality control, and rapid construction processes. Prefabricated construction technologies optimize the manufacturing process and decrease carbon emissions during material processing and assembly.

A relevant activity to be considered is the transportation of the prefabricated compontets from the production site to the construction site. Dimensional restraints need to be considered while designing such componets [66].



For the panel research, the focus is on second façade retrofit systems, concerning the addition of the system to the existing façade. The modular component aims to solve issues related to refurbishment, representing a valuable option both in architectural and economic terms. Accordingly, the facade has become an integrated complex system, made of modular components with different functionalities, structural, insulation and view appearance [81].

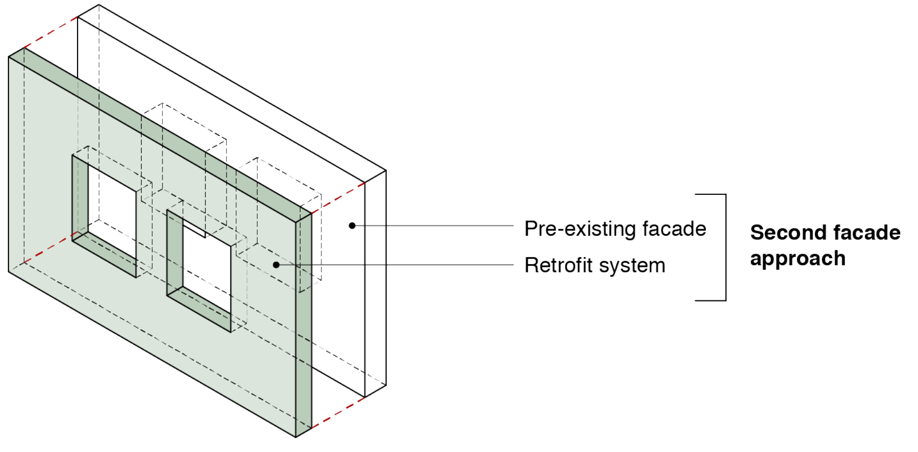


FIGURE 27 | Representation of production-transportation-construction steps related to prefabricated modules

FIGURE 28 | Retrofit tyology: second facade approach.

Moreover, modularity enhances prefabrication and standardization from a design and production point of view. A module is defined as "an essential and self-contained functional unit relative to the product of which it is part. It has standardised interfaces and interactions that allow the composition of products by combination".

The advantages of module are several:

- Standardisation: it can significantly reduce the cost, enable mass production, make it easier for training, support and problem-solving.
- Simplicity: from the management side, the modular process could enable the establishment of independent working units, speeding up the manufacture or installation process.
- Flexibility: it is often reflected during in-use stage which involves maintenance, upgrade or disposal.
- Customisation: the interchangeable parts of modular components and its adaptability in shape and size can also offer customised design solutions.

Hence, the retrofit system is focused both on the product development and on the production development. In fact, it considers raw bio-based materials issue, building method, labour requirements and supply.

The panel design description is based on [11]:

- Concept description;
- Value creation;
- Value proposition.

Concept description

The component is an environmentally appropriate panel for structural, energy, and architectural retrofit of existing non-historical building. It consists of a modular construction system which enable prefabrication, dry assembly, fast disassembly and possible component reuse and recycling. This method allows the installation of prefabricated solutions, the use of the building during the renovation, reducing the impact on the inhabitant's life avoiding the use of scaffoldings. Furthermore, better insulation allows the use of a less amount of energy for heating, reducing CO_2 emissions.

Value creation

The main objective has been to design an optimized system compared to the one's already in the market, able to generate a profitable industry. The cost-efficient refurbishment aims to provide a future-oriented product.

Value proposition

Below, the main features of the retrofit system are underlined:
- Prefabrication;
- Dry assembly;
- Low construction costs;
- Increased thermal insulation buildings in mass production;
- Reduced transportation costs;
- Reduced time spent on-site and disturbance;
- Less mistakes due to prefabrication and modularity.

According to the studies mentioned above, the selected techniques for the panel design include the combination of timber frame as structural layer, rice straw for the energy layer, and a cladding system for the external architectural appearance.

Structural layer

Based on the current technologies available, timber frame has been selected over CLT panels. Skeleton constructions can also be used to enable greater flexibility and zoning diversity [29]. GL24h spruce timber has been selected among others to ensure system's stiffness.

Materials: CLT vs TIMBER FRAME

CLT

PROS

- Suitable for structural, seismic and energy retrofit
- Performs well in earthquakes
- Suitable for extending existing buildings (ex. façade) within minimal modification of the pre-existing structure
- Suitable for multi-storey buildings
- Easily prefabricated and well-suited to modular construction
- High quality due to off-site construction
- Low tolerance: manufacture in highly controlled conditions with precision CNC machines
- High carbon sequestering material
- High mechanical performance
- Better disassembly and possibility to re-use the components

CONS

- Not as carbon friendly as might first appear due to the presence of glue
- Shortage of design and construction expertise

TIMBER FRAME

PROS

- Lightweight (do not burden on the existing structure)
- Quick and easy to assemble on site
- Off-site construction and control
- Usage of less material than CLT
- Less expensive than CLT
- Easier manufacture

CONS

- Can't cover very large spans
- Can't be used for structural retrofit as CLT
- Lower carbon sequestering material than CLT

Connections: CLT vs TIMBER FRAME

CLT

- panel-to-panel ⟶ screws, steel nails
- panel to existing structure ⟶ friction dampers
- panel to foundation system

TIMBER FRAME

- frame elements ⟶ screws, steel nails
- panel-to-panel ⟶ screws, steel nails
- panel to existing structure — friction dampers

POSSIBILITY OF OPTIMIZATION

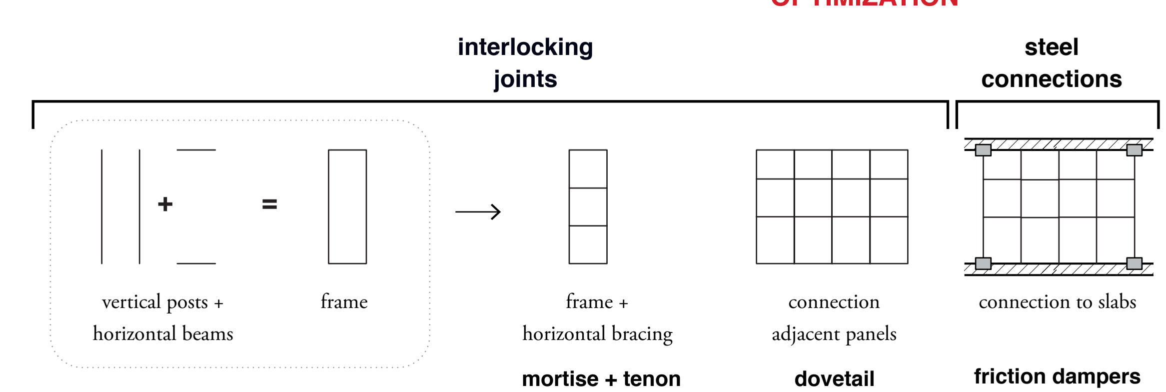


FIGURE 29 | Synthetic diagram of materials and connections pros and cons . Timber frame is selected over CLT for the higher degree of possible optimization.

Energy layer

Rice straw has been selected over the other bio-based insulation materials since its cultivation is well developed in the Italian context. Moreover, this natural resource is available in all 5 continents, demonstrating a great potential for its wide application[21]. The waste from the harvesting of rice is used in various forms, ensuring a high degree of flexibility in the construction industry.
Between the simple plaster finishing and the cladding system, the second one has been selected

FIGURE 30 | Bio-based insulation materials: rice husk(left), rice straw (right).

Architectural layer

for its possibility of disassembly and reuse.

The UNI 11018 standard, which there's the need to refer for the design and construction of ventilated façades, defined them as "a type of advanced screen façade in which the cavity between the cladding and the wall is designed in such a way that the air can flow in by chimney effect in a natural manner and/or in an artificially controlled manner, depending on seasonal and/or daily needs, in order to improve its overall thermal-energy performance."

The integration of building components such as windows, building service systems as HVAC is ensured. Moreover, ready-made surfaces of the façade in a controlled working environment are assembled, allowing extra customization and quality control.

The benefits of a ventilated façade are:
- Permeability;
- Water protection;
- Elimination of thermal bridges;
- Noise absorption through several layers.

To ensure its correct operation, the cladding system must be separated from the wall by profiles, installed vertically to allow air circulation in the chamber. For the prototype design, aluminium profiles have been selected over wooden ones for their flexibility, ensuring the application in tall buildings[22].

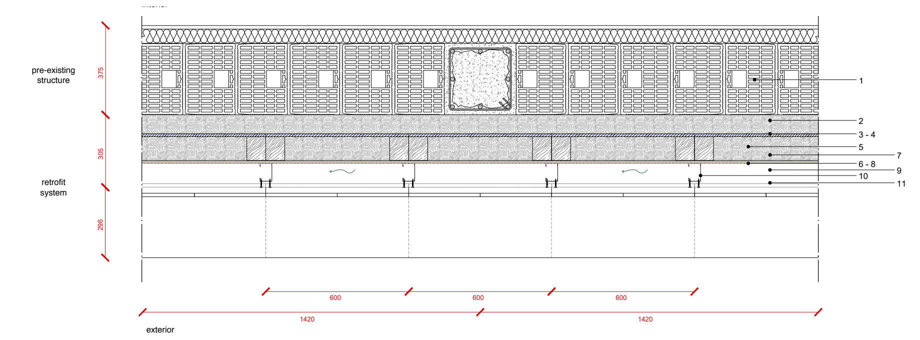
21 | https://www.ricehouse.it/

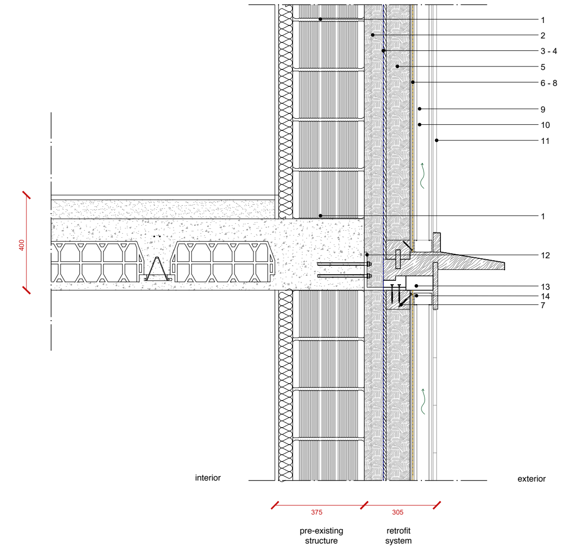
22 | https://www.archdaily.com/887042/how-to-install-ventilated-facades-using-wooden-panels

Stratigraphy

The panel is constituted by a GL24h spruce timber frame. It is closed on both sides: inwards with a fibreboard panel, and outwards, in order to prevent fire propagation, with a 12 mm thick gypsum plasterboard sheet. The inner cavity of the panel is filled with free-form rice husks. Towards the pre-existing wall, the panel have a rice-straw wool insulation, while towards the outside the finishes is constituted by a ventilated façade with wooden slats, defining a specific façade pattern.

Below the stratigraphy of the system has been described by bullet points.
1. Insulating, sound-absorbing and compensating layer for irregularities in pre-compressed rice straw fibre (Ricehouse RH50 type) - 80 mm thick.
2. Vapour and air infiltration layer with natural and recycled cellulose reinforcement.
3. Inner closing layer of the panel, fibreboard - 12 mm thick.
4. Insulating and sound-absorbing layer of rice husk – 100 mm thick.
5. Outer closing and fire protection layer of the façade in non-combustible gypsum-fibre, reaction to fire class A1, resistant to humidity with relative upper/lower and side flaps on the panel – 12 mm thick.
6. Waterproof and breathable anti-drip layer
7. Ventilated façade with attached substructure and wooden slats coating layer.





Details:

1. pre-existing structure system
2. bio-based insulation by Ricehouse | type: RH50
3. vapour barrier
4. fibreboard panels
5. bio-based insulation by Ricehouse | type: RH-L
6. gypsum plasterboard
7. structural timber component GL24
8. waterproof layer
9. air gap
10. cladding system aluminium profiles
11. wood lamellae coating
12. steel connection
13. fire proofing layer type Paraflam©

FIGURE 31 | Retrofit system stratigraphy: plan and section.

Pre-existince

The goal of the system is to ensure flexibility for adaptation. The basic pre-existing structure taken in consideration is a reinforced concrete RC frame structure filled with traditional hollow bricks.

The structure has the following dimensions:
- Slab height = 400 mm
- Internal storey height = 2900
- Pre-existing wall thickness = 375 mm.

Regarding the envelope, from the interior the stratigraphy is composed by a first 15 mm layers of plaster, 6 mm of generic insulation and 30 mm traditional hollow bricks.

Dimensioning

Height and width are strictly dependent from the pre-existing structure. One of the advantages of the timber frame system is the flexibility to meet most of the demand of existing structures and dimensions of housing or office buildings. The element dimension depends on different renovation object parameters such as pre-existing bearing structure, functional distribution, construction grids (axis, floor heights, binding joist, ring beam). Additionally, there are restrictions caused by machinery and transport restrictions, in most cases < 13 x 3,8 m. [35]

Based on literature analysis, the frame dimensioning has been accomplished. Below the measures of base cross section, frame height and frame width.
- Cross section= 80 x 100 mm
- Panel height= 3200 mm
- Panel width= 600 mm

The facade has been subdivided through a costant offset, creating a 60 cm spacing. This value derives from the study of the current literature regarding retrofit bio-based solutions.

MODULE A:
wall
height = slab height
width = 60 cm

MODULE B:
above window
height = variable
width = 60 cm

MODULE D:
under window
height = variable
width = 60 cm

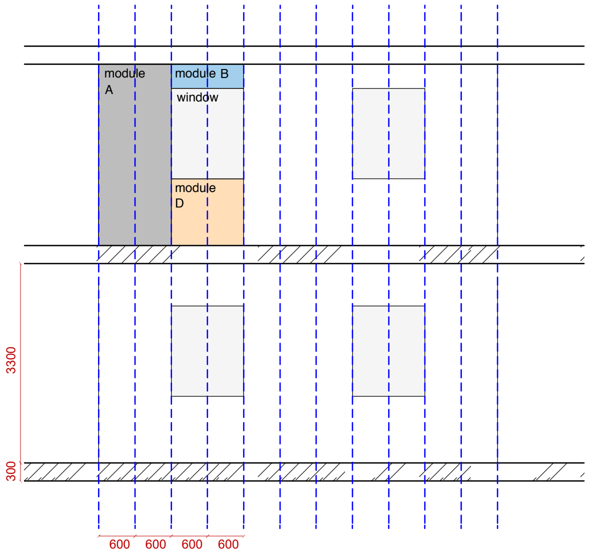
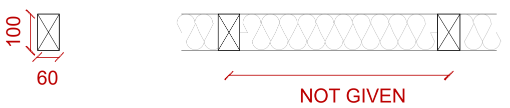


FIGURE 32 | Representation of facade subdivision in three different modules : A, B, D.

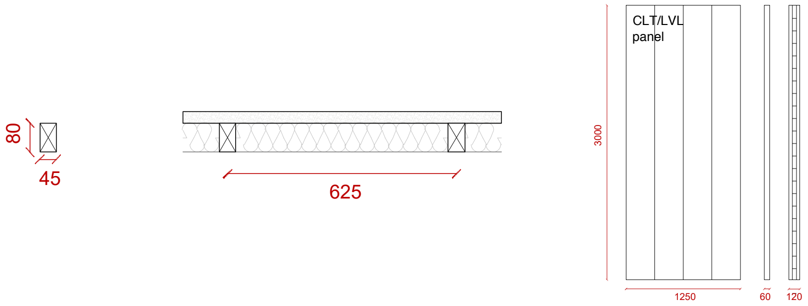
→ FIGURE 33 | Cross section optimization based on literature review.

Cross section optimization

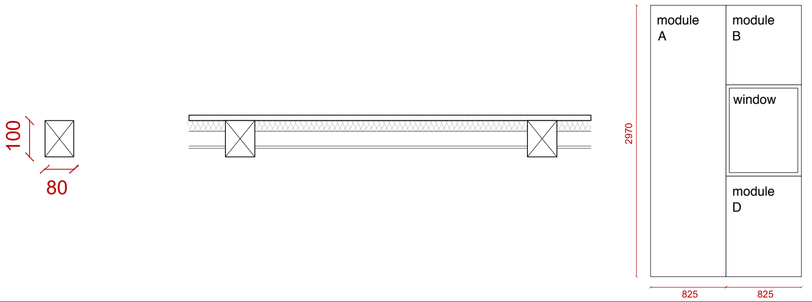
REF 1:
TES system [35]
URM-RC buildings



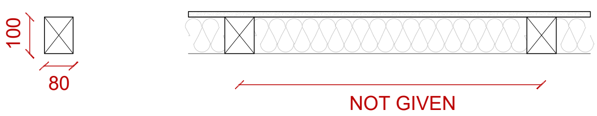
REF 2:
strong-backs + CLT/LVL panels [47]
URM buildings



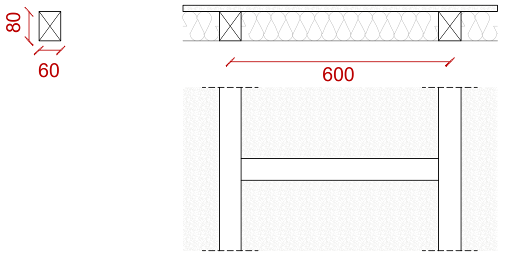
REF 3:
Naturwall [62]
RC framed buildings



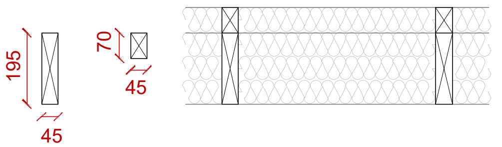
REF 4:
e-PANEL [73]
RC framed buildings



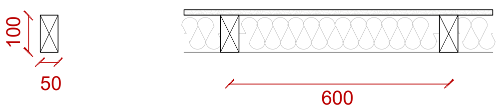
REF 5:
vertical posts, horizontal nogging + OSB panels [79]
URM cavity wall



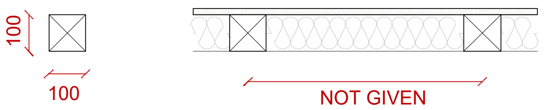
REF 6:
MORE-CONNECT [29]
URM-RC buildings



REF 7:
Termowood system [66]
Timber, URM-RC buildings



REF 8:
Strong Thermal and Seismic Backs [77]
URM-RC building



Based on the three main features which could be implemented in the system, modularity – connections – assembly/disassembly, the research has been subdivided into the following phases.

STEP_0: internal joints study
STEP_1: horizontal joints study between adjacent panels
STEP_2: vertical joints study, "marcapiano" issue
STEP_3: connection between panels and existing RC slabs
STEP_4: insulation with bio-based materials

OBJECTIVE → Identify a construction system for the retrofit of non-historical reinforced concrete buildings. The technique involves the use of dry-assembled modules with bio-based internal insulation.

SHORT-TERM OUTCOME → Providing an optimization of the existing retrofit technologies based on the use of timber frame.

FIGURE 34 | Visual representation of the experimental project steps.

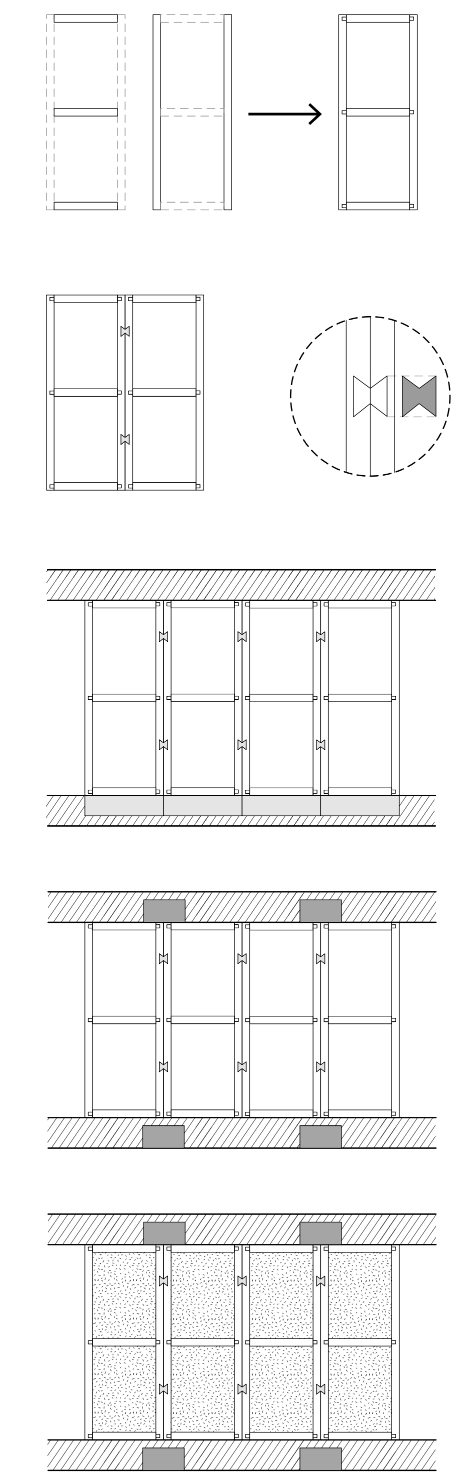
STEP_0:
internal joint study

STEP_1:
horizontal joints study between adjacent panels

STEP_2:
vertical joints study, "marcapiano" issue

STEP_3:
connection between panels and existing RC slabs

STEP_4:
insulation with bio-based materials



STEP_0: internal joints study

The technology of the connections is essential in all design processes. In timber construction, half the costs are determined by the volume of material used and the other half by the installation and connection costs [83]. The joints between assembled façade panels are among the most prominent detail of a prefabricated building. They must protect against heavy downpours, compensate for the expansion and contraction of façade elements in hot summers and cold winters, and avoiding birds and insects' attacks [29].

Considering the existing technological systems, the bigger part of connection between elements is made in steel. On such microscale, the use of metal connectors as nails, screws and clamps could be avoided taking advantage of the ancient interlocking joints. For instance, the long tradition hand-crafted Japanese joints can be taken as reference. Mortise and tenon, dovetail, scarf joints are all valuable examples [84]. Accordingly, new sustainable timber structure can be realized, facilitating both production, assembly, and sorting process for disposal.

Dovetail joints are interlocking joints with great mechanical strength. They are constructed with an angled male part shaped like a dovetail that fits into a similarly shaped female socket. Mortise-and-tenon joints are also very common, having a tongue, the tenon, that fits into a hole, named mortise. Such connections are reversible and feature several complex wooden parts, enabling sophisticated locking mechanisms without glue. According to the direction and dimension of the timber pieces to join, certain nodes are more appropriate than others. [84]

Recently, as digital fabrication devices have become more common, a growing number of projects have featured CAD joints. Automated fabrication allows the production of differently shaped interlocking joints with CNC machines. In this case, the mechanical performance of the joints depends on fabrication precision. The cutting method has been optimized with rotating cylinder-shaped milling tools [85].
Moreover, a first experimental investigation of the mechanical strength of CNC wood joints was performed in 2012. The aim was to show the possibility of using such joints in building structures. Indeed, a stiffness compared to a connection with wood screws can be achieved with CNC cut dovetail joints on CLT plates [85].

Regarding the internal joints in each panel, mortise and tenon connection have been used in six points. The two vertical timber elements have been linked to the three horizontal elements avoiding the use of steel elements.

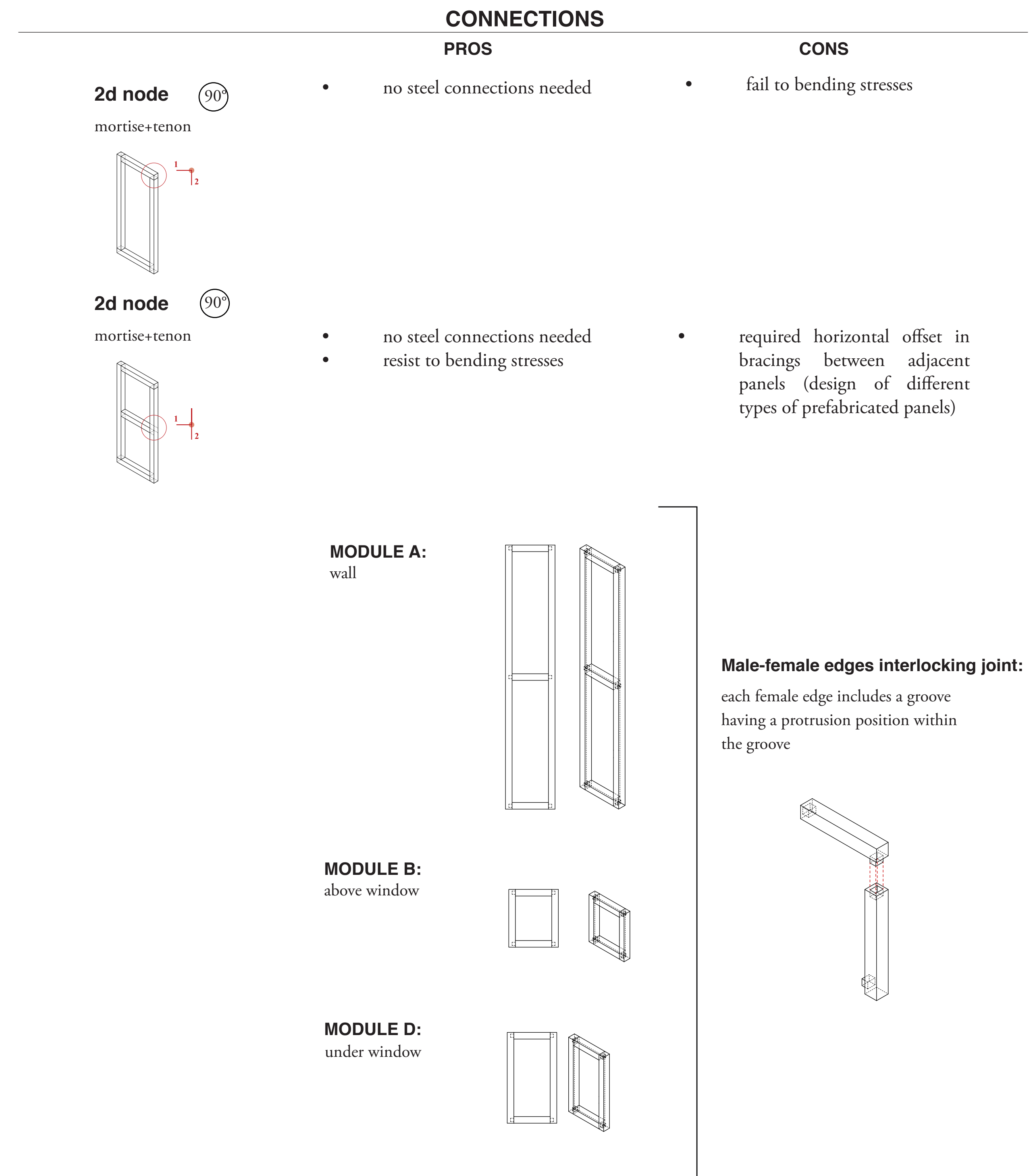


FIGURE 35 | Visual representation of the Step_01.

STEP_1: horizontal joints study between adjacent panels

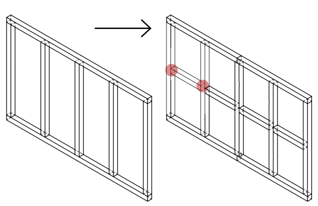
Considering the actual retrofit panels, which are constituted by several modules mounted together, the connection inside the panel is usually in steel or made with wood screws.

By using interlocking joints such as dovetail, local displacement, or disengagement in relation to the adjacent frame is prevented [83].

For the prototype, each frame is connected by two dovetails. There's no the distinction between male and female pieces, in order to avoid complicated CNC milling profiles, enhancing easier and faster assembly. Accordingly, the adjacent frames are linked together by a dovetail-shape wood screw.

CONNECTIONS

2d node (90°)
dovetail



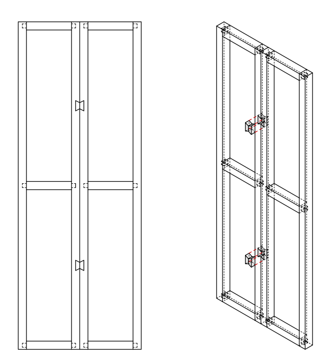
PROS

- no steel connections needed
- resist to bending stresses
- prevent local displacement or disengagement in relation to the adjacent frame

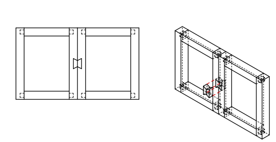
CONS

- Can't cover very large spans

MODULE A:
wall



MODULE B:
above window



MODULE D:
under window

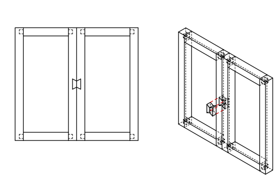
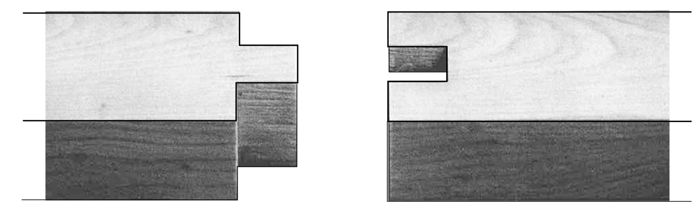


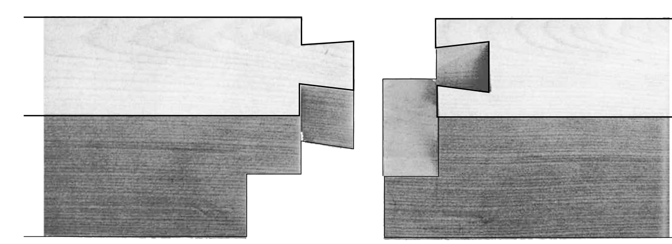
FIGURE 36 | Visual representation of the Step_02.

FIGURE 37 | Representation of interlocking joints types by [84].

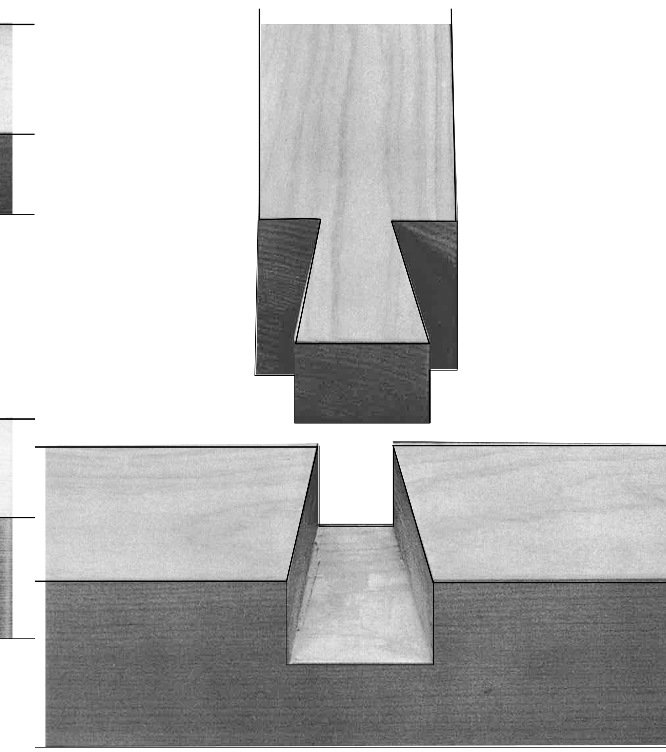
Interlocking joints types



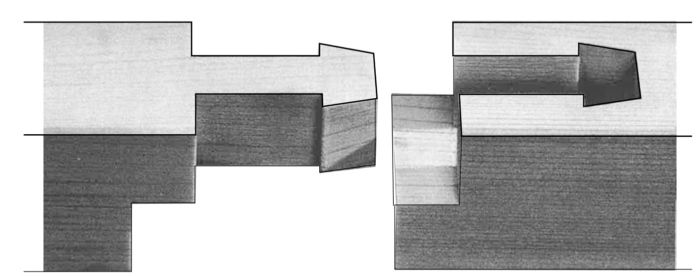
Stub tenon joint



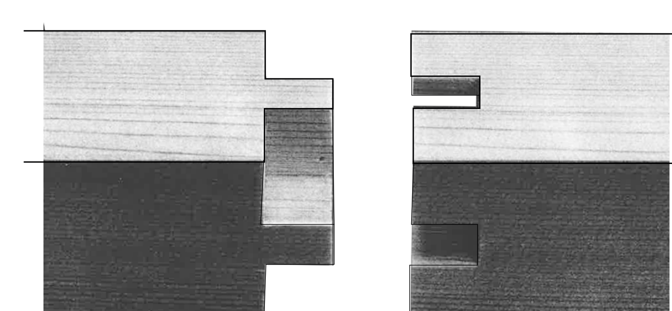
Dovetail lap joint



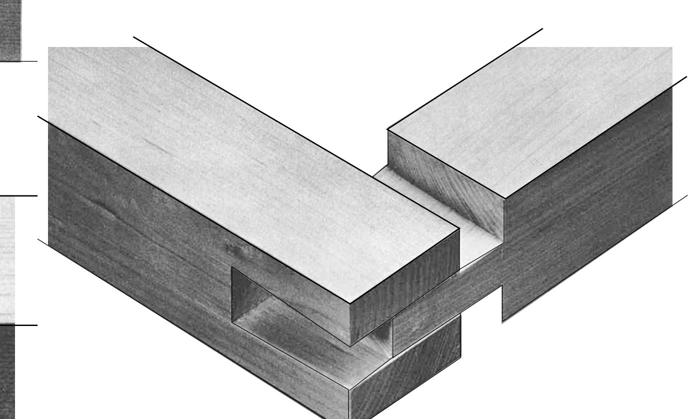
Dovetail joint



Lapped gooseneck mortise and tenon joint



Half blind L-shaped stub tenon



Open slot mortise

STEP_2: vertical joints study - marcapiano issue

Considering the architectural essence of the retrofit system, the existing solutions' research has shown a repetitive horizontal subdivision of the façade. This characteristic appearance is the consequence of the necessary connection of the retrofit system to the pre-existing slab. Each component of the envelope is fixed to the slab through metal connectors, behaving also as earthquake dissipator named friction dampers. On the other hand, the presence of such restrains make difficult a customization of the exterior cladding system. Furthermore, for fire safety regulations, it is always needed a non-bio-based break fire element which runs all around the building plane at each floor. An example of such component is Paraflam®. It is a non-combustible perimeter fire stop stone wool-based product with aluminium foil, for curtain walling and cavity barrier external rain-screen facades[23].

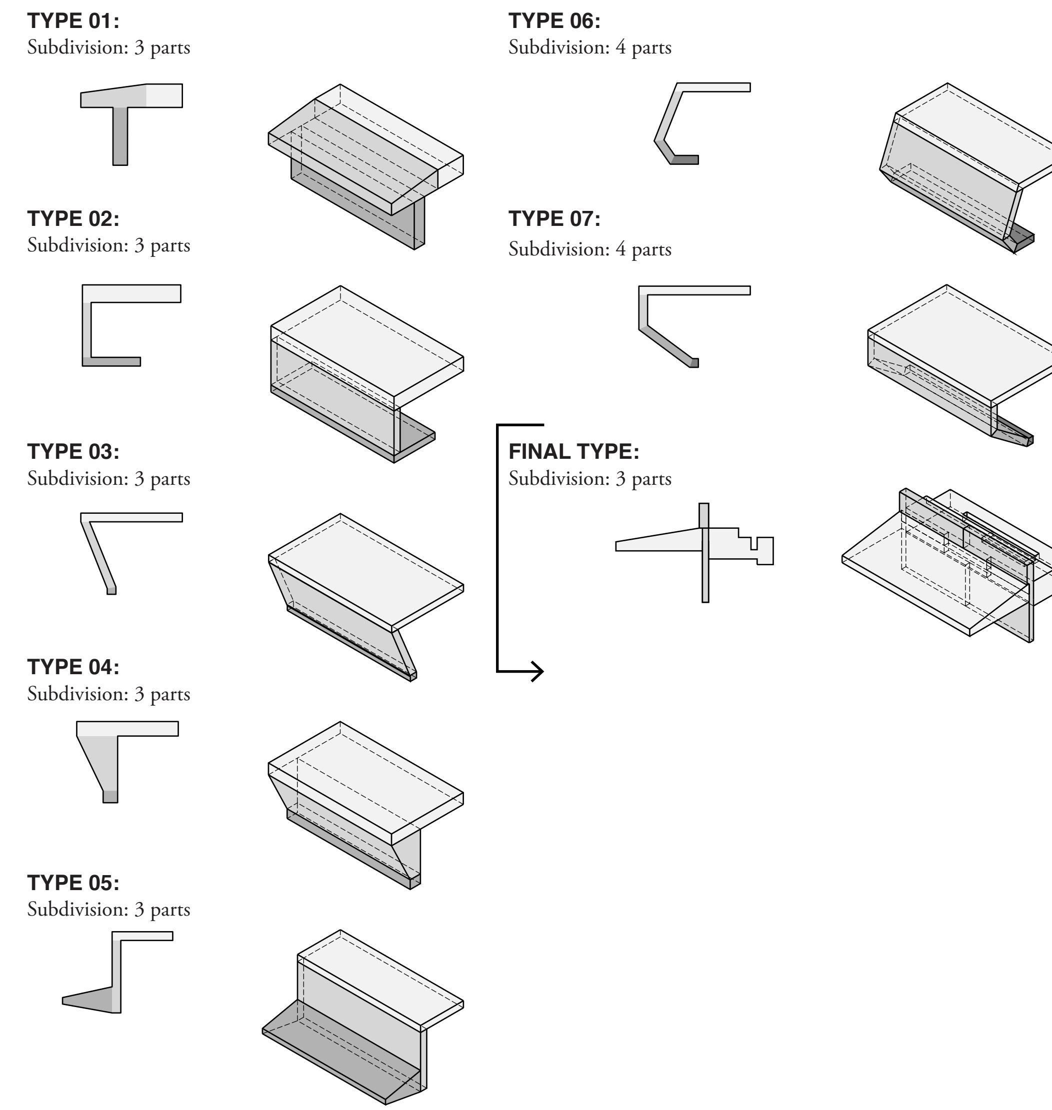
Hence, the typical horizontal subdivision of the panels in relation to the "marcapiano" has been studied.

The idea is to underline the marcapiano with a designed architectural element which also serves the purpose of removing water by integrating it with the protective flashing[24].

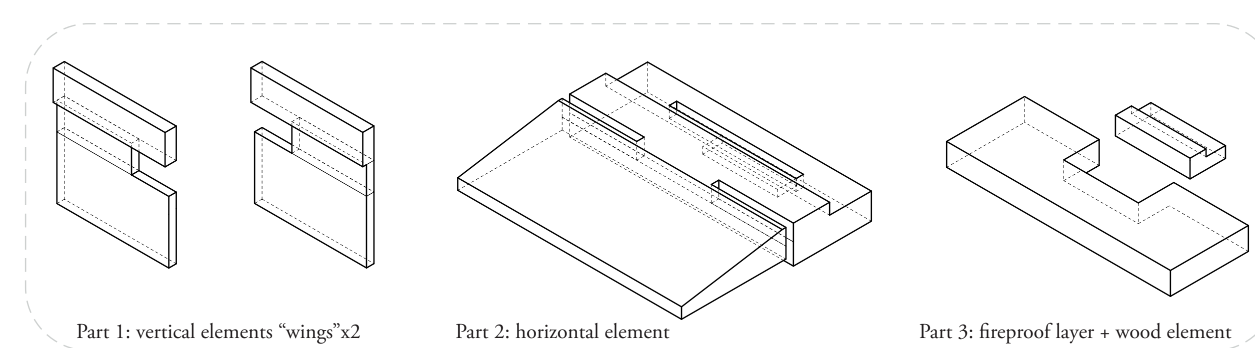
Taking advantage to timber interlocking joints, the marcapiano element constitute a unique system with the timber frame, optimizing the process of production, assembly and disassembly. Accordingly, the technological system become architecture, by condensing the duality of the aspects.

Several studies and trials have been made to optimize the result.

Marcapiano iterations



ELEMENTS:



23 | https://fsiltd.com/product/paraflam%C2%A8-seb/

24 | http://www.plbecs.com/flashing-assemblies.html

FIGURE 38 | Marcapiano form-finding and final version's elements.

STEP_3: connection between system and pre-existing RC slab

As underline in the previous step, the connections of the new retrofit system and the existing RC slabs is done with steel plates. The reason is connected to the necessity of strength of the system in case an earthquake occurs, dissipating the seismic action. These metal connectors are named friction dampers.

On one side the metal plates are connected to the RC slab, on the other side their function is to link the timber frame. The distance between each plate is 1200 mm.

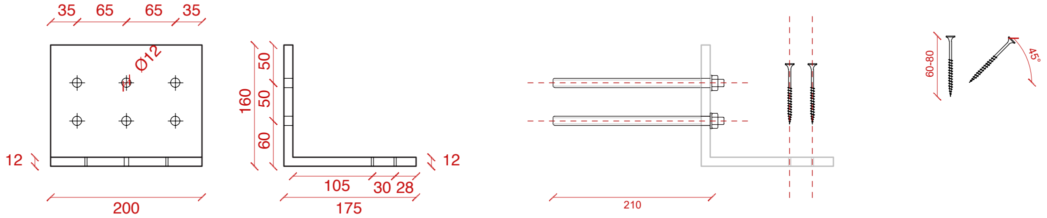


FIGURE 39 | Steel conenction types and dimenions.

STEP_4: insulation with bio-based materials

The energy layer of the system uses rice straw and rice husk to improve the overall performance.

Rice husk is the agricultural product resulting from the husking process of raw rice. It is similar in chemical composition to wood, consisting mainly of cellulose, lignin, minerals and silicates. Its production does not imply treatments or the addition of additives. It is an excellent material for pursuing energy efficiency in buildings. The low thermal conductivity value translates into a strong insulating capacity[25]. Moreover, the materials are obtained from the recovery of vegetable processing waste, closing the circular loop of lifecycle.

For the experimental prototype, two different components are considered.

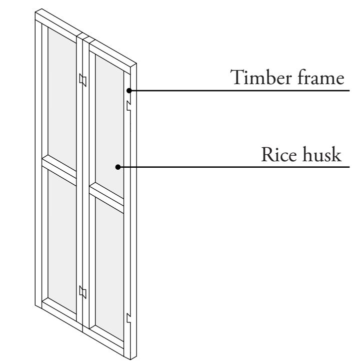
The internal layer of the retrofitted system, which is directly attached to the pre-existing wall, consists of 8 mm insulation coat. It is a semi-rigid panel composed by pre-compressed rice straw fibre with insulating, sound-absorbing and irregularities compensation properties. The reference component produced by Ricehouse is named RH50.

The second type of Ricehouse product taken as reference is RH-L. In this case, the rice husk is in free-form, meanings that it is not shaped in panels. As shown in the images below, it is inflated in cavities by a machine. It is inserted in between the timber frame, closed on one side by a fibreboard panel and on the other side by a gypsum plasterboard.

25 | https://www.ricehouse.it/

Basic modules

Timber frame + rice straw



Wall example

Timber frame + rice straw

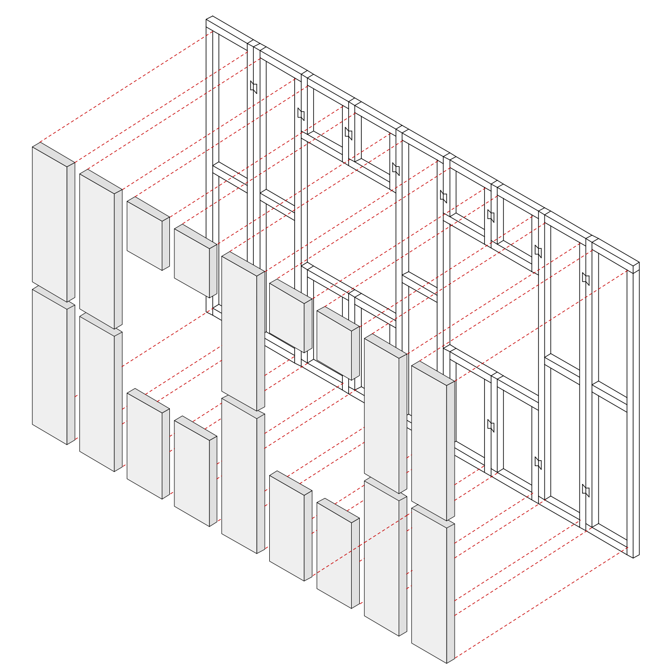
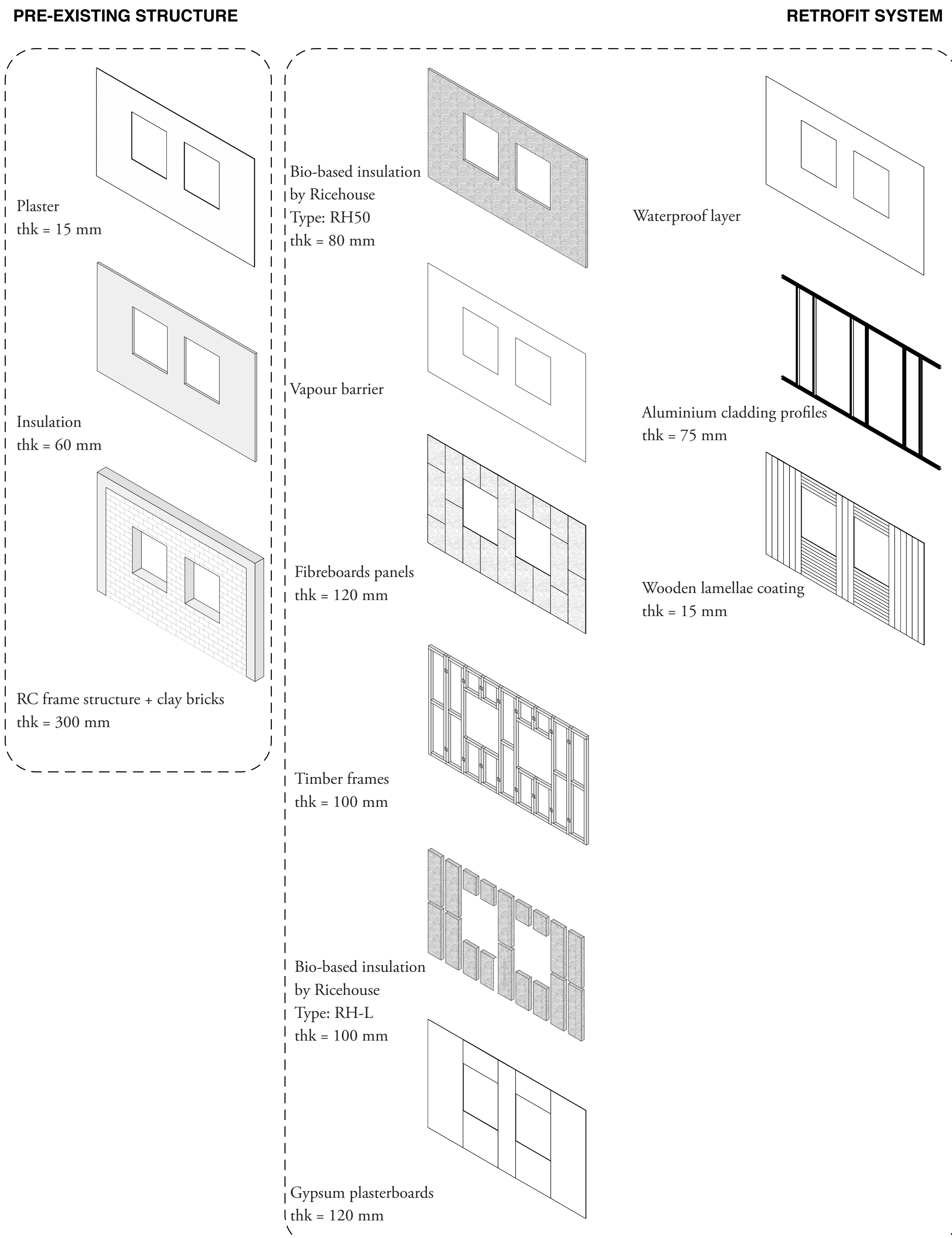


FIGURE 40 | Visual representation of the Step_04.

SYSTEM REPRESENTATION

LAYERING - system composition

Axonometry



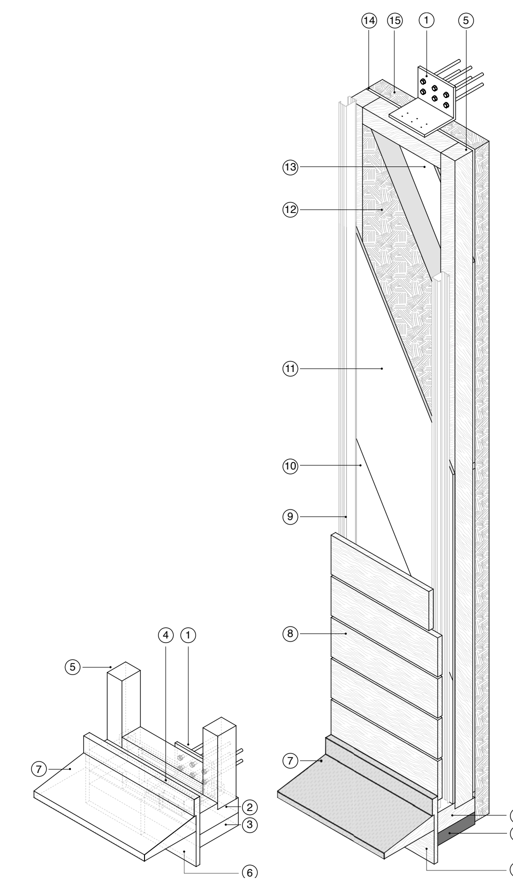
MODULARITY - technological system

Detailed axonometry - plan - section

Vertical panel (adjustable dims) + **Horizontal marcapiano** (adjustable dims) = **Prefabricated module**

Marcapiano detail - elements

1. metal plate connected to RC slab
2. horizontal timber element "marcapiano"
3. fire proofing layer type Paraflam©
4. filling timber element
5. timber frame (horizontal+vertical components)
6. vertical timber "wings"
7. waterproofing zinc foil
8. wood lamellae coating
9. aluminium cladding profiles
10. waterproof layer
11. gypsum plasterboard
12. bio-based insulation by Ricehouse | type: RH-L
13. fibreboard panels
14. vapour barrier
15. bio-based insulation by Ricehouse | type: RH50



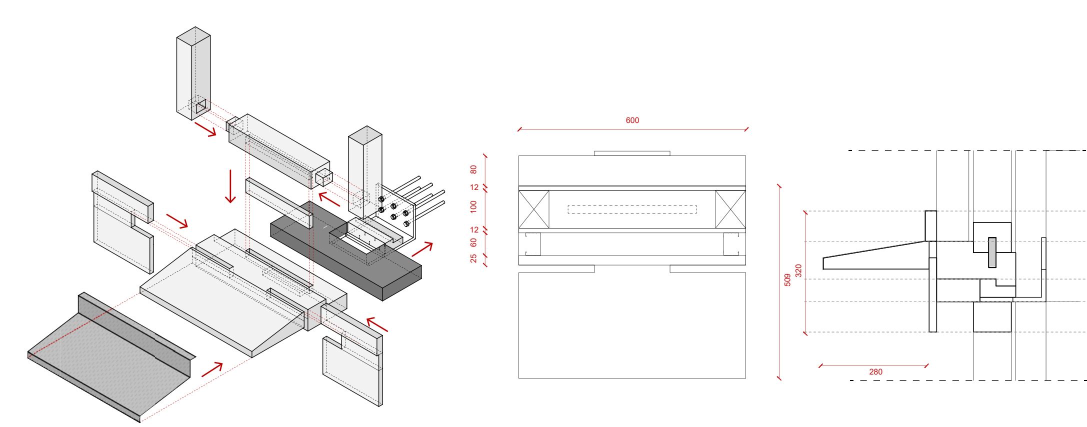


FIGURE 41 | Representation of pre-existing and retrofit layers.

FIGURE 42 | System module axonometry and marcapiano detail focus.

FIGURE 43 | Marcapiano detail assembly and dimensioning.

RETROFIT - dimensioning

Plans - elevations - sections

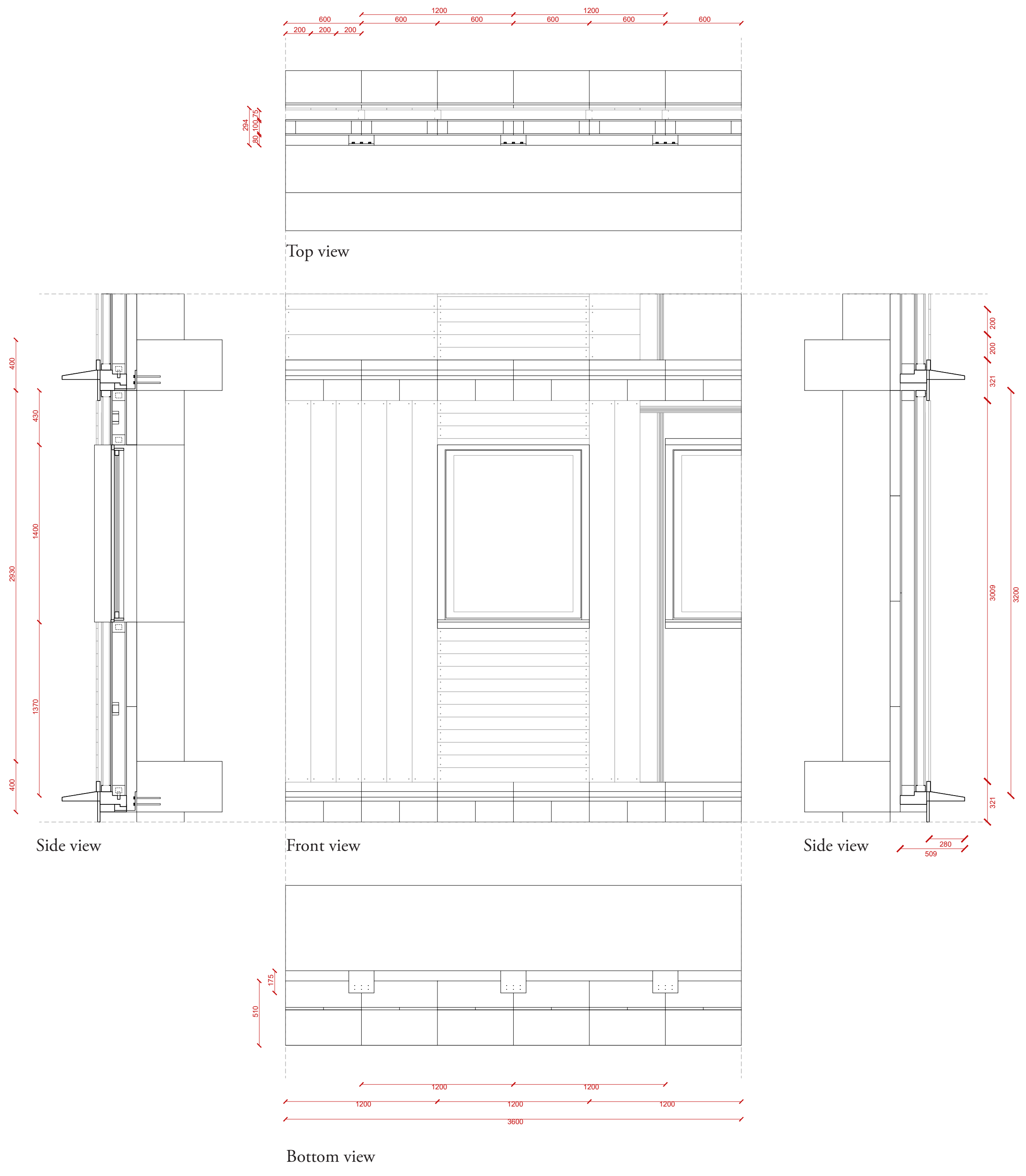


FIGURE 44 | Third angle projection with dimensioning of the facade system.

MODULARITY - technological system

Detailed axonometry

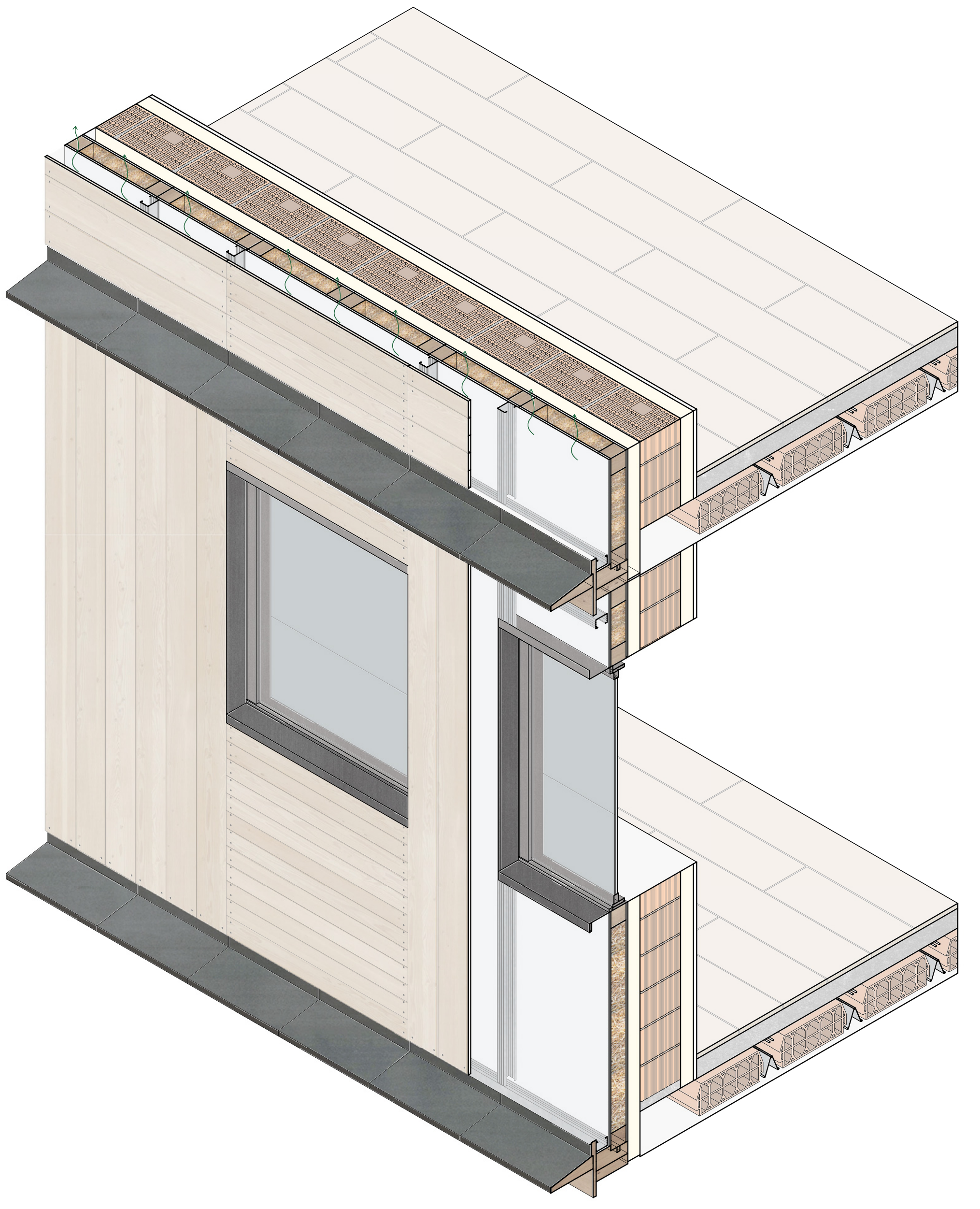


FIGURE 45 | Textured axonometry of the facade system connected to the pre-existing URM walls.

RETROFIT - technical and architectural system

Elevation + section

Materials:

Wood_douglas fir

External cladding - facade

Wood_oak

External cladding - marcapiano

Rice straw

insulation for coplanarity connection between pre-existing and retrofit system

Rice husk

insulation inside the timber frame system

Zinc

waterproof covering layer for the upper part of the marcapiano

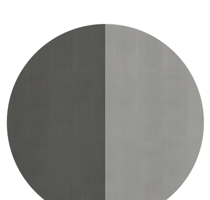
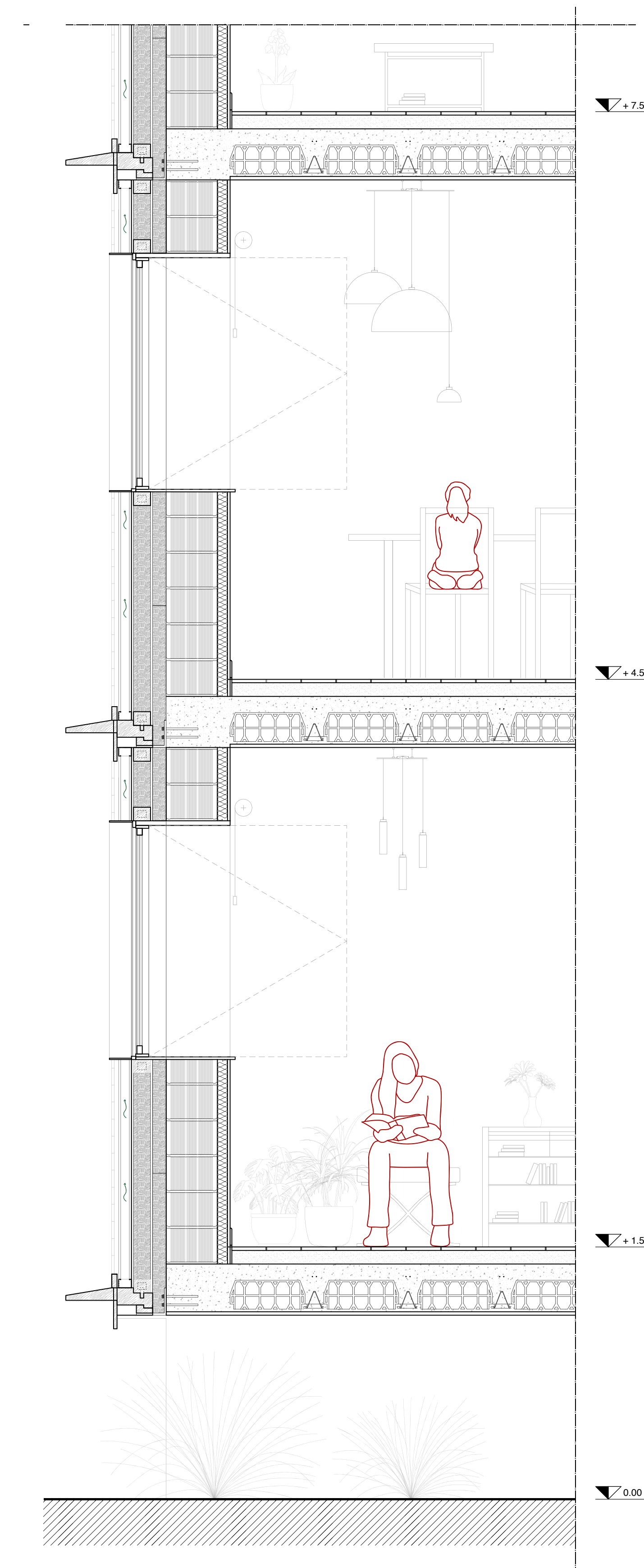


FIGURE 46 | Textured elevation of the facade system.

FIGURE 47 | Technical section of the facade system connected to the pre-existing URM walls.



4/ FINDINGS

The study of the theoretical background together with the research field analysis has set the basis for the experimental project of a technological-architectural component for the retrofit of the existing-non historical building stock.

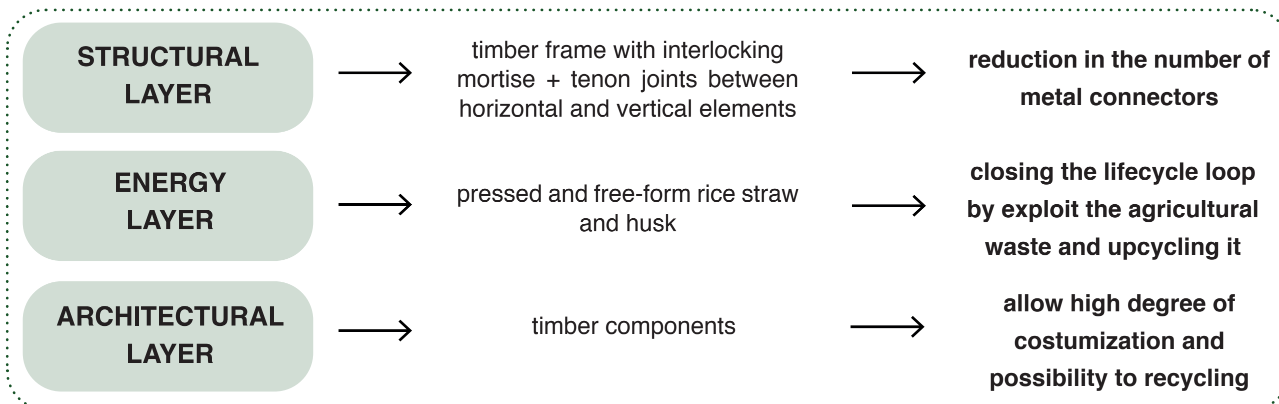
Each step has been propaedeutic for the succeeding one. The bibliographic research has helped setting the problem statement and the main objectives to proceed. It has founded the proper deep knowledge to progress in the following phases. Accordingly, the survey has been the way to understand in the real practice which are the questions coming from the actors who participate in the supply chain. By merging the information coming from the theory on one side and the practice on the other side, the prototyping phase has been reached.

Since the research questions set at the beginning of the work clearly stated, it is possible to evaluate the results obtained.

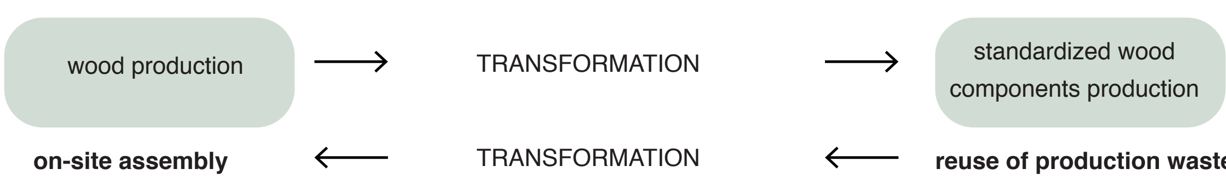
In general terms, the aim has been to understand how much impactful a large-scale application of bio-based materials in terms of sustainability could be. According to the outcomes reached in the first and second steps, the retrofit of the existing building stock is a valuable option to decrease energy requirements for buildings, ensuring a wide application of those materials.
Hence, the proposal of an optimized technological and architectural system to pursue the retrofit has been made.

What is important to emphasize it is the issue that the research it is not just about the last stages of design of the component, off-site production, and on-site assembly. Actually, this study aims to lead to a deeper consciousness of the interconnecting relationships between architects, engineers, first material transformation companies, components' producers, construction companies, standardization institutes, who all participate to the general goal of construction. Moreover, speaking in terms of sustainability, the contribution of each activity by lowering its environmental impact using natural resources, make such chain an interesting model study.

On the design side, the focus has been both on the structure layer and on the skin layer.



On the production side, the prefabrication has been stressed, increasing the pre-manufactured value of the components and allowing fast and easy on-site assembly. Together with standardization, they lead to circularity improvements.



Below the main results obtained.

- Design of a prefabricated system constituted by the vertical panel and horizontal element named "marcapiano", which constitute a unicum component easy to be assembled on the pre-existing structure, by decreasing the number of metal connectors.
- Connection between panel and marcapiano with interlocking joints.
- Connection between timber frame horizontal and vertical elements with mortise and tenon interlocking joints instead of metal components such as screws, plates, brackets.
- Connection between timber adjacent panels with dovetail interlocking joints and wood screws instead of metal components such as screws, plates, brackets.
- Use of bio-based insulation materials coming from harvesting rice waste, closing the lifecycle loop avoiding its disposal.

Considering the typical retrofit composition of timber frame systems already in the market, a reduction in the use of metal connectors can be underlined. In fact, timber frame components are assembled with screws, in a number which can vary from 18 to 24, according to the elements' dimension. Moreover, in the points of conjunctions between adjacent panels, other metal connectors, screws or clamps, are required. Hence, between 40 and 50 screws are needed to join timber elements, increasing both the costs and the quantity of non-bio-based materials.

Prototype system composition:
- Fibreboard panel. 8 screws
- Timber frame. 0 screws
- Gypsum plasterboard. 8 screws
- Metal profiles – Gypsum plasterboard. 12 screws
- Metal profiles - timber cladding. 60 screws
- Zinc foil. 6 screws
- Metal plate connection. 6 screws + 6 bolts

The retrofit proposal has tried to decrease the amount of metal elements needed, by applying traditional ancient techniques with contemporary design and fabrication tools.

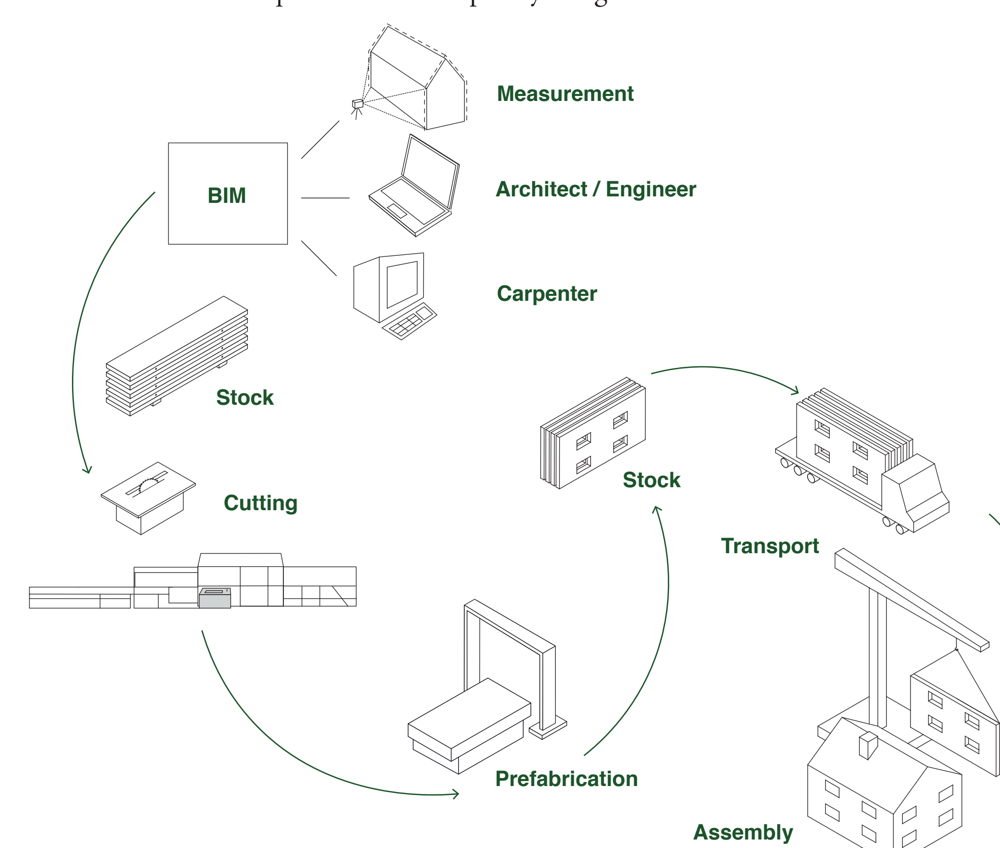


FIGURE 48 I Adaptation of prefabrication and installation process by [35].

5/ DISCUSSION AND FUTURE WORKS

To accelerate the transition and to meet the carbon budget limits required by 2050, it is necessary to increase the renovation rate of buildings in Europe. In fact, only with a drastic acceleration of the energy renovation of buildings, it would be possible to generate a significant benefit due to the carbon storage in the building stock [86].

The future direction of the construction sector should be connected to traditional construction methods applied to modern engineered science, capable in sustaining the global economy supply chains.

This study aiming at demonstrating that by designing for disassembly and by incorporating new circular economic strategies/principles from the early design phase, it is possible to show that there is a business case for converting today's model of demolition and downgrading of materials into a future model of disassembling and reusing of materials without degrading [15].

The scientific community is now responsible for studying strategies and methodologies to meet the EU targets on energy efficiency in buildings, as requested by the Directive (EU) 2018/844, with particular attention to the national building stock.

This study offers a general overview of the most common approaches tested in the field of building retrofits. Researchers are encouraged to develop faster, more reliable, flexible, and straightforward decision support systems to help asset holders to enhance existing stocks.

Some successful technological solutions are being developed (TES, BERTIM, MORE-CONNECT, CLT panel façade system). However, there has not been a general leading technique for the broader use of such solutions.

The above-mentioned prefabricated solutions have significant potential, yet there are still gaps in the process of optimizing them for the use of renewable materials. Moreover, industry-optimized processes increase cost-effectiveness reducing time on the construction sites in the building refurbishment. This could minimize mistakes, improve modules' quality, and reduce construction waste.

Differences in costs between retrofitting based on ETICS (External Thermal Insulation Composite System) and prefabricated panels are generally small; prefabricated panels can provide a higher standard of living since they may combine other characteristics beyond the thermal insulation function (mechanical ventilation, new heating piping, electrical wiring and other systems). However, such solutions have special requirements regarding worker skills and techniques needed for assembling the system that are somewhat more complex than standard practices.

Designing, building, and constructing new possibilities can often lead to the idea of a complete shift from the present conditions. At the same time, the review has shown that supply chain, industrial practices and legislative frameworks are pre-existing conditions that need to bond with new materials use.

Hence, this work is intended as the starting point to imagine a decision-making procedure for managing bio-based components in architecture that is not always straightforward.

Below the main outcomes from the analysis.

- Foster collaboration and transparency with partners and manufactures;
- Use local materials, when possible, to minimize environmental impact;
- Use certified materials, long lasting, from certain suppliers in and environmental conscious optic;
- Smart production with less materials waste characterized by prefabrication and modularity;
- Dry assembly and rapid dismantling without affecting its technical and aesthetic properties;
- Reuse and recycle of components and materials.

Nevertheless, a couple of open issues have been identified, with the chance to be developed more in future works.

POSSIBLE STEP_5: angled joints study, "corner" issue

The question of the angle in architecture has always been problematic, in the point where exterior panels come together, illustrating how the walls relate one to another. In general, the corner panels are special elements that are different from the rest of the elements that compose the façade. Two main ways of dealing with it can be developed: the building is covered by a uniform skin that emphasise the closed character of the building or the edge could make clear that two different walls are being joined, producing different effects. [29]

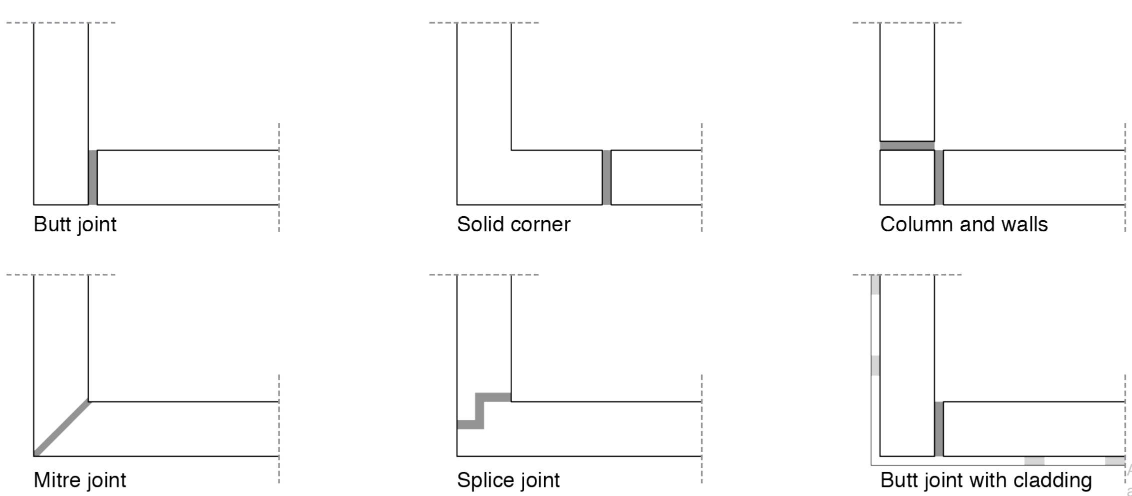


FIGURE 49 | Adaptation by the author of corner joint types.

POSSIBLE STEP_6: possibility of structural retrofit with steel tension rods

The general idea concerns post-tensioned timber systems. This technology takes advantage of unbonded post-tensioned steel tendons passing through internal cavities in timber beams or walls to create a moment resisting connection [87]. The integration between timber frame structure with steel bars would provide a structural hybrid system, combining different materials to reach high levels of stiffnesses.

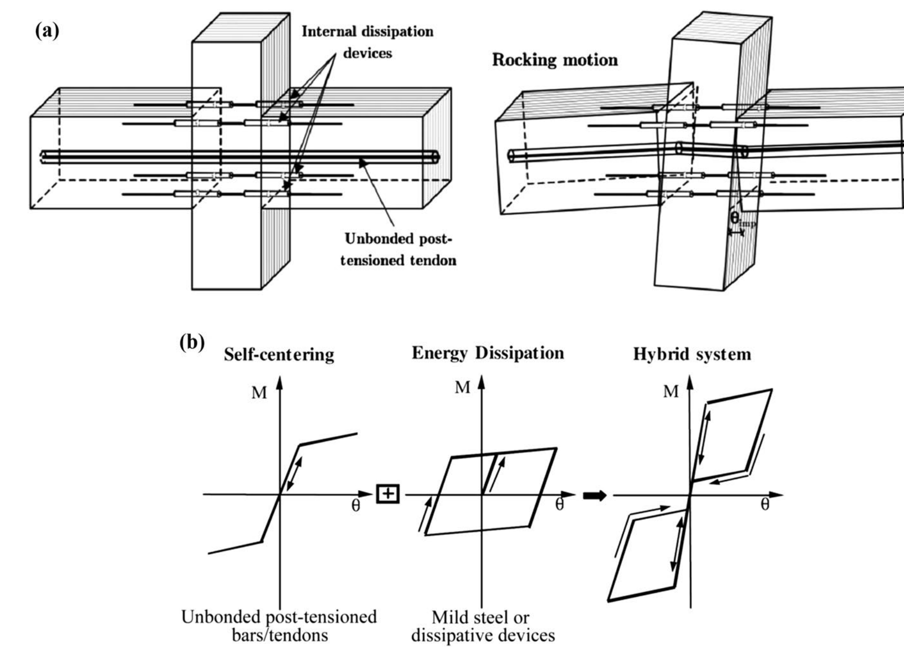


FIGURE 50 | Structural retrofit system by [85].

Herein, a highly flexible integrated façade system has been proposed. To achieve such a comprehensive objective, a deep and dense research through theoretical and practical examples has been necessary, underlined the essentiality of cross-disciplinary teamwork between all stakeholders, which should be involved from the early stages of the project.

However, such collaboration is often denied. In fact, an important issue is the fragmentation of the construction industry. Fostering collaboration and technical advancement is difficult, especially when involving new technologies which ideally would twist existing working methods.

Different from other industries, construction tasks have multiple steps, which involve numerous actors. Each construction phase is carried out by specific professionals with different interests. The absence of efficient communication and common goals stops such development. Moreover, building construction is dependant from on-site conditions, weather, professionals' skills, and the economic climate.

Therefore, promoting a new system requires close cooperation between stakeholders. Collaboration is extremely important when developing a new proposal of a system, oriented to the future market adoption. [72]

Nevertheless, auspicious news came from the interviews. In fact, in the wood industry, it is quite common to establish different partnership at each level of the supply chain. For example, first material transformation companies and components' producers work together with government and local authorities to recycle production waste.

"In the past we used to take the materials and put it into the litter. So, now we take it back and it is a quite good partnership now, between the suppliers and us. So, we've reduced the waste which is quite good."

Even between competitors there's the need to share ideas, building a common ground for the scale up of the sector. "If you share one idea that helps both companies but ultimately is about how the whole business operates and what your culture is. I think people should be more open to sharing ideas" have been said by a representative of Engineering firms.

Competition is seen as a good practice to improve and develop new standards.

There are several inspiring proposals which grow every day, a great number of professionals who push innovation, so more than new realities, there's the need of effective working tables. Meeting places for start-ups and entrepreneurs would help put ideas into circulation and create real synergies to foster research and development in a bio-based optic.

Appendix

A. Interview guide

For each interview, a guide has been followed.
The types of questions and the related thematic are different according to the actor of the supply chain interviewed.

Stakeholders:

- Architecture/Engineering firms;
- First material transformation companies;
- Component producers;
- Construction companies;
- Standardization institutes.

A. Interview guide

TOPIC 1: General overview

- How long have your company been present in the business?
- During the design phase, which are the actors in the supply chain with which you interact the most? Are you used to carry on R&D projects or innovation projects in collaboration with other actors?
- How do you deal with the increasing sustainability requests coming from the market?

TOPIC 2: Potentials and Benefits of the use of Timber/Bio-Based materials

- How much widespread are prefabricated timber solutions for new buildings and for the renovation of existing buildings nowadays?
- Who will be the main supporter for the introduction of these materials? Why? (Government, final customer, other companies, ...)
- Do you think that temporary solutions made with bio-based materials could represent a transition from the actual way of building/living toward a new modern way of building/living?

TOPIC 3: Challenges of the use of Timber/Bio-Based materials

3.1 Technical aspects

- Which is the most challenging problem that you're facing in the use of bio-based materials nowadays?
- Considering the benefits of timber constructions (prefabrication, lightness, resistance, biogenic percentage), what are, in your opinion, the most critical drawbacks to manage during the life cycle of a residential building?
- Which is the entity of the technological change to be faced by your company due to the widespread adoption of these new materials?
- Since the materials with biogenic composition are more degradable than traditional ones, do you think that the management of the maintenance phase will have to change? May it become an additional, self-sustained business?
- What are the specific interventions for bio-based material products compared to conventional products?

3.2 Economical aspects

- Is there an economical impact on the on the supplier and on the user side for the development of a sustainable project? Is the sustainability creating both an added value but also an added cost?

3.3 Environmental aspects

- Which are the most important challenges that your company is facing to reach a lower environmental impact? Why?
- Do you know the design philosophy Cradle 2 Cradle? Do you apply its principles systematically? What are the barriers preventing from the application of this design philosophy?
- How is the disassembly / maintenance / final destination of hybrid constructions (as concrete and timber structures) managed? How much is the Design for Disassembly philosophy applied?

3.4 Social/political aspects

- Which kind of social and political implication does the use of bio-based materials have?
- Do you think that the future users of your products will consider the presence of bio-based materials in their house as a key choice factor?
- Do you think that governments should do more to foster the use of new bio-based materials in the construction industry? (i.e. measures like "superbonus 110%") Or do you think the change in the industry should start from the companies and the governments should adapt to the new behaviors?

3.5 Specific aspects

- What are the differences in the design phase between temporary and permanent buildings (especially in terms of disassembly and recycling)? Does it imply the use of different technologies?
- During the design phase, are future maintenance activities already considered in order to facilitate their execution?

TOPIC 4: Supply Chain adaptations to accommodate more wood/Bio-Based materials

- Are there any new players that may help your company to respond to the growing demand of sustainable buildings? How could their involvement be incentivized?
- How important do you consider the need to certify the origin of the wood used? Does your company use FSC or PEFC certified wood? If yes, how challenging is it to obtain these certifications (in relation to the management system called Chain Of Custody)?

TOPIC 5: Business model

- Are customers willing to pay for more environmentally friendly solutions?
- Which partners does your company consider indispensable? How do you interact?

TOPIC 6: Certifications

- Considering all the documents (COP26 etc.) undertaken towards environmental sustainability issues and the resonance given to that these issues in the public opinion especially of young people, what are the practical steps that your company is taking to boost that change?
- What is your awareness of environmental impact certifications (EPD, C2C)? Are you familiar with them? Does your company apply them? Does their adoption have tangible impacts on business processes?
- How does the energy impact in a building change between using bio-based materials and traditional materials in construction? (LEED, BREEAM, WELL Certifications)
- Given that there are already several design constraints aimed at improving the performance of buildings, if LEED or BREEAM certification would become mandatory for new buildings, what would change in practical terms in the management of the construction project during all its phases?

TOPIC 7: Future perspectives

- What is your vision for the future development of the construction sector? And in detail, for the residential construction sector in Europe?
- With respect to bio-based materials, do you see potential for their wide application in the European context?
- BIM + LCA technology can push forward the integrated building management across all phases of a building's life. What is holding back the adoption of this technology in the Italian context? What differences from the Italian context make BIM adoption easier in Europe?
- According to your experience, which construction element/component/part made of bio-based material will have a bigger impact in the future on people's daily life?
- How much the cooperation between different actors is important?
- Are there any specific partner that you would like to work with?
- Are you available to participate in workshops for the future development of a sustainable construction sector?

A. Interview guide

TOPIC 1: General overview

- How long have your company been present in the business?
- Could you describe in a nutshell which is the contribution of your work / products in the building application? How many activities are you performing in your SC?
- Which are the actors in the supply chain with which you interact the most? Are you used to carry on R&D projects or innovation projects in collaboration with other actors?
- How do you deal with the increasing sustainability requests coming from the market?

TOPIC 2: Potentials and Benefits of the use of Timber/Bio-Based materials

- How much widespread are prefabricated timber solutions for new buildings and for the renovation of existing buildings nowadays?
- Who will be the main supporter for the introduction of these materials? Why? (Government, final customer, other companies, ...)
- Do you think the introduction of these materials may open new opportunities for your company? (New services example maintenance to be offered or complementary/new products)

TOPIC 3: Challenges of the use of Timber/Bio-Based materials

3.1 Technical aspects

- Which is the most challenging problem that you're facing in the use of bio-based materials nowadays?
- Considering the benefits of timber constructions (prefabrication, lightness, resistance, biogenic percentage), what are, in your opinion, the most critical drawbacks to manage during the life cycle of a residential building?
- Which is the entity of the technological change to be faced by your company due to the widespread adoption of these new materials?
- Since the materials with biogenic composition are more degradable than traditional ones, do you think that the management of the maintenance phase will have to change? May it become an additional, self-sustained business?
- What are the specific interventions for bio-based material products compared to conventional products?

3.2 Economical aspects

- Is there an economical impact on the on the supplier and on the user side for the development of a sustainable project? Is the sustainability creating both an added value but also an added cost?
- In broad terms, which is your cost structure? Which are your main cost items and your main sources of revenues?
- Which are your top-selling products?
- With the widespread usage of timber based or more in general bio-based materials, do you believe that your cost structure will change? How?

3.3 Environmental aspects

- Which are the most important challenges that your company is facing to reach a lower environmental impact? Why?
- Do you know the design philosophy Cradle 2 Cradle? Do you apply its principles systematically? What are the barriers preventing from the application of this design philosophy?
- How is the disassembly / maintenance / final destination of hybrid constructions (as concrete and timber structures) managed? How much is the Design for Disassembly philosophy applied?

3.4 Social/political aspects

- Which kind of social and political implication does the use of bio-based materials have?
- Do you think that the future users of your products will consider the presence of bio-based materials in their house as a key choice factor?
- Do you think that governments should do more to foster the use of new bio-based materials in the construction industry? (i.e. measures like "superbonus 110%") Or do you think the change in the industry should start from the companies and the governments should adapt to the new behaviors?

3.5 Specific aspects

- How do you manage the tree life cycle? In forest management, how are track and trace policies implemented? How easy is it to reconstruct the path of each tree according to its destination?
- Tree growth involves long waiting periods. Is there any risk sharing mechanisms with other actors in the chain? When does the sale of the product take place?

TOPIC 4: Supply Chain adaptations to accommodate more wood/Bio-Based materials

- Are there any new players that may help your company in answering the growing demand of sustainable buildings? How could their involvement be incentivized?
- How important do you consider the need to certify the origin of the wood used? Does your company use FSC or PEFC certified wood? If yes, how challenging is it to obtain these certifications (in relation to the management system called Chain Of Custody)?
- Do you think that an increased demand from the market of timber and bio-based materials can be managed by your Supply Chain?

TOPIC 5: Business model

- Are customers willing to pay for more environmentally friendly solutions?
- Which partners does your company consider indispensable? How do you interact?
- Do you think that to answer the new requests of the market it will be needed the development of new business models?
- Do you believe that a higher integration of biogenic materials will lead to a shrink or a stretch of the margin? Will the introduction of this new building material increase more the revenues or the costs?

TOPIC 6: Certifications

- Considering all the documents (COP26 etc.) undertaken towards environmental sustainability issues and the resonance given to that these issues in the public opinion especially of young people, what are the practical steps that your company is taking to boost that change?
- What is your awareness of environmental impact certifications (EPD, C2C)? Are you familiar with them? Does your company apply them? Does their adoption have tangible impacts on business processes?
- How does the energy impact in a building change between using bio-based materials and traditional materials in construction? (LEED, BREEAM, WELL Certifications)
- Given that there are already several design constraints aimed at improving the performance of buildings, if LEED or BREEAM certification would become mandatory for new buildings, what would change in practical terms in the management of the construction project during all its phases?

TOPIC 7: Future perspectives

- What is your vision for the future development of the construction sector? And in detail, for the residential construction sector in Europe?
- With respect to bio-based materials, do you see potential for their wide application in the European context?
- BIM + LCA technology can push forward the integrated building management across all phases of a building's life. What is holding back the adoption of this technology in the Italian context? What differences from the Italian context make BIM adoption easier in Europe?
- According to your experience, which construction element/component/part made of bio-based material will have a bigger impact in the future on people's daily life?
- How much the cooperation between different actors is important?
- Are there any specific partner that you would like to work with?
- Are you available to participate in workshops for the future development of a sustainable construction sector?

A. Interview guide

TOPIC 1: General overview

- How long have your company been present in the business?
- Could you describe in a nutshell which is the contribution of your work / products in the building application? How many activities are you performing in your SC?
- Which are the actors in the supply chain with which you interact the most? Are you used to carry on R&D projects or innovation projects in collaboration with other actors?
- How do you deal with the increasing sustainability requests coming from the market?

TOPIC 2: Potentials and Benefits of the use of Timber/Bio-Based materials

- How much widespread are prefabricated timber solutions for new buildings and for the renovation of existing buildings nowadays?
- Who will be the main supporter for the introduction of these materials? Why? (Government, final customer, other companies, ...)
- Do you think the introduction of these materials may open new opportunities for your company? (New services example maintenance to be offered or complementary/new products)

TOPIC 3: Challenges of the use of Timber/Bio-Based materials

3.1 Technical aspects

- Which is the most challenging problem that you're facing in the use of bio-based materials nowadays?
- Considering the benefits of timber constructions (prefabrication, lightness, resistance, biogenic percentage), what are, in your opinion, the most critical drawbacks to manage during the life cycle of a residential building?
- Which is the entity of the technological change to be faced by your company due to the widespread adoption of these new materials?
- Since the materials with biogenic composition are more degradable than traditional ones, do you think that the management of the maintenance phase will have to change? May it become an additional, self-sustained business?
- What are the specific interventions for bio-based material products compared to conventional products?

3.2 Economical aspects

- Is there an economical impact on the on the supplier and on the user side for the development of a sustainable project? Is the sustainability creating both an added value but also an added cost?
- In broad terms, which is your cost structure? Which are your main cost items and your main sources of revenues?
- Which are your top-selling products?
- With the widespread usage of timber based or more in general bio-based materials, do you believe that your cost structure will change? How?

3.3 Environmental aspects

- Which are the most important challenges that your company is facing to reach a lower environmental impact? Why?
- Do you know the design philosophy Cradle 2 Cradle? Do you apply its principles systematically? What are the barriers preventing from the application of this design philosophy?
- How is the disassembly / maintenance / final destination of hybrid constructions (as concrete and timber structures) managed? How much is the Design for Disassembly philosophy applied?

3.4 Social/political aspects

- Which kind of social and political implication does the use of bio-based materials have?
- Do you think that the future users of your products will consider the presence of bio-based materials in their house as a key choice factor?
- Do you think that governments should do more to foster the use of new bio-based materials in the construction industry? (i.e. measures like "superbonus 110%") Or do you think the change in the industry should start from the companies and the governments should adapt to the new behaviors?

3.5 Specific aspects

- How much important is the disassembly/replacement phase during the development of new components? Do you have already developed specific solutions for the reuse/recycling of your components?

TOPIC 4: Supply Chain adaptations to accommodate more wood/Bio-Based materials

- Are there any new players that may help your company in answering the growing demand of sustainable buildings? How could their involvement be incentivized?
- How important do you consider the need to certify the origin of the wood used? Does your company use FSC or PEFC certified wood? If yes, how challenging is it to obtain these certifications (in relation to the management system called Chain Of Custody)?
- Do you think that an increased demand from the market of timber and bio-based materials can be managed by your Supply Chain?

TOPIC 5: Business model

- Are customers willing to pay for more environmentally friendly solutions?
- Which partners does your company consider indispensable? How do you interact?
- Do you think that to answer the new requests of the market it will be needed the development of new business models?
- Do you believe that a higher integration of biogenic materials will lead to a shrink or a stretch of the margin? Will the introduction of this new building material increase more the revenues or the costs?

TOPIC 6: Certifications

- Considering all the documents (COP26 etc.) undertaken towards environmental sustainability issues and the resonance given to that these issues in the public opinion especially of young people, what are the practical steps that your company is taking to boost that change?
- What is your awareness of environmental impact certifications (EPD, C2C)? Are you familiar with them? Does your company apply them? Does their adoption have tangible impacts on business processes?
- How does the energy impact in a building change between using bio-based materials and traditional materials in construction? (LEED, BREEAM, WELL Certifications)
- Given that there are already several design constraints aimed at improving the performance of buildings, if LEED or BREEAM certification would become mandatory for new buildings, what would change in practical terms in the management of the construction project during all its phases?

TOPIC 7: Future perspectives

- What is your vision for the future development of the construction sector? And in detail, for the residential construction sector in Europe?
- With respect to bio-based materials, do you see potential for their wide application in the European context?
- BIM + LCA technology can push forward the integrated building management across all phases of a building's life. What is holding back the adoption of this technology in the Italian context? What differences from the Italian context make BIM adoption easier in Europe?
- According to your experience, which construction element/component/part made of bio-based material will have a bigger impact in the future on people's daily life?
- How much the cooperation between different actors is important?
- Are there any specific partner that you would like to work with?
- Are you available to participate in workshops for the future development of a sustainable construction sector?

A. Interview guide

TOPIC 1: General overview

- How long have your company been present in the business?
- Could you describe in a nutshell which is the contribution of your work / products in the building application? How many activities are you performing in your SC?
- Which are the actors in the supply chain with which you interact the most? Are you used to carry on R&D projects or innovation projects in collaboration with other actors?
- How do you deal with the increasing sustainability requests coming from the market?

TOPIC 2: Potentials and Benefits of the use of Timber/Bio-Based materials

- How much widespread are prefabricated timber solutions for new buildings and for the renovation of existing buildings nowadays?
- Who will be the main supporter for the introduction of these materials? Why? (Government, final customer, other companies, ...)
- Do you think the introduction of these materials may open new opportunities for your company? (New services example maintenance to be offered or complementary/new products)

TOPIC 3: Challenges of the use of Timber/Bio-Based materials

3.1 Technical aspects

- Which is the most challenging problem that you're facing in the use of bio-based materials nowadays?
- Considering the benefits of timber constructions (prefabrication, lightness, resistance, biogenic percentage), what are, in your opinion, the most critical drawbacks to manage during the life cycle of a residential building?
- Which is the entity of the technological change to be faced by your company due to the widespread adoption of these new materials?
- Since the materials with biogenic composition are more degradable than traditional ones, do you think that the management of the maintenance phase will have to change? May it become an additional, self-sustained business?
- What are the specific interventions for bio-based material products compared to conventional products?

3.2 Economical aspects

- Is there an economical impact on the on the supplier and on the user side for the development of a sustainable project? Is the sustainability creating both an added value but also an added cost?
- In broad terms, which is your cost structure? Which are your main cost items and your main sources of revenues?
- Which are your top-selling products?
- With the widespread usage of timber based or more in general bio-based materials, do you believe that your cost structure will change? How?

3.3 Environmental aspects

- Which are the most important challenges that your company is facing to reach a lower environmental impact? Why?
- Do you know the design philosophy Cradle 2 Cradle? Do you apply its principles systematically? What are the barriers preventing from the application of this design philosophy?
- How is the disassembly / maintenance / final destination of hybrid constructions (as concrete and timber structures) managed? How much is the Design for Disassembly philosophy applied?

3.4 Social/political aspects

- Which kind of social and political implication does the use of bio-based materials have?
- Do you think that the future users of your products will consider the presence of bio-based materials in their house as a key choice factor?
- Do you think that governments should do more to foster the use of new bio-based materials in the construction industry? (i.e. measures like "superbonus 110%") Or do you think the change in the industry should start from the companies and the governments should adapt to the new behaviors?

3.5 Specific aspects

- From the constructive point of view, what does it change for a terraced house and a multi-unit house? And between a temporary and a permanent building?
- How important is it to propose an integrated site management system (BIM) for sustainability? What is the most relevant management aspect that differentiates a construction site using prefabricated wood technologies from traditional building systems?

TOPIC 4: Supply Chain adaptations to accommodate more wood/Bio-Based materials

- Are there any new players that may help your company in answering the growing demand of sustainable buildings? How could their involvement be incentivized?
- How important do you consider the need to certify the origin of the wood used? Does your company use FSC or PEFC certified wood? If yes, how challenging is it to obtain these certifications (in relation to the management system called Chain Of Custody)?
- Do you think that an increased demand from the market of timber and bio-based materials can be managed by your Supply Chain?

TOPIC 5: Business model

- Are customers willing to pay for more environmentally friendly solutions?
- Which partners does your company consider indispensable? How do you interact?
- Do you think that to answer the new requests of the market it will be needed the development of new business models?
- Do you believe that a higher integration of biogenic materials will lead to a shrink or a stretch of the margin? Will the introduction of this new building material increase more the revenues or the costs?

TOPIC 6: Certifications

- Considering all the documents (COP26 etc.) undertaken towards environmental sustainability issues and the resonance given to that these issues in the public opinion especially of young people, what are the practical steps that your company is taking to boost that change?
- What is your awareness of environmental impact certifications (EPD, C2C)? Are you familiar with them? Does your company apply them? Does their adoption have tangible impacts on business processes?
- How does the energy impact in a building change between using bio-based materials and traditional materials in construction? (LEED, BREEAM, WELL Certifications)
- Given that there are already several design constraints aimed at improving the performance of buildings, if LEED or BREEAM certification would become mandatory for new buildings, what would change in practical terms in the management of the construction project during all its phases?

TOPIC 7: Future perspectives

- What is your vision for the future development of the construction sector? And in detail, for the residential construction sector in Europe?
- With respect to bio-based materials, do you see potential for their wide application in the European context?
- BIM + LCA technology can push forward the integrated building management across all phases of a building's life. What is holding back the adoption of this technology in the Italian context? What differences from the Italian context make BIM adoption easier in Europe?
- According to your experience, which construction element/component/part made of bio-based material will have a bigger impact in the future on people's daily life?
- How much the cooperation between different actors is important?
- Are there any specific partner that you would like to work with?
- Are you available to participate in workshops for the future development of a sustainable construction sector?

A. Interview guide

TOPIC 1: General overview

- How long have your company been present in the business?
- Could you describe in a nutshell which is the contribution of your work / products in the building application? How many activities are you performing in your SC?
- Which are the actors in the supply chain with which you interact the most? Are you used to carry on R&D projects or innovation projects in collaboration with other actors?
- How do you deal with the increasing sustainability requests coming from the market?

TOPIC 2: Potentials and Benefits of the use of Timber/Bio-Based materials

- How much widespread are prefabricated timber solutions for new buildings and for the renovation of existing buildings nowadays?
- Who will be the main supporter for the introduction of these materials? Why? (Government, final customer, other companies, ...)
- Do you think the introduction of these materials may open new opportunities for your company? (New services example maintenance to be offered or complementary/new products)

TOPIC 3: Challenges of the use of Timber/Bio-Based materials

3.1 Technical aspects

- Which is the most challenging problem that you're facing in the use of bio-based materials nowadays?
- Considering the benefits of timber constructions (prefabrication, lightness, resistance, biogenic percentage), what are, in your opinion, the most critical drawbacks to manage during the life cycle of a residential building?
- Which is the entity of the technological change to be faced by your company due to the widespread adoption of these new materials?
- Since the materials with biogenic composition are more degradable than traditional ones, do you think that the management of the maintenance phase will have to change? May it become an additional, self-sustained business?
- What are the specific interventions for bio-based material products compared to conventional products?

3.2 Economical aspects

- Is there an economical impact on the on the supplier and on the user side for the development of a sustainable project? Is the sustainability creating both an added value but also an added cost?
- In broad terms, which is your cost structure? Which are your main cost items and your main sources of revenues?
- Which are your top-selling products?
- With the widespread usage of timber based or more in general bio-based materials, do you believe that your cost structure will change? How?

3.3 Environmental aspects

- Which are the most important challenges that your company is facing to reach a lower environmental impact? Why?
- Do you know the design philosophy Cradle 2 Cradle? Do you apply its principles systematically? What are the barriers preventing from the application of this design philosophy?
- How is the disassembly / maintenance / final destination of hybrid constructions (as concrete and timber structures) managed? How much is the Design for Disassembly philosophy applied?

3.4 Social/political aspects

- Which kind of social and political implication does the use of bio-based materials have?
- Do you think that the future users of your products will consider the presence of bio-based materials in their house as a key choice factor?
- Do you think that governments should do more to foster the use of new bio-based materials in the construction industry? (i.e. measures like "superbonus 110%") Or do you think the change in the industry should start from the companies and the governments should adapt to the new behaviors?

TOPIC 4: Supply Chain adaptations to accommodate more wood/Bio-Based materials

- Are there any new players that may help your company in answering the growing demand of sustainable buildings? How could their involvement be incentivized?
- How important do you consider the need to certify the origin of the wood used? Does your company use FSC or PEFC certified wood? If yes, how challenging is it to obtain these certifications (in relation to the management system called Chain Of Custody)?
- Do you think that an increased demand from the market of timber and bio-based materials can be managed by your Supply Chain?

TOPIC 5: Business model

- Are customers willing to pay for more environmentally friendly solutions?
- Which partners does your company consider indispensable? How do you interact?
- Do you think that to answer the new requests of the market it will be needed the development of new business models?
- Do you believe that a higher integration of biogenic materials will lead to a shrink or a stretch of the margin? Will the introduction of this new building material increase more the revenues or the costs?

TOPIC 6: Certifications

- Considering all the documents (COP26 etc.) undertaken towards environmental sustainability issues and the resonance given to that these issues in the public opinion especially of young people, what are the practical steps that your company is taking to boost that change?
- What is your awareness of environmental impact certifications (EPD, C2C)? Are you familiar with them? Does your company apply them? Does their adoption have tangible impacts on business processes?
- How does the energy impact in a building change between using bio-based materials and traditional materials in construction? (LEED, BREEAM, WELL Certifications)
- Given that there are already several design constraints aimed at improving the performance of buildings, if LEED or BREEAM certification would become mandatory for new buildings, what would change in practical terms in the management of the construction project during all its phases?
- Is there any support provided by you especially to small companies for the construction of buildings that meet the guidelines developed? (i.e.: a consultant assigned to the project/applicant company; moments of review and joint creation of a roadmap; ...)
- What are the main barriers related to standards adoption? What are the drivers?
- Do you think that mandatory certification and the need for a design that integrates the use phase and the end of life of the product could lead to the inclusion of new players in the supply chain? In which areas could new players be involved?

TOPIC 7: Future perspectives

- What is your vision for the future development of the construction sector? And in detail, for the residential construction sector in Europe?
- With respect to bio-based materials, do you see potential for their wide application in the European context?
- BIM + LCA technology can push forward the integrated building management across all phases of a building's life. What is holding back the adoption of this technology in the Italian context? What differences from the Italian context make BIM adoption easier in Europe?
- According to your experience, which construction element/component/part made of bio-based material will have a bigger impact in the future on people's daily life?
- How much the cooperation between different actors is important?
- Are there any specific partner that you would like to work with?
- Are you available to participate in workshops for the future development of a sustainable construction sector?

B. Interview transcript

Each interview has been recorded and transcribed. The data and information provided have been treated confidentially and no specific information has been disclosed without prior permission.

C. Data sheets

Attached below:

- Ricehouse CAM certificatio;
- Ricehouse product: RH50;
- Ricehouse product: RH-L.

SODDISFA I REQUISITI DEL SUPER-ECOBONUS 100%

C.A.M Compliant

DECRETO RILANCIO 2020 – INTRODUCE IL RISPETTO DEI REQUISTI PREVISTI DAI CAM, SEZIONE 2.4, COME CRITERI DI ACCESSO ALL'SUPER ECOBONUS 110% CON VALIDITA' FINO AL 31 DICEMBRE 2021.

DICHIARAZIONE COMPATIBILITA' CAM PRODOTTI RICEHOUSE

Con la presente Ricehouse S.r.l. SB dichiaria che:

I materiali biocomposti **RH** risultano di fatto compatibili alle definizioni introdotte dalla normativa vigente in termini di Criteri Ambientali Minimi e per questo **definiti CAM Compliant.**
I prodotti finiti sono completamente naturali, sono costituiti da materie prime rinnovabili ed impiegano i **sottoprodotti recuperati dalla filiera risicola**. La lolla e la paglia, infatti, rientrano nell'elenco dei materiali di cui il **D.M. 16 Ottobre 2016, n°264** e soddisfano le condizioni generali cui l'art. 184-bis del D.lgs 152/2006 (Testo Unico dell'Ambiente). Secondo quanto previsto dalla tabella del paragrafo 2.4.2.9 comma 6 (DM 11/10/2017), i nostri prodotti a base di scarti di riso **non sono soggetti alla valutazione della quantità minima di riciclato**.

SUPER–ECOBONUS 110%: I CRITERI AMBIENTALI MINIMI (CAM)

Il Superbonus, grazie al **Decreto Rilancio 2020 (D.L.n. 34/2020)**, promuove attività di riduzione del fabbisogno energetico degli edifici privati grazie all'**agevolazione fiscale del 110%**. Tra i numerosi requisiti richiesti il decreto impone che l'impiego di **materiali isolanti per il raggiungimento dei livelli di efficientamento debba rispondere ai requisiti previsti dai CAM**, con particolare riferimento ai requisiti del **paragrafo 2.4**.
I Criteri ambientali minimi, in vigore dal 2017, hanno introdotto delle **limitazioni nell'uso di materiali particolarmente inquinanti** allo scopo di ridurre l'impatto ambientale sulle risorse naturali e **promuovere il recupero dei rifiuti**, con particolare riguardo per i rifiuti da demolizione e costruzione.
A tale proposito **i nostri biocomposti**, in base ai requisiti previsti dal DM 11/10/2017 (CAM), rispondono ai criteri di:

2.4.1.1. DISASSEMBLABILITÀ	Le procedure di assemblaggio, composizione e prefabbricazione rendono le nostre stratigrafie disassemblabili e sottoponibili a demolizione selettiva, riciclo e riutilizzo.
2.4.1.2. ASSENZA SOSTANZE PERICOLOSE	I prodotti vengono realizzati miscelando lolla, pula e paglia di riso con leganti completamente naturali privi di formaldeide e di materiali derivanti dalla petrolchimica.
2.4.2.9. MATERIALI ISOLANTI	- Non sono prodotti con ritardante di fiamma - Non sono prodotti con agenti espandenti con una riduzione dell'ozono superiore a zero - Non sono prodotti utilizzando catalizzatori al piombo - Non hanno resine di polistirene espandibili - Non sono costituiti da lane minerali - Il prodotto finito non contiene cellulosa, lana di vetro, lana di roccia, perlite espansa, polistirene espanso, polistirene estruso, poliuretene espanso, Agglomerato di poliuretano, Agglomerati di gomma, Isolante riflettente d'alluminio.
2.6.4.1. UTILIZZO DI MATERIE PRIME RINNOVABILI	Le materie prime utilizzate nella realizzazione dei prodotti sono biodegradabili e si rinnovano annualmente.

ricehouse srl SB
via Aosta, 4
20155 Milano, (MI) - Italia

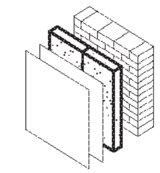
Tel. + 39 329 1869562
info@ricehouse.eu
www.ricehouse.it

rice house
riso per l'architettura

Ultimo aggiornamento 11/20

Scheda tecnica

RH50



Dimensioni

120 x 60 cm x 45-200 mm

Dati operativi

- Spessore: 45-200 mm.
- Dimensione del pannello: 120 x 60 cm
- Dimensione del bancale carico: 120 x 120 cm x 255 cm

PANNELLO ISOLANTE

Pannello isolante semi-rigido in paglia di riso.

Componenti

RH50 è una composizione formata dal 92% di fibre di paglia di riso, unite tra loro dall'8% di fibre termofusibili in poliestere a formare un materassino semirigido isolante.

Descrizione del prodotto

Il pannello isolante RH50 è formato da materiale raccolto dal campo e direttamente utilizzato. È progettato per nuove costruzioni, ma è adatto anche per ristrutturazioni termiche e igrometriche di edifici esistenti. Garantendo ottime prestazioni di isolamento termico e acustico, trova applicazione in molti spazi della progettazione. Sano, senza impatto sulla salute, termicamente ed acusticamente efficiente, assicura anche un mantenimento della forma nel tempo. A livello di durabilità, questa fibra vegetale, intrinsecamente a basso tenore di carbonio, è estremamente resistente al deterioramento.

Caratteristiche tecniche

Composizione	92% paglia di riso 8% legante, fibra hot melt
Conducibilità termica	$\lambda_{10\,dry}$ 0,039 (W/mK)
Conducibilità termica Dichiarata	λ_D 0,045 (W/mK)
Resistenza alla diffusione del vapore acqueo	μ 2,8 (-)
Capacità di assorbimento acustico	0,5 < aw < 0,9 (in base allo spessore)
Densità	50 (kg/m³)
Calore specifico	1790 (J/kgK)
Reazione al fuoco	Euroclass E
Qualità dell'aria interna	A+
COV (composti organici volatili) e aldeidi	non emette sostanze iquinanti volatili ne cancerogene

Abbattimento acustico Rw (C; Ctr)

Parete con struttura in legno: OSB, RH50 _ 45 mm, barriera al vapore e finitura interna		
Cartongesso 13 mm in poi	traversine in legno	46 (-1 ;-5) dB
	struttura in metallo	47 (-1 ;-5) dB
Fermacell 12,5 mm in poi	traversine in legno	47 (-1 ;-4) dB
	struttura in metallo	48 (-1 ;-4) dB
Partizione di distribuzione: Struttura metallica, cartongesso 13 mm per lato, RH50 _ 45 mm al centro		48 (-1 ;-4) dB

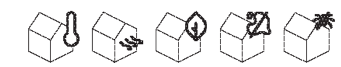
Forte potere di assorbimento acustico

RH50 _ 45 mm: w = 0.5 (H), classe D
RH50 _ 60 mm: w ≥ 0.9 (H), classe A
RH50 _ 100 mm: w = 0.6 (H), classe C
RH50 _ 120 mm e più spesso: w = 0.8 (H), classe B

I dati riportati si riferiscono a prove realizzate dal laboratorio CMR snc (VI); nelle applicazioni pratiche di cantiere questi possono essere sensibilmente modificati a seconda delle condizioni di messa in opera. L'utilizzatore deve comunque verificare l'idoneità del prodotto all'impiego previsto, assumendosi ogni responsabilità derivante dall'uso. I nostri prodotti sono soggetti a continui controlli, sia sulle materie prime sia sul prodotto finito, per garantire una qualità costante. I nostri tecnici e consulenti sono a vostra disposizione per informazioni, chiarimenti e quesiti sull'impiego e la lavorazione dei nostri prodotti. Ricehouse srl SB si riserva il diritto di apportare eventuali modifiche senza alcun preavviso.

Ricehouse srl SB
via Aosta 4, 20155 Milano, Italia
telefono +39 329 1869562
info@ricehouse.eu / ricehouse.it

Qualità



Il pannello isolante **RH50**, grazie alla simbiosi perfetta dei materiali naturali, garantisce ottime prestazioni.

- **Comfort abitativo**: miglioramento delle condizioni interne dell'ambiente e della salute di chi lo vive;
- **Abbattimento dell'inquinamento**: sottrae CO2 dall'aria presente all'interno delle strutture del fabbricato grazie alle proprietà dei suoi componenti;
- **Salubrità delle murature e gestione dell'umidità interna**: sfrutta le sue caratteristiche per il massimo benessere abitativo;
- **Isolamento e sfasamento termico:** amplifica la sensazione di naturale benessere sia in estate che in inverno;
- **Durevolezza e inattacabilità**: grazie all'elevato contenuto in silice della lolla, il pannello è garantito dall'attacco di agenti biologici come muffe e insetti;
- **Comfort acustico**: la sua porosità genera un effetto di assorbimento dei rumori;
- **Compatibilità prestazionale**: buona aderenza con ogni tipologia di supporto;
- **Resistenza al fuoco**: difficoltà di combustione per la presenza di silice nella paglia.

AVVERTENZE!

Attenersi alle indicazioni contenute in questa scheda tecnica.
In caso di dubbio consultare il nostro servizio tecnico al numero +39 329 1869562.

Non contiene sostanze e miscele classificate come pericolose per la salute e l'ambiente.

Modi d'impiego

1. Preparazione del supporto (in caso di riqualificazione)
- Eliminare la presenza di qualsiasi isolamento esistente.
- Assicurarsi che le strutture esistenti che riceveranno l'isolamento possano sostenere il peso dell'isolamento aggiunto.
- I supporti devono essere sani, solidi, asciutti e protetti dall'umidità di risalita.

2. Installazione dei pannelli isolanti

Sui tetti:
- L'isolamento può essere applicato in uno o due strati. In questo caso l'installazione è a giunti sfalsati o incrociati. Non è possibile riporre oggetti sull'isolamento. È vietato calpestare l'isolante.

Sui muri:
- Lo spessore dell'isolante utilizzato è definito in base alla resistenza termica desiderata. Le dimensioni dei montanti e delle guide della struttura devono essere adattate allo spessore dell'isolante utilizzato in modo da garantire un contatto continuo tra la superficie dell'isolante e il muro di sostegno. La coibentazione viene tagliata ad una larghezza pari a quella tra i montanti più circa 1,5 cm e viene posata da bordo a bordo per garantire la continuità termica del muro.
- Il sistema di tenuta all'aria che funge da barriera al vapore è installato su tutta la parete, lato ambiente caldo. È preferibile la posa perpendicolare a quella dei montanti e deve essere assicurata la completa continuità coprendo tutte le fasce di 10cm in tutte le direzioni.

3. Conservazione
- Il prodotto deve essere conservato in un luogo asciutto, al riparo dalle intemperie.

4. Sicurezza
- Rispettare la distanza di sicurezza tra l'isolamento e qualsiasi fiamma.
- È vietato qualsiasi contatto diretto tra l'isolante e una fonte di calore (faretto, trasformatore, ecc.).

I prodotti Ricehouse, pur essendo di facile applicazione, sono soggetti alla bontà o meno della messa in opera. La posa in opera dei materiali di nostra produzione dovrà necessariamente sottostare alle indicazioni dei nostri responsabili di zona. Ricehouse si riserva di valutare le opportune migliorie tecnico/qualitative, qualora si ritenga necessario.

Ricehouse srl SB
via Aosta 4, 20155 Milano, Italia
telefono +39 329 1869562
info@ricehouse.eu / ricehouse.it

Scheda tecnica

RH-L

DIMENSIONI E PESO

Sacchi in PVC riciclato
70 l (0,07 m³) / 8,5 – 9 kg
46 x 14 x 84 cm

BigBag
Tipo 1
1130 l (1,18 m³) / 160 kg
Tipo 2:
1781 l (1,86 m³) / 250 kg
100 x 100 x 210 – 230 cm

CE
ETA 21/1037

BIOMASSA ISOLANTE

Fibra vegetale essiccata e depolverizzata composta da lolla di riso pura.

Componenti

La lolla di riso viene raccolta, vagliata e insacchettata senza l'applicazione di ulteriori trattamenti né l'aggiunta di additivi.

Descrizione del prodotto

La lolla di riso rappresenta il sottoprodotto agricolo risultante dal processo di sbramatura del riso grezzo o risone. Si accomuna per composizione chimica al legno, essendo costituita principalmente da cellulosa, lignina, minerali e silicati. Risulta essere a tutti gli effetti un ottimo materiale per il conseguimento dell'efficienza energetica dell'edificio. Il suo basso valore di conducibilità termica si traduce in una forte capacità isolante. Garantisce la perfetta traspirabilità delle pareti in cui viene impiegata, evitando fenomeni di condensa superficiale e assicurando un ottimo comfort negli spazi abitativi e un ambiente di vita più sano. È un perfetto isolante acustico oltre che un materiale biodegradabile che si rinnova annualmente e che non genera rifiuto. È semplice da gestire nell'utilizzo in opera e la sua cantierizzazione la accomuna agli altri materiali edili naturali.
Per merito della sua composizione chimica e dell'elevato contenuto di silice, possiede elevata resistenza alla marcescenza e alla formazione di muffe. Lo scarso contenuto in nutrienti la rende inoltre inattaccabile dagli insetti.

Nelle applicazioni pratiche di cantiere, i dati contenuti in questa scheda tecnica possono essere sensibilmente modificati a seconda delle condizioni di messa in opera. Pur non essendo un prodotto marchiato CE, può essere introdotto in cantiere, secondo quanto previsto dal d.lgs. n. 106/2017 art. 5 comma 6, sotto la piena responsabilità del direttore lavori, che deve comunque verificare l'idoneità del prodotto all'impiego previsto, assumendosi inoltre ogni responsabilità derivante dall'uso. I nostri prodotti sono soggetti a continui controlli per garantire una qualità costante. I nostri tecnici e consulenti sono a vostra disposizione per informazioni, chiarimenti e quesiti sull'impiego e la lavorazione dei nostri prodotti. RiceHouse srl si riserva il diritto di apportare eventuali modifiche senza alcun preavviso.

Caratteristiche tecniche

Materiale organico	73,87%
Composizione chimica	Al_2O_3 1,23%
	Fe_2O_3 1,28%
	CaO 1,24%
	MgO 0,21%
	SiO_2 21,12%
	MnO_2 0,074%
Conducibilità termica	$\lambda_{10\,dry}$ 0,051 (W/mK)
Conducibilità termica Dichiarata	λ_D 0,053 (W/mK)
Densità	125 (kg/m³)
Resistenza alla diffusione del vapore acqueo	μ 3,5 (-)
Calore Specifico	1480 (J/KgK)
Porosità	93,4%
Classe reazione al fuoco	C-s2,d0

rice house
Ricehouse srl SB
via Aosta 4, 20155 Milano, Italia
telefono +39 329 1869562
info@ricehouse.eu / ricehouse.it

Qualità

L'isolamento con lolla di riso garantisce ottime qualità in merito a:

_ **Comfort abitativo**: miglioramento delle condizioni interne dell'ambiente e della salute di chi lo vive;
_ **Abbattimento dell'inquinamento**: sottrae CO_2 dall'aria presente all'interno delle strutture del fabbricato grazie alle proprietà dei suoi componenti;
_ **Salubrità delle murature e gestione dell'umidità interna**: sfrutta le sue caratteristiche per il massimo benessere abitativo;
_ **Isolamento e sfasamento termico**: amplifica la sensazione di naturale benessere sia in estate che in inverno;
_ **Durevolezza e inattacabilità**: grazie all'elevato contenuto di silice nella lolla, è garantito dall'attacco di agenti biologici come muffe e insetti;
_ **Comfort acustico**: la sua porosità genera un effetto di assorbimento dei rumori;
_ **Impatto ambientale**: tutti i componenti utilizzati sono di origine naturale e del tutto riciclabili;
_ **Made in Italy**: costituito solamente da materie prime prodotte in Italia da filiera corta;

AVVERTENZE!
Non esporre il sacco al sole per oltre 30 giorni. Conservare in sacchi integri e chiusi, in luogo asciutto e ben aerato, lontano da fonti di calore, scintille o fiamme libere. Attenersi alle indicazioni contenute in questa scheda tecnica.
In caso di dubbio consultare il nostro servizio tecnico al numero +39 329 1869562.

Caratteristiche del prodotto naturale

1. Permette il raggiungimento di elevatissime prestazioni tecniche
La conducibilità termica pari a 0,051 W/mk consente alla lolla di riso di essere classificata come materiale termoisolante. Grazie alla sua alta densità possiede inoltre eccellenti caratteristiche come isolante acustico.

2. È un materiale sano, privo di colle, vernici e affini
È un materiale organico, naturale e anallergico. Migliora la qualità dell'aria di un'abitazione in quanto non emette alcuna sostanza nociva come, ad esempio, la formaldeide. Combinata con intonaci naturali favorisce la traspirazione delle pareti, la regolazione dell'umidità e l'assenza di polveri.

3. Non teme l'umidità
L'alto contenuto di silice inibisce la marciscenza. Teme tuttavia l'acqua stagnante e necessità di essere protetta per mezzo di una copertura ed un adeguato isolamento da terra.

4. Non costituisce nutrimento per insetti
Non è un nutrimento per insetti, in quanto non contiene riso o altri tipi di nutrienti. L'elevato contenuto di silice la rende nociva per la loro alimentazione.

5. È un investimento sull'ambiente
È un materiale da costruzione rinnovabile: in Italia ogni anno vengono coltivati a riso circa 230.000 ettari di terreno, e la lolla di riso è uno scarto riutilizzato in percentuali estremamente ridotte. La sua produzione e il relativo trasporto producono una quantità minima di biossido di carbonio.

I prodotti Ricehouse, pur essendo di facile applicazione, sono soggetti alla bontà o meno della messa in opera. La posa in opera dei materiali di nostra produzione dovrà necessariamente sottostare alle indicazioni dei nostri responsabili di zona. Ricehouse si riserva di modificare i prodotti in qualsiasi momento, qualora lo ritenesse necessario, anche senza preavviso.

rice house
Ricehouse srl SB
via Aosta 4, 20155 Milano, Italia
telefono +39 329 1869562
info@ricehouse.eu / ricehouse.it

Tables' list

Figure and credits' list

Acronyms' list

PNRR: Piano Nazione di Ripresa e Resilienza
LCA: Life Cycle Assessment
C2C: Cradle to Cradle
DfMA: Design for Manufacture and Assembly
DfM: Design for Manufacture
DfA: Design for Assembly
DfD: Design for Disassembly
COP26: Conference of the Parties
IUCN: International Union for Conservation of Nature
NbSs: Nature-based Solutions
UN: United Nations
GHG: Greenhouse gas
SDGs: Sustainable Development Goals
AEC: Architecture, Engineering, & Construction
BAMB: Building as Material Banks
EPD: Environmental Product Declaration
GWP: Global Warming Potential
ODP: Ozone Depletion Potential
AP: Acidification Potential
EP: Eutrophication Potential
POPC: Formation Potential of Tropospheric Ozone
ADP: Abiotic Depletion Potential
LEED: Leadership in Energy and Environmental Design
BREEAM: Building Research Establishment Environmental Assessment Method
CLT: Cross Laminated Timber
GLT: Glued Laminated Timber
ICE: Institute of Civil Engineers
BIM: Building Information Modeling
MC: moisture content
SC: supply chain
RC: reinforced concrete
OSB: Oriented Strand Board
LVL: Laminated Veneer Lumber
EU: European Union
EUTR: European Union Timber Regulation
CE: Conformité Européene
FSC: Forest Stewardship Council
PEFC: Programme for the Endorsement of Forest Certification
IFC: Industry Foundation Classes
EPBD: Energy Performance of Buildings Directive
BPIE: Building Performance Institute Europe
Eurima: European insulation manufacturer association
HVAC: heating, ventilation and air conditioning
CAD: Computer aided drawing
CNC: Computerized Numerical Control

Websites

https://materialconnexion.com/
https://materialdistrict.com/
https://www.materially.eu/it/
https://unric.org/it/che-cosa-sono-i-cambiamenti-climatici/
https://sdgs.un.org/goals
https://www.agenziacoesione.gov.it/comunicazione/agenda-2030-per-lo-sviluppo-sostenibile/?lang=en
https://www.eea.europa.eu/help/glossary/eea-glossary/life-cycle-assessment
https://ec.europa.eu/environment/ipp/lca.htm
https://knowledge4policy.ec.europa.eu/glossary-item/cradle-cradle
https://www.bamb2020.eu/topics/materials-passports/
https://madaster.com/our-purpose/
https://www.environdec.com/about-us/global-house-of-epd
https://www.rts.com/resources/guides/what-is-leed-certification/)
https://www.breeam.com/
https://www.bollinger-grohmann.com/en.what-we-think.html
https://www.lombardini22.com/ricerca-innovazione
https://www.robertson.co.uk/business/robertson-timber-engineering
https://www.ergodomus.it/it/
https://www.pfeifergroup.com/it/
https://www.edilcanapasrl.it/
https://www.klh.at/it/
https://www.storaenso.com/en
https://www.xlamdolomiti.it/
https://colombo-costruzioni.it/
https://www.huf-haus.com/it-it/
https://www.lignoalp.com/
https://www.marlegno.it/
https://onehaus.it/
https://www.riko-hise.si/it/
https://makbuilding.eu/
https://www.agenziacasaclima.it/it/home-1.html
https://single-market-economy.ec.europa.eu/sectors/biotechnology/bio-based-products_en
https://www.bpie.eu/
https://www.ricehouse.it/
https://www.archdaily.com/887042/how-to-install-ventilated-facades-using-wooden-panels
https://fsiltd.com/product/paraflam%C2%A8-seb/
http://www.plbecs.com/flashing-assemblies.html

Bibliography

[1] IUCN, 'IUCN position paper for UNFCCC COP26', 2021. [Online]. Available: https://nbsguidelines.info/
[2] European Commission, 'The European Green Deal', 2019. Accessed: Nov. 15, 2022. [Online]. Available: https://ec.europa.eu/info/sites/default/files/european-green-deal-communication_en.pdf
[3] G. Carra, S. Ilardi, C. Perkins, and D. Acharya, 'The Urban bio-loop Growing, making and regenerating', Milan, 2017.
[4] 'EU construction sector: in transition towards a circular economy European Construction Sector Observatory Trend Paper Series', 2019. [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?lang=en&dataset=env_wasgen
[5] Governo italiano. Presidenza del Consiglio dei Ministri, 'Piano nazionale di ripresa e resilienza', 2021. Accessed: Nov. 15, 2022. [Online]. Available: https://www.governo.it/sites/governo.it/files/PNRR.pdf
[6] S. Pryke, Successful Construction Supply Chain Management: Concepts and Case Studies, Second Edition. Wiley, 2019.
[7] S. Li, H. Wu, and Z. Ding, 'Identifying sustainable wood sources for the construction industry: A case study', Sustainability (Switzerland), vol. 10, no. 1, Jan. 2018, doi: 10.3390/su10010139.
[8] L. Koskela, R. Vrijhoef, and R. Dana Broft, 'Construction Supply Chain Management through a Lean Lens', 2019.
[9] D. Thelen et al., 'Scaling the circular build environment: pathways for business and governments', 2018. [Online]. Available: https://docs.wbcsd.org/2018/12/Scaling_the_Circular_Built_Environment-pathways_for_business_and_government.pdf
[10] S. Chopra and P. Meindl, Supply chain management : strategy, planning, and operation, Sixth edition. Pearson Education Limited, 2016.
[11] A. Bystedt, L. Östman, M. Knuts, J. Johansson, K. Westerlund, and H. Thorsen, 'Fast and Simple - Cost Efficient Façade Refurbishment', Energy Procedia, vol. 96, no. October, pp. 779–787, 2016, doi: 10.1016/j.egypro.2016.09.140.
[12] S. Piesik, HABITAT: Vernacular Architecture for a Chancing Planet. Thames & Hudson Ltd, 2017.
[13] J. Zanni et al., 'Integrated deep renovation of existing buildings with prefabricated shell exoskeleton', Sustainability (Switzerland), vol. 13, no. 20, pp. 1–27, Oct. 2021, doi: 10.3390/su132011287.
[14] R. Zimmann, H. O'Brien, J. Hargrave, and M. Morrell, 'The Circular Economy in the Built Environment', 2016.
[15] K. G. Jensen et al., 'Building a Circular Future', 2019. Accessed: Nov. 04, 2022. [Online]. Available: https://gxn.3xn.com/wp-content/uploads/sites/4/2018/09/Building-a-Circular-Future_3rd-Edition_Compressed_V2-1.pdf
[16] 'Towards the Circular Economy: accelerating the scale-up across global supply chains', World Economic Forum Report, 2014, Accessed: Nov. 04, 2022. [Online]. Available: https://www3.weforum.org/docs/WEF_ENV_TowardsCircularEconomy_Report_2014.pdf
[17] A. Sáez-de-Guinoa, D. Zambrana-Vasquez, V. Fernández, and C. Bartolomé, 'Circular Economy in the European Construction Sector: A Review of Strategies for Implementation in Building Renovation', Energies, vol. 15, no. 13. MDPI, Jul. 01, 2022. doi: 10.3390/en15134747.
[18] D. Lee and L. Bony, 'Cradle-to-Cradle Design at Herman Miller: Moving Toward Environmental Sustainability', Dec. 2009. [Online]. Available: http://www.hermanmiller.com,
[19] Bollinger+Grohmann and Park Associati, INLEGNO - Cambiare prospettiva per costruire il futuro. LetteraVentidue Edizioni, 2022.
[20] M. Heinrich and W. Lang, 'Material passports - Best practices'.
[21] J. Sherwood, J. H. Clark, T. J. Farmer, L. Herrero-Davila, and L. Moity, 'Recirculation: A new concept to drive innovation in sustainable product design for bio-based products', Molecules, vol. 22, no. 1, Jan. 2017, doi: 10.3390/molecules22010048.
[22] Legambiente, '100 MATERIALI PER UNA NUOVA EDILIZIA - Rapporto dell'osservatorio Recycle-legambiente'.
[23] E. Gourlay, P. Glé, S. Marceau, C. Foy, and S. Moscardelli, 'Effect of water content on the acoustical and thermal properties of hemp concretes', Constr Build Mater, vol. 139, pp. 513–523, May 2017, doi: 10.1016/j.conbuildmat.2016.11.018.
[24] L. Aditya et al., 'A review on insulation materials for energy conservation in buildings', Renewable and Sustainable Energy Reviews, vol. 73. Elsevier Ltd, pp. 1352–1365, 2017. doi: 10.1016/j.rser.2017.02.034.
[25] O. B. Carcassi, I. Paoletti, and L. E. Malighetti, 'Reasoned catalogue of biogenic products in Europe.An anticipatory vision between technical potentials and availability', TECHNE, vol. 22, pp. 63–70, Oct. 2021, doi: 10.36253/techne-10578.
[26] L. R. Caldas, M. Y. R. da Gloria, F. Pittau, V. M. Andreola, G. Habert, and R. D. Toledo Filho, 'Environmental impact assessment of wood bio-concretes: Evaluation of the influence of different supplementary cementitious materials', Constr Build Mater, vol. 268, Jan. 2021, doi: 10.1016/j.conbuildmat.2020.121146.
[27] M. Kuittinen, C. Zernicke, S. Slabik, and A. Hafner, 'How can carbon be stored in the built environment? A review of potential options', Archit Sci Rev, 2021, doi: 10.1080/00038628.2021.1896471.
[28] T. Konstantinou, 'Façade Refurbishment Toolbox Supporting the Design of Residential Energy Upgrades'.
[29] P. Meuser and A. Jutta, Construction and design Manual: Prefabricated Housing, vol. 1. DOM publishers, 2018.
[30] N. Craig, 'Accelerating low-carbon costruction with wood - A Nordic Policy Snapshot', 2021. Accessed: Jan. 17, 2022. [Online]. Available: www.norden.org/publications
[31] F. Pittau, G. Dotelli, N. Villa, E. de Angelis, G. Iannaccone, and L. Zampori, 'Wood products for the italian construction industry-An LCA-based sustainability evaluation'. [Online]. Available: https://www.researchgate.net/publication/289201344
[32] J. von Geibler, K. Kristof, and K. Bienge, 'Sustainability assessment of entire forest value chains: Integrating stakeholder perspectives and indicators in decision support tools', Ecol Modell, vol. 221, no. 18, pp. 2206–2214, Sep. 2010, doi: 10.1016/j.

ecolmodel.2010.03.022.
[33] R. Vrijhoef and L. Koskela, 'Roles of Supply Chain Management in Construction ROLES OF SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION Vrijhoef and Koskela'.
[34] A. Sandak, J. Sandak, M. Brzezicki, and A. Kutnar, Bio-based Building Skin. 2019. doi: https://doi.org/10.1007/978-981-13-3747-5.
[35] 'TES EnergyFaçade-prefabricated timber based building system for improving the energy efficiency of the building envelope'.
[36] D. A. Gioia, K. G. Corley, and A. L. Hamilton, 'Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology', Organ Res Methods, vol. 16, no. 1, pp. 15–31, Jan. 2013, doi: 10.1177/1094428112452151.
[37] M. Schreier, Qualitative Content Analysis in Practice, First. London: SAGE Publications Ltd, 2012. [Online]. Available: www.sagepub.co.uk/schreier
[38] M. Skjott Linneberg and S. Korsgaard, 'Coding qualitative data: a synthesis guiding the novice', Qualitative Research Journal, vol. 19, no. 3. Emerald Group Holdings Ltd., pp. 259–270, Jun. 04, 2019. doi: 10.1108/QRJ-12-2018-0012.
[39] V. Corrado, I. Ballarini, and S. P. Corgnati, Typology Approach for Building Stock Energy Assessment D6.2 National scientific report on the TABULA activities in Italy. 2012.
[40] Eames et all, Retrofit 2050: Critical Challenges for Urban Transitions. 2014.
[41] G. Margani, G. Evola, C. Tardo, and E. M. Marino, 'Energy, seismic, and architectural renovation of RC framed buildings with prefabricated timber panels', Sustainability (Switzerland), vol. 12, no. 12, p. 4845, Jun. 2020, doi: 10.3390/SU12124845.
[42] G. M. and F. P. Olga Beatrice Carcassi, Enrico De Angelis, Giuliana Iannaccone, Laura Elisabetta Malighetti et al., 'Bio-Based Materials for the Italian Construction Industry: Buildings as Carbon Sponges', Journal of Building Engineering, vol. 78, no. August 2020, pp. v–vi, 2020, doi: 10.1007/978-3-030-33256-3.
[43] M. Kuittinen, C. Zernicke, S. Slabik, and A. Hafner, 'How can carbon be stored in the built environment? A review of potential options', Archit Sci Rev, 2021, doi: 10.1080/00038628.2021.1896471.
[44] L. Liu et al., 'The development history and prospects of biomass-based insulation materials for buildings', Renewable and Sustainable Energy Reviews, vol. 69, pp. 912–932, Mar. 2017, doi: 10.1016/J.RSER.2016.11.140.
[45] L. Aditya et al., 'A review on insulation materials for energy conservation in buildings', Renewable and Sustainable Energy Reviews, vol. 73, pp. 1352–1365, Jun. 2017, doi: 10.1016/J.RSER.2017.02.034.
[46] O. B. Carcassi, I. Paoletti, and L. E. Malighetti, 'Reasoned catalogue of biogenic products in Europe.An anticipatory vision between technical potentials and availability', Techne, vol. 22, pp. 63–70, 2021, doi: 10.36253/techne-10578.
[47] M. Busselli, D. Cassol, A. Prada, and I. Giongo, 'Timber based integrated techniques to improve energy efficiency and seismic behaviour of existing masonry buildings', Sustainability (Switzerland), vol. 13, no. 18, 2021, doi: 10.3390/su131810379.
[48] D. Jones, 'Introduction to the performance of bio-based building materials', in Performance of Bio-based Building Materials, Elsevier Inc., 2017, pp. 1–19. doi: 10.1016/B978-0-08-100982-6.00001-X.
[49] G. M. and F. P. Olga Beatrice Carcassi, Enrico De Angelis, Giuliana Iannaccone, Laura Elisabetta Malighetti and Abstract, Bio-Based Materials for the Italian Construction Industry: Buildings as Carbon Sponges. Springer International Publishing, 2020. doi: 10.1007/978-3-030-33256-3.
[50] F. Pittau, L. E. Malighetti, G. Iannaccone, and G. Masera, 'Prefabrication as Large-scale Efficient Strategy for the Energy Retrofit of the Housing Stock: An Italian Case Study', Procedia Eng, vol. 180, pp. 1160–1169, 2017, doi: 10.1016/j.proeng.2017.04.276.
[51] F. Asdrubali, F. D'Alessandro, and S. Schiavoni, 'A review of unconventional sustainable building insulation materials', Sustainable Materials and Technologies, vol. 4, no. 2015, pp. 1–17, Jul. 2015, doi: 10.1016/j.susmat.2015.05.002.
[52] S. L. Platt et al., 'Sustainable bio & waste resources for thermal insulation of buildings', Constr Build Mater, vol. 366, no. January, p. 130030, 2023, doi: 10.1016/j.conbuildmat.2022.130030.
[53] B. Marques, A. Tadeu, J. Almeida, J. António, and J. de Brito, 'Characterisation of sustainable building walls made from rice straw bales', Journal of Building Engineering, vol. 28, no. November 2019, 2020, doi: 10.1016/j.jobe.2019.101041.
[54] M. Palumbo, A. M. Lacasta, M. P. Giraldo, L. Haurie, and E. Correal, 'Bio-based insulation materials and their hygrothermal performance in a building envelope system (ETICS)', Energy Build, vol. 174, pp. 147–155, 2018, doi: 10.1016/j.enbuild.2018.06.042.
[55] F. Asdrubali, F. D'Alessandro, and S. Schiavoni, 'A review of unconventional sustainable building insulation materials', Sustainable Materials and Technologies, vol. 4, pp. 1–17, Jul. 2015, doi: 10.1016/j.susmat.2015.05.002.
[56] F. Pittau, G. Lumia, N. Heeren, G. Iannaccone, and G. Habert, 'Retrofit as a carbon sink: The carbon storage potentials of the EU housing stock', J Clean Prod, vol. 214, pp. 365–376, Mar. 2019, doi: 10.1016/j.jclepro.2018.12.304.
[57] V. Göswein, J. Reichmann, G. Habert, and F. Pittau, 'Land availability in Europe for a radical shift toward bio-based construction', Sustain Cities Soc, vol. 70, no. April, Jul. 2021, doi: 10.1016/j.scs.2021.102929.
[58] A. Sandak, J. Sandak, M. Brzezicki, and A. Kutnar, Bio-based building skin. 2019. doi: 10.1007/978-981-13-3747-5_6.
[59] L. Pozza, F. Evangelista, and R. Scotta, 'CLT used as seismic strengthener for existing masonry walls CLT used as seismic strengthener for existing masonry walls', XVII Xonvegno ANIDIS, pp. 210–220, 2017.
[60] F. Stazi, M. Serpilli, G. Maracchini, and A. Pavone, 'An experimental and numerical study on CLT panels used as infill shear walls for RC buildings retrofit', Constr Build Mater, vol. 211, pp. 605–616, Jun. 2019, doi: 10.1016/j.conbuildmat.2019.03.196.
[61] V. Model et al., 'Impact of retrofit of RC frames by CLT panels and friction dampers', COMPDYN Proceedings, vol. 2021-June, no. September, pp. 1–16, 2021, doi: 10.7712/120121.8636.18851.
[62] G. Callegari, A. Spinelli, L. Bianco, V. Serra, and S. Fantucci, 'NATURWALL© - A solar timber façade system for building refurbishment: Optimization process through in field measurements', in Energy Procedia, Elsevier Ltd, Nov. 2015, pp. 291–296. doi: 10.1016/j.egypro.2015.11.641.
[63] A. Spinelli, '"NaturWall © _ facciate in legno multifunzionali per la riqualificazione del patrimonio edilizio" " NaturWall © _ multifunctional wood façade in existent building refurbishment"'.
[64] W. I. Sheet, 'Wood Information Sheet Timber cladding for building refurbishment', 2018.
[65] S. Ruud, L. Östman, and P. Orädd, 'Energy Savings for a Wood Based Modular Pre-fabricated Façade Refurbishment System Compared to Other Measures', in Energy Procedia, Elsevier Ltd, 2016, pp. 768–778. doi: 10.1016/j.egypro.2016.09.139.
[66] K. Sandberg, T. Orskaug, and A. Andersson, 'Prefabricated Wood Elements for Sustainable Renovation of Residential Building Façades', in Energy Procedia, Elsevier Ltd, 2016, pp. 756–767. doi: 10.1016/j.egypro.2016.09.138.
[67] G. Malacarne, G. P. Monizza, J. Ratajczak, D. Krause, C. Benedetti, and D. T. Matt, 'Prefabricated Timber Façade for the Energy Refurbishment of the Italian Building Stock: The Ri.Fa.Re. Project', in Energy Procedia, Elsevier Ltd, 2016, pp. 788–799. doi: 10.1016/j.egypro.2016.09.141.
[68] F. Pittau, L. E. Malighetti, G. Iannaccone, and G. Masera, 'Prefabrication as Large-scale Efficient Strategy for the Energy Retrofit of the Housing Stock: An Italian Case Study', Procedia Eng, vol. 180, pp. 1160–1169, 2017, doi: 10.1016/j.proeng.2017.04.276.
[69] G. Salvalai, M. M. Sesana, and G. Iannaccone, 'Deep renovation of multi-storey multi-owner existing residential buildings: A pilot case study in Italy', Energy Build, vol. 148, pp. 23–36, Aug. 2017, doi: 10.1016/j.enbuild.2017.05.011.
[70] G. Salvalai, G. Iannaccone, M. M. Sesana, E. Pizzi, M. M. Sesana, and E. Pizzi, 'Outer facade retrofitting trough precast insulation panels : method and planning tool applied to an Italian residential building', vol. 3, no. 2, 2017.
[71] F. Rosso, A. Peduzzi, L. Diana, S. Cascone, and C. Cecere, 'A sustainable approach towards the retrofit of the public housing building stock: Energy-architectural experimental and numerical analysis', Sustainability (Switzerland), vol. 13, no. 5, pp. 1–19, Mar. 2021, doi: 10.3390/su13052881.
[72] W. Pan et al., 'A conceptual design of an integrated Façade system to reduce embodied energy in residential buildings', Sustainability (Switzerland), vol. 12, no. August 2017, pp. 1–23, Jul. 2016, doi: 10.3390/su12145730.
[73] C. Tardo, G. Fiore, and G. Margani, 'Technological analysis of prefabricated timber-based panels for the integrated renovation of RC framed buildings', 2020.
[74] F. Pittau, G. Lumia, N. Heeren, G. Iannaccone, and G. Habert, 'Retrofit as a carbon sink: The carbon storage potentials of the EU housing stock', J Clean Prod, vol. 214, pp. 365–376, Mar. 2019, doi: 10.1016/j.jclepro.2018.12.304.
[75] A. Egerter and C. Martha, 'Prefabricated Zero Energy Retrofit Technologies: A Market Assessment', no. March, 2020, [Online]. Available: www.osti.gov
[76] S. Kurzinski, P. Crovella, M. Razkenari, and W. B. Smith, 'A Zero-carbon Bio-based Wall Panel as an Energy Retrofit Solution for Buildings', no. March, 2022.
[77] S. S. Zuluaga, S. Kallioras, and A. Tsiavos, 'Optimization of Synergetic Seismic and Energy Retrofitting Based on Timber Beams and Bio-Based Infill Panels: Application to an Existing Masonry Building in Switzerland', Buildings, vol. 12, no. 8, Aug. 2022, doi: 10.3390/buildings12081126.
[78] A. Bystedt, L. Östman, M. Knuts, J. Johansson, K. Westerlund, and H. Thorsen, 'Fast and Simple - Cost Efficient Façade Refurbishment', Energy Procedia, vol. 96, no. October, pp. 779–787, 2016, doi: 10.1016/j.egypro.2016.09.140.
[79] M. Miglietta, N. Damiani, G. Guerrini, and F. Graziotti, 'Full-scale shake-table tests on two unreinforced masonry cavity-wall buildings: effect of an innovative timber retrofit', Bulletin of Earthquake Engineering, vol. 19, no. 6, pp. 2561–2596, 2021, doi: 10.1007/s10518-021-01057-5.
[80] G. Zweifel, 'Prefabricated Systems for Low Energy Renovation of Residential Buildings: Retrofit Simulation Report IEA ECBCS Annex 50', Mar. 2011.
[81] H. Du, P. Huang, and P. Jones, 'Modular facade retrofit with renewable energy technologies: The definition and current status in Europe', Energy Build, vol. 205, 2019, doi: 10.1016/j.enbuild.2019.109543.
[82] U. Knaack, T. Klein, M. Bilow, and T. Auer, 'Façades: Principles of Construction', 2007.
[83] Y. Weinand, 'Advanced timber structures', Lausanne, 2017.
[84] K. Seike, Tha Art of Japanese Joinery. Weatherhill, 1977.
[85] F. Bianconi and M. Filippucci, 'Lecture Notes in Civil Engineering Digital Wood Design Innovative Techniques of Representation in Architectural Design'. [Online]. Available: http://www.springer.com/series/15087
[86] O. B. Carcassi, E. de Angelis, G. Iannaccone, L. E. Malighetti, G. Masera, and F. Pittau, 'Bio-based materials for the ital-

ian construction industry: Buildings as carbon sponges', in Research for Development, Springer, 2020, pp. 237–247. doi: 10.1007/978-3-030-33256-3_23.
[87] L. Badini, S. Ott, P. Aondio, and S. Winter, 'Seismic strengthening of existing RC buildings with external cross-laminated timber (CLT) walls hosting an integrated energetic and architectural renovation', Bulletin of Earthquake Engineering, vol. 20, no. 11, pp. 5963–6006, Sep. 2022, doi: 10.1007/s10518-022-01407-x.