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Sustainable Architecture: Innovations and Perspectives for Multi-Family Housing in Timber-based Structures †

Łukasz Mazur

Faculty of Engineering, Helena Chodkowska University of Technology and Economics, Jagiellońska 82f, 03-301 Warsaw, Poland.
* Correspondence: arch.lukaszmazur@gmail.com
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Abstract: The current methods of designing and using wood-based construction systems are going through exciting changes. By adopting new and innovative technologies, it is now possible to create residential buildings with less environmental impact. After examining the available research, this article presents and describe five main categories of wood construction systems, highlighting their advantages and applications. Choosing the right structural system is crucial in facing the sustainability challenges of today. It is important to consider different factors, such as the building function or economic aspects.

Keywords: Wooden construction; Building technologies; Green buildings; Sustainable development; Architecture; Multi-family housing; Prefabrication; Renewable materials; Construction innovations; Hybrid structures.

1. Introduction

With global climate change and increasing environmental awareness, sustainable architecture is not just a trend but a necessity. Interest in environmentally friendly technologies that minimise the impact of construction on the planet is greater than ever [1]. In this context, wood is increasingly important as a low-energy material with a low carbon footprint, especially for use in multifamily housing. Traditionally, wood has been associated with small single-family homes or temporary structures. However, modern technology, innovative construction methods, and advanced scientific research have made it possible to break these stereotypes. Today's multi-storey timber residential buildings are becoming a symbol of sustainable architecture, combining the beauty of natural materials with advanced technical solutions [2].

Changing environmental conditions present a new challenge for urban planners and developers. Today's metropolises, while important centres of innovation and research, are also major sources of greenhouse gas (GHG) emissions that contribute to progressive climate change [3,4]. The world's cities, although occupying only about 3% of the Earth's surface, are the epicentre of global energy consumption and the source of significant GHG emissions. Statistics record that up to 60–80% of total energy consumption and 75% of global carbon emissions come from these population centres [5]. The excessively high values indicate an urgent need to rethink urban planning and energy practises in cities. Incorporating renewable energy sources, such as solar, wind, or geothermal energy, can significantly help decrease noxious gas emissions. Other steps include changing the methods and materials used in construction. Wood may be essential to reduce CO2 emissions as an alternative to harmful and energy-intensive building materials [6].

Today's architecture of multifamily housing in the European Union (EU) is experiencing a revolution in the use of building materials and technologies. One of the most prominent trends that is gaining popularity is the return to its roots: the use of timber as

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the primary construction material. The following publication examines timber-based construction systems used in recent residential developments in EU countries. As a material with a long tradition in European construction, wood is experiencing a renaissance in the context of innovative solutions. Innovative technologies make wood more durable, flexible, and adaptable to the needs of today's property market [7]. A major aspect of this paper is the analysis of a variety of construction systems. Each of these systems has its own unique properties and potential applications, which are discussed in depth in the context of the requirements and expectations of today's residential market.

2. Materials and Methods

The purpose of the study is to describe the options for building method of multifamily residential buildings with wood-based construction in Europe. To achieve this goal, where used the desk research method and analysis of timber construction projects that have been completed in EU countries. Based on this desk-research, it was possible to identify the most used contemporary methods for the development of timber residential buildings – these data are presented in Table 1. The rest of the paper discusses wood-based construction systems and their use on a larger scale in construction industry.

3. Results

Timber building is one of the oldest construction systems and has evolved to meet the changing needs of communities and technological advances. After reviewing the literature on timber structural systems, the author proposed categorising technologies used in multifamily buildings into five main categories, as detailed in Table 1.

Table 1. Characteristics of technology for multi-family residential buildings in timber construction.

lp.	Structural system	Classification	Components	Prefabrication possibility
1	Wood frame construction	Platform frame	1. Studs; 2. Joists; 3. I/Metal web Beams; 4. OSB / Plywood.	Yes
		Balloon frame		Yes
2	Post and beam		1. Post; 2. Beam.	Yes
3	Mass timber	Glued laminated timber (GLULAM/GLT)	1. Beams; 2. Columns.	Yes
		Laminated veneer lumber (LVL)	1. Beams; 2. Columns; 3. Stressed skin cassette panels.	Yes
		Cross-laminated timber (CLT)	1. Walls; 2. Floors; 3. Roofs; 4. Stairs.	Yes
4	Prefabricated structure	Panel construction (2D)	1. LVL; 2. GLT; 3. CLT.	Yes
		Volumetric modular (3D)	1. LVL; 2. GLT; 3. CLT; 4. Hybrid-timber.	Yes
5	Hybrid-timber	Timber-steel hybrids	1. Steel Components: Beams and Columns; Steel Connectors. 2. Concrete Components: Beams and Columns; Concrete Slabs. 3. Timber Components: LVL; GLT; CLT.	Yes
		Timber-concrete hybrids		
		Concrete-timber hybrid		

4. Composite steel-timber-concrete

3.1. Wood Frame Construction

Wood frame structures are a highly innovative and effective construction method in the building industry. Lightweight frameworks such as platform and balloon construction integrate traditional techniques with modern solutions to offer effective and sustainable solutions. The platform frame building method gives structure to a building by creating it layer by layer. Each successively higher level is added to a previously completed platform. This method allows easy adjustments to the plans and modifications to the structure during construction. It is commonly used in modern projects, providing stability and resistance to different loads. A characteristic feature of balloon frame construction is that the external walls of the building are built as one continuous section, extending from the foundation to the roof. It is based on long timber posts that carry loads throughout the height of the building. Although this is a method that can speed up the construction process in certain applications, it requires careful design and accurate connections to ensure the durability and safety of the structure [8].

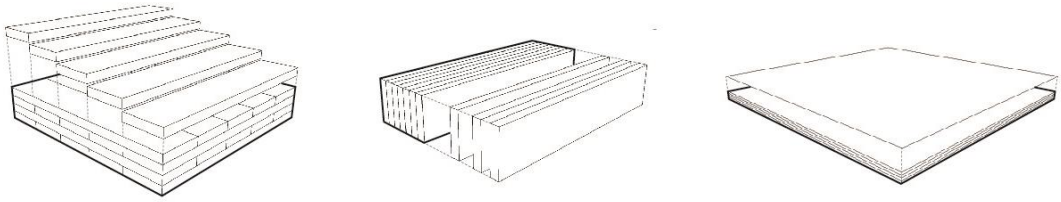
3.2. Post and Beam

Post and Beam is a traditional construction method that learns from centuries-old techniques while meeting modern building standards. Post and beam construction uses large timber columns and equally large beams to form the basic structural frame. These main elements are usually exposed, giving the building a distinctive and aesthetically pleasing appearance. As technology has advanced, traditional post and beam construction methods have been improved and adapted to meet today's needs. Modern connection methods – using special joints, bolts and other advanced materials – give the structure greater stability and durability. The design allows larger spans with fewer internal columns than other timber building systems, giving greater freedom in interior layout. It is also common today to use Mass Timber material (e.i. CLT) as a building material for Post and Beam. This increases the application possibilities for use in high-rise buildings, while also replacing concrete.

3.3. Mass Timber

Mass timber construction is characterised by the use of large solid wood panels for walls, floors, and roofs. It also includes innovative forms of sawn timber and can be used in combination with other materials. Mass timber components are known for their strength and can be used in tall structures, challenging traditional thinking that only concrete and steel can be used in tall and high-rise buildings. Combining tradition and innovation, mass timber construction offers a sustainable, aesthetically pleasing, and structurally sound approach to modern housing buildings [9]. Examples of (selected) components:

- Cross-Laminated Timber (CLT): A multilayer wood panel made by gluing together layers of wood at right angles to each other (Figure 1a).
- Glued laminated timber (GLULAM): Beams made by stacking layers of wood and bonding them together with durable and moisture-resistant adhesives (Figure 1b).
- Laminated veneer lumber (LVL): It is made by gluing several thin wood layers together. Its enhanced strength makes it ideal for numerous construction uses (Figure 1c).



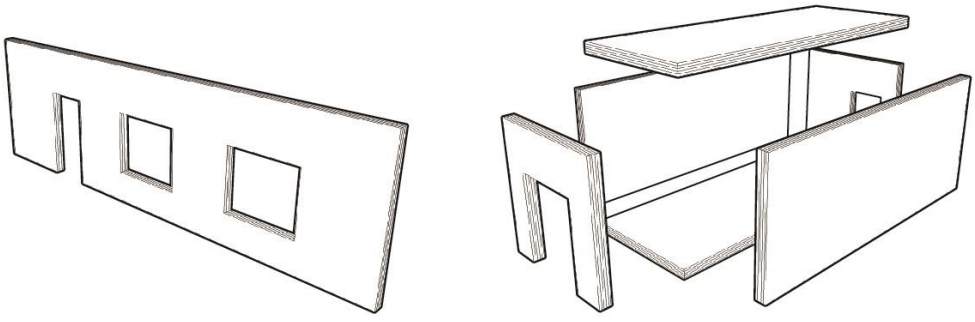
(**a**) (**b**) (**c**)

Figure 1. Examples of components mass timber: [a] CLT; [b] GLULAM; [c] LVL [source: Author].

3.4. Prefabricated Structure

Timber panel construction, also known as 2D construction (Figure 2a), has its roots in traditional balloon and platform construction methods. It has become a cornerstone of modern construction in countries such as the United States, Canada, and Scandinavian countries. There are a several of reasons for its growing popularity: (i) flexibility in design, it gives architects more freedom to create unique designs; (ii) ease of construction, this feature makes the method accessible to a wide range of contractors, regardless of their experience; (iii) sequentiality of installation, the ability to build floor by floor ensures efficiency and an orderly workflow; (iv) speed of execution, the limited assembly time on site speeds up the entire investment process. Given these advantages, both in terms of time and cost savings and the possibility of creating unique designs, it is expected that wood panel construction technology will gain even greater interest in the construction world.

Volumetric modular (3D) (Figure 2b) timber structures refer to complete building units or modules manufactured off-site under controlled factory conditions. Each module is pre-fabricated with interior finishes, fittings, and the necessary equipment. Once completed, they are transported to the installation site. Unlike 2D prefabricated structures, volumetric modular units are three-dimensional and can include entire rooms or sections of a building, fitted with interiors such as a kitchenette or bathroom, fully wired and plumbed. In summary, modular volumetric timber structures are at the forefront of innovative construction, offering a combination of speed, efficiency, and sustainability. They represent a significant change in the way we think about construction, focussing on off-site fabrication to increase on-site productivity [10].



(**a**) (**b**)

Figure 2. Prefabricated structure: [a] wall – panel construction 2D; [b] volumetric modular (3D) [source: Author].

3.5. Hybrid-Timber

Hybrid timber systems use Mass Timber components in combination with other materials, including steel and concrete. Hybrid systems take advantage of the properties of each of the building materials used to maximise structural performance, and minimise the amount of material used. Due to their structural properties, steel and concrete are most commonly used as beams and columns in hybrid systems. Steel beams are typically used where longer spans or greater height of the building are required. However, concrete in

hybrid construction allows the requirements for fire and flood protection to be met, which is why it is often used on the ground floor of a building. In addition, hybrid systems allow buildings to be constructed in areas with difficult ground conditions, are lightweight due to the use of wood, and can be used to support a wide range of materials [11].

Figure 3. High-rise wooden residential buildings: a) "Dalston Lane" building from London - height 33,8 m CLT construction; b) "The Tree" building from Bergen - height 49,0 m CLT construction, Glulam; c) "Haut" building from Amsterdam - height 73,0 m, Timber-Concrete Hybrid construction [source: Internet, accessed 10/09/2023].

4. Discussion

Modern multifamily housing is adapting to a rapidly changing reality in which the priority is no longer just satisfying quantitative needs in terms of the number of available dwellings, but also paying attention to qualitative and environmental aspects [12]. In developed countries (such as the EU), there is a noticeable increase in public awareness of environmental issues. This growing awareness is increasingly affecting the construction industry, especially in the multi-family housing sector [13]. This trend determines not only the choice of materials and technologies, but also the overall approach to the design and construction process, with increasing emphasis on energy efficiency and minimising environmental impact.

Undoubtedly, choosing the appropriate construction system is crucial. Contemporary and innovative wood-based construction techniques allow architects to design impressive structures. These buildings are not only visually attractive, but also less harmful to the environment [14,15]. As a result, both the scientific and the economic factors have refocused their attention on the potential of using wood as a renewable material for extensive construction. New building methods and materials using wood have been developed as a result of increased interest. Now, multifamily residential buildings such as Dalston Lane in London, UK, The Tree in Bergen, Norway, and Haut in Amsterdam, The Netherlands (Figure 3) can be built using these innovations.

Architects and engineers face the challenge of considering a wide range of factors when selecting the right structural system for a particular project. One of the most crucial factors is the purpose and type of building. As an example, a retirement home will require a different design approach compared to a contemporary apartment block for young professionals. Height is a factor in choosing materials and technology for stability, fire safety, and protection against earthquakes. These are just some aspects to consider. Other factors include local conditions such as soil and water levels and subsoil strength. When planning a project, it is important to consider economic factors such as budget, material costs, implementation expenses, and transport capacity. These should be balanced against several

factors, including energy efficiency, durability, aesthetics, cost, and environmental impact, to find the best solution for the project.

5. Conclusions

Research has shown that the use of ecofriendly wood-based technologies is becoming increasingly important in sustainable architecture. The study analysed completed multistorey wooden residential buildings in Europe to identify five common timber building systems (Table 1). The research also showed that increasing growth in the construction of multistorey timber housing relates to the progress made in engineered wood materials. These can be wood-based panels, structural composite lumber, mass timber, and Engineered wood flooring. The number of new and innovative wood-based construction technologies is constantly increasing, so choosing the right construction system for a project is an important task. Modern wood-based technologies make it possible to create diverse and interesting residential environments that meet high environmental standards and residents' expectations.

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