Chapter

Tallest Timber Buildings: Main Architectural and Structural Design Considerations

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Abstract

Since the end of the twentieth century, the question of how to deal with the increasing scarcity of resources has been at the center and the need for renewable materials has come to the fore, especially in the construction sector. A possible solution to these environmental challenges is represented by the development of engineered timber products, which allowed the realization of tall timber structures. Their main drivers are decarbonization, forest management, and timber life cycle, urbanization, and densification, productivity in the construction industry, and the benefits of using timber indoors. In this context, this chapter will analyze data from the 10 tallest timber building cases to enhance the understanding of contemporary trends. Data are collected through literature surveys and case studies to analyze the main architectural and structural design concerns to contribute to the knowledge about the growing tall timber structures around the world. By revealing up-to-date features of the tallest timber towers, it is thought that this chapter will contribute to aiding and directing key construction professionals such as architects, structural engineers, and contractors, in the design and construction of future tall timber building developments.

Keywords: timber/wood, engineered timber/wood products, tall building, timber construction, architectural design considerations, structural design considerations, dovetail massive wooden board elements

1. Introduction

The utilization of timber in the construction sector has been revived since the mid-1990s [1, 2], and particularly in the last 10 years [3, 4], due to environmental concerns, urbanization challenges, and productivity in the construction industry [5–7]. Since the end of the twentieth century, the question of how to deal with the increasing scarcity of resources has been at the center and the need for renewable (building) materials has come to the fore, especially in the building construction industry [8]. A potential solution to these challenges is the development of engineered timber products (ETPs) that enable the erection of tall timber buildings [9] as in the case of the 18-story and 85 m high Mjøstårnet (Brumunddal, 2019).

CO_2 has been a game-changer since 1970, sparking a revolution in the way buildings are built. With the successful implementation of issues such as efficiency and passive standards in just a few years, there has been an increased emphasis on sustainability during and after the construction site [10]. Furthermore, today, the construction industry accounts for approximately 40% of annual greenhouse gas emissions, 40% of global resource consumption, 40% of energy use, and 50% of global waste, timber is a valuable alternative material [11, 12].

In this sense, the use of timber can enable the construction industry to avoid significant greenhouse gas emissions associated with unsustainable material use, as it is a natural carbon sink [13]. In other words, the fact that it is a renewable building material that can store CO_2 compared with steel and concrete, which are traditional building materials, has brought timber to an important point as a construction material [14, 15].

On the other hand, simultaneously, the world population doubled in less than a century, and for the first time in history, more people lived in cities than in the countryside [16]. The overall effect of this high density of people in cities forced buildings to rise. However, combined with the chronically low productivity of the construction sector since the 1990s and the high demand for new buildings in the future [17], there may be other challenges to reducing greenhouse gas emissions. The assessment of a skilled and aging workforce and slow construction time, among other factors, are significant challenges for both established and future companies [18]. Prefabrication is recommended as the best way to improve productivity, and timber is perfectly suited for this as it is light and easy to work with [19, 20].

Latest technical developments in ETPs (e.g., [21]) and systems, as well as regulatory procedures in fire codes, other building codes, and various government regulations initiatives, have allowed timber construction to reach new heights [22]. Multistory construction is a new and promising business with high potential to support the bioeconomy [23] as in the case of the 25-story and 87 m high Ascent (Milwaukee, under construction) (**Figure** 1). Besides the potential for substantial

Figure 1.
Ascent (image courtesy of Jason Korb/Korb + Associates Architects).

environmental and economic life cycle advantages can contribute to social sustainability in the processing of materials, as in both primary production and timber-based value chains [24].

In the literature, numerous surveys present the technical features of ETPs, their use in building construction, and diverse technical solutions (e.g., [25–28]). Several surveys focus on timber as a construction material from the viewpoints of key specialists (e.g., [29–32]) and users or inhabitants (e.g., [33, 34]); whereas there is a very limited number of comprehensive comparative design studies on architectural and structural parameters of multistory and tall timber buildings (e.g., [35–37]).

This chapter aims to identify, organize, and combine the data about the tallest timber buildings from the primary architectural and structural aspects to enhance understanding of the design and construction of these towers. To accomplish this goal, data were collected from the 10 tallest timber buildings under construction and completed.

The scope of the chapter is limited to the information available and uses key points to provide a representative understanding of contemporary trends in tallest timber buildings: general information (building name, location, height, number of stories, completion, gross floor area, amount of timber used), architectural and structural design parameters (building form, core type, structural system, and material). It is thought that this study will contribute to aiding and directing architects in the design and construction of future tallest timber towers.

2. Materials and methods

The chapter was mainly conducted through a literature review including peer-reviewed research, official documents and reports, fact sheets, architectural and structural magazines, and other Internet sources. Additionally, case studies were used to identify, gather, and combine the data about the tallest timber buildings to examine the architectural and structural perspectives. The study sample included 10 tallest timber buildings under construction and completed, in a variety of countries (two from Norway, two from Finland, two from Canada, one from Austria, one from the Netherlands, one

#	Name	City (country)	Height (m)	# of stories	Completion date	Gross floor area	Amount of timber used*
1	Ascent	Milwaukee (USA)	87	25	UC	30,136 m^2	NA
2	Mjøstårnet	Brumunddal (Norway)	85	18	2019	11,300 m^2	2600 m^3/GL (structural timber)
3	HoHo	Vienna (Austria)	84	24	2020	25,000 m^2	4350 m^3 (entire construction)
4	HAUT	Amsterdam (Netherlands)	73	22	2022	14,500 m^2	2000 m^3 (entire timber)
5	Brock Commons Tallwood House	Vancouver (Canada)	58	18	2017	15,115 m^2	1973 m^3/CLT 260 m^3/GLPSL
6	Treet	Bergen (Norway)	49	14	2015	7140 m^2	550 m^3/GL 385 m^3/CLT

#	Name	City (country)	Height (m)	# of stories	Completion date	Gross floor area	Amount of timber used*
7	Lighthouse Joensuu	Joensuu (Finland)	48	14	2019	5935 m^2	2000 m^3 (entire construction)
8	HOAS Tuuliniitty	Tuuliniitty (Finland)	42	13	2021	7584 m^2	NA
9	Origine	Quebec (Canada)	41	13	2017	13,124 m^2	3111 m^3 (mass timber)
10	Trafalgar Place	London (UK)	36	10	2015	16,661 m^2	750 m^3 (timber volume)

Note on abbreviation: 'UC' indicates under construction; 'NA' indicates not available; 'CLT' indicates cross-laminated timber; 'GL' indicates glue-laminated timber; 'PSL' indicates parallel strand lumber. *Different levels and kinds of data for "the amount of timber" e.g. structural timber, entire construction, or only CLT were given by various references.*

Table 1.
10 tallest timber buildings.

from the United Kingdom, and one from the United States) as seen in **Table** 1. In the study, a "tall building" was defined as a building with over eight story [22].

In terms of functionality, tall buildings can be classified as single-use or mixed-use. In this study, hotel, residence, and office were considered as primary functions, whereas their combinations were considered mixed-use. Taking into account existing literature (e.g., [36–43]), the classifications based on their structural behavior under lateral loads by Ilgın [44–46] and Ilgın et al. [47] were used in this paper due to its more comprehensive and clearer structures (see **Table** 2).

Core	Building form	Structural system	Structural material
Central core	Prismatic form	Shear-frame system	Steel
• Central	Setback form	• Shear trussed frame	Reinforced concrete
• Central split	Tapered form	• Shear walled frame	Composite
Atrium core	Twisted form	Mega core system	
• Atrium	Leaning/tilted form	Mega column system	
• Atrium split	Fee form	Outriggered frame system	
External core		Tube system	
• Attached		• Framed-tube	
• Detached		• Trussed-tube	
• Partial split		• Bundled tube	
• Full split			
Peripheral core			
• Partial peripheral			
• Full peripheral			
• Partial split			
• Full split			

Table 2.
Core, building form, structural system, and structural material classifications.

3. Findings: main architectural and structural design considerations

As can be seen in **Table** 3, the case study buildings were designed mostly for residential purposes, and the two mixed-use cases also included residential use. Additionally, central core arrangement was the dominant core typology (only one case with peripheral core). The benefits of a central core are factors, e.g., structural contribution, compactness, making the exterior facade open to light and scenery, and facilitating fire escape, which can aid in the dominant formation of this typology.

Prismatic forms were the most common and occurred in eight case studies including HoHo (**Figure** 2). The reason why prismatic forms are common may be due to ease of workmanship, practicability, and efficient use of interior space (especially in rectangular floor plans) compared with complicated forms.

The advantages of shear wall systems in buildings up to approximately 35 stories such as construction speed, suitability for prefabrication, and sufficient rigidity to withstand lateral loads may be the reasons behind this occurrence [48] as in the case of the 22-story and 73 m high HAUT (Amsterdam, 2022) (**Figure** 3) with a concrete

#	Name	Function	Core type	Form	Structural system	Structural material	Structural description
1	Ascent	R	Central	Prismatic	Shear-walled frame	Composite	Core: RC Column: GL
2	Mjøstårnet	R/H/O	Central	Prismatic	Trussed-tube	Timber	Nonstructural core: CLT Column: GL exterior brace: GL
3	HoHo	R/H/O	Central	Prismatic	Shear-walled frame	Composite	Core: RC Column: GL
4	HAUT	R	Central	Free	Shear wall	Composite	Core: RC Shear wall: CLT
5	Brock Commons Tallwood House	R	Central	Prismatic	Shear-walled frame	Composite	Core: RC Column: GL and PSL
6	Treet	R	Central	Prismatic	Trussed-tube	Timber	Nonstructural core: CLT exterior braces, belt, outrigger: GL
7	Lighthouse Joensuu	R	Central	Prismatic	Shear wall	Timber	Core and shear wall: LVL
8	HOAS Tuuliniitty	R	Central	Prismatic	Shear wall	Timber	Core and shear wall: CLT
9	Origine	R	Central	Free	Shear wall	Timber	Core and shear wall: CLT
10	Trafalgar Place	R	Peripheral	Prismatic	Shear wall	Timber	Core and shear wall: CLT

Note on abbreviations: 'R' indicates residential; 'H' indicates hotel; 'O' indicates office; 'RC' indicates reinforced concrete.

Table 3.
Tallest timber buildings by function, core type, form, structural system, and structural material.

Figure 2.
HoHo (photo courtesy of DERFRITZ).

core and CLT shear walls. Additionally, Mjøstårnet (**Figure** 4) and Treet took the advantage of trussed-tube system, in which exterior multistory GL trusses handle the horizontal and gravity loads to ensure the required rigidity of the structure and the CLT core has a nonstructural function [49, 50].

On the other hand, the interstory drift between adjacent floors of upper stories in shear wall systems and the interstory drift between adjacent floors of lower stories in rigid frame systems are problematic issues, but shear frame systems (namely shear trussed frame and shear-walled frame systems) offer a solution where both systems compensate for each other's disadvantages as in the case of the 18-story and 58 m high Brock Commons Tallwood House (Vancouver, 2017) (**Figure** 5).

In terms of structural material, CLT was the structural material commonly used in 10 selected cases (**Table** 3). In the buildings where composite/hybrid systems were employed, concrete was utilized in all four cases. Additionally, in all case studies, the ground floor or podium was made of concrete and had a reinforced concrete core. Moreover, among them, in Ascent, mass timber residential floors were built over 5-story-concrete parking. Concrete podium construction has many advantages, including ground-level housing facilities and services, offering high clearances in public areas and large openings, and creating fireproof zones for primary mechanical

Figure 3.
HAUT (photo courtesy of Jannes Linders).

Figure 4.
Mjøstårnet (photo courtesy of Voll Arkitekter AS + Ricardo Foto).

and electrical components [51]. Furthermore, the reason for employing concrete core: (i) to provide the lateral rigidity and strength of the structure to a great extent; (ii) to take advantage of the natural resistance of concrete against fire; (iii) to benefit from

Figure 5.
Brock Commons Tallwood House (photo by Michael Elkan and courtesy of Acton Ostry Architects).

its advantage in damping wind-induced building sway, which is one of the commonly confronted issues in high-rise buildings [52].

4. Concluding remarks

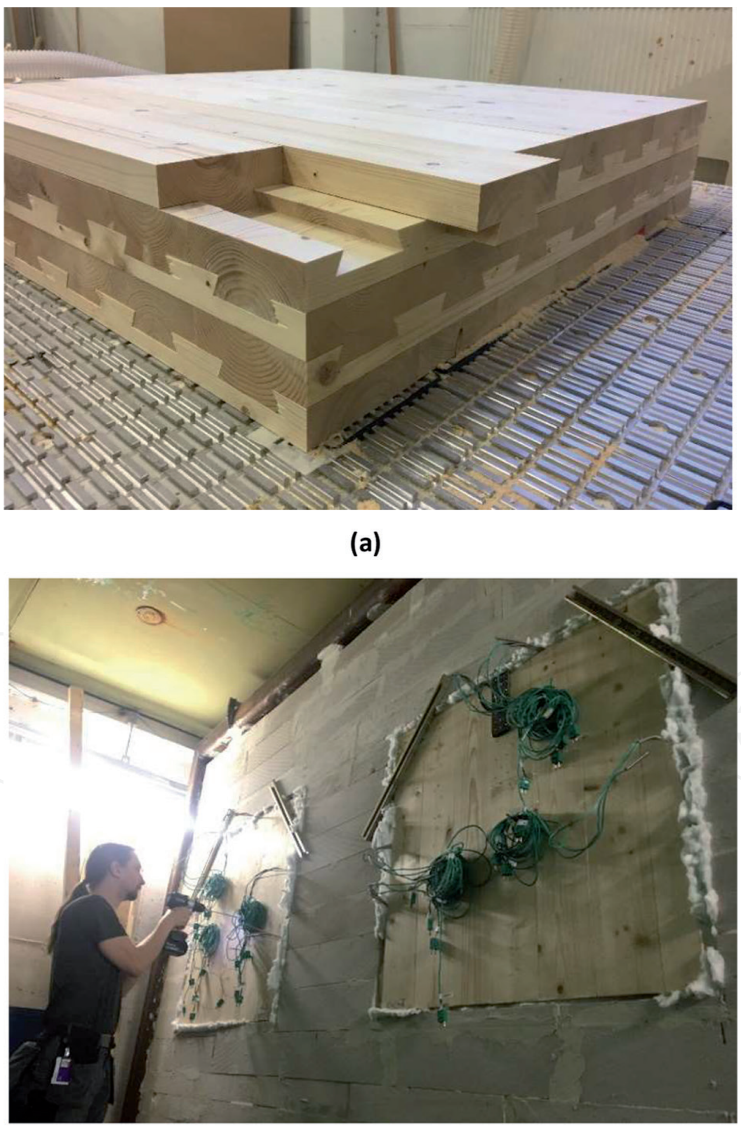
Driven predominantly by decarbonization, forest management, and timber life cycle, urbanization and intensification, and productivity in the construction industry, tall timber buildings have been at the forefront of construction practices in the global urban context for over one decade with an ever-increasing trend of height. It is thought that the analysis of the key architectural and structural design concerns of the 10 tallest buildings (one is under construction) will contribute to the planning of future timber buildings that will push the height limits.

The tallest timber buildings were mostly designed as residential. Central core arrangement was the dominant core typology. Prismatic forms were most widely used. Shear wall systems were preferred in five cases. In terms of structural material, six cases used pure wood, mostly CLT, while others opted for composite, usually concrete.

Rules, expectations, requirements, and typologies for tall wooden buildings, whose design dynamics are associated with technological developments and new construction techniques, have not yet been clarified. The diversity in the design and construction methods of these structures is still evolving to meet various building codes, market demands, contexts, and environments. This chapter has given the most up-to-date information on this pioneer building typology.

This report also has its limitations, since the empirical data presented in this chapter were limited to 10 buildings, it seems difficult to generalize about timber tall buildings of the future. On the other hand, given the increase in the number of tall timber buildings erected, further research can be conducted with larger sample groups to obtain broader generalizations and new information.

Additionally, the increase in global environmental awareness strengthens the attractiveness of timber construction, which leads the search for innovative and environmentally friendly engineered timber product solutions such as the DoMWoB



(a)

(b)

Figure 6.
(a) Dovetail massive wood board prototype manufactured at Vocational College Lapland (Ammattiopisto Lappia), Kemi, Finland; (b) Fire test specimens mounted to supporting construction made of aerated concrete blocks at Tampere University Fire Laboratory, Tampere, Finland (photos by Hüseyin Emre Ilgın).

project (Dovetailed Massive Wood Board Elements for Multi-Story Buildings); see Acknowledgments and Funding (**Figure** 6) [53] in the future. Although for example, the uptake of dovetail massive timber elements for industrial applications is very limited at the moment, with new research projects to be developed, these elements can be used more in multistory and even tall building construction.

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