Timber High-Rises in Nordic Countries: Current Trends

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Abstract

Timber high-rises have emerged as an innovative and sustainable solution for vertical urban development, with the Nordic countries leading the way in their implementation. This research paper explores the regional expression and current trends of timber high-rises in the Nordic countries. It delves into the unique architectural characteristics, environmental advantages, and the driving forces behind the growing popularity of timber high-rises in the region. The regional expression and current trends of timber high-rises in Nordic countries exemplify a harmonious blend of sustainable design, cultural identity, and environmental stewardship. Through their unique architectural characteristics, environmental advantages, and embrace of technological advancements, Nordic timber high-rises are redefining the urban landscape and setting a global benchmark for sustainable vertical construction.

Keywords: Construction, High-Rise, Scandinavia, Timber

Introduction

Wood has been an integral part of Scandinavian architecture for centuries, deeply rooted in the region's culture and history. The abundance of forests and the skillful craftsmanship of local communities have fostered a deep connection to wood as a building material. From traditional stave churches to iconic timber houses, Scandinavia's architectural heritage embraces the use of wood in various structural systems. The drawing of the Borgund Stave Church in Figure 1, for instance, shows this unique system of raised roofs, with which the tall internal posts (*staver*) are interconnected with brackets (*bueknær*). Many of these practices have been carried forward into contemporary high-rise construction. For instance, the inclined timber frame crowning Mjøstårnet, in Brumunddal, Norway, resembles a conventional single-family timber frame home with a pitched roof (see Figure 2).

By utilizing locally sourced timber, Nordic countries foster a circular economy, reducing transportation emissions and promoting regional economic growth. Regional expression also supports the United Nations'

Figure 1. Norway has a long tradition of building substantial timber structures. Borgund Stave Church, circa 1200 AD, still stands today. Drawing by G. A. Bull (Public domain).

> "Multifamily housing ranging from two to eight stories has been identified as the biggest potential market for increased use of timber in Norway."

Sustainable Development Goal (SDG) 9—"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"—by enhancing manufacturing capabilities and creating job opportunities in the timber industry. Moreover, timber high-rises embody the cultural heritage and design aesthetics of the region, contributing to the preservation of cultural identities and promoting sustainable tourism, fulfilling key aspects of SDG 11 as well: "Make cities and human settlements inclusive, safe, resilient, and sustainable."

The Cambridge sustainable development report showcases the overall performance of all 193 UN Member States, in which Finland, Denmark, Sweden, and Norway stand in the top rank of performance by SDG. The overall score measures the total progress towards achieving all 17 SDGs. The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved (Sachs et al. 2022) (see Table 1).

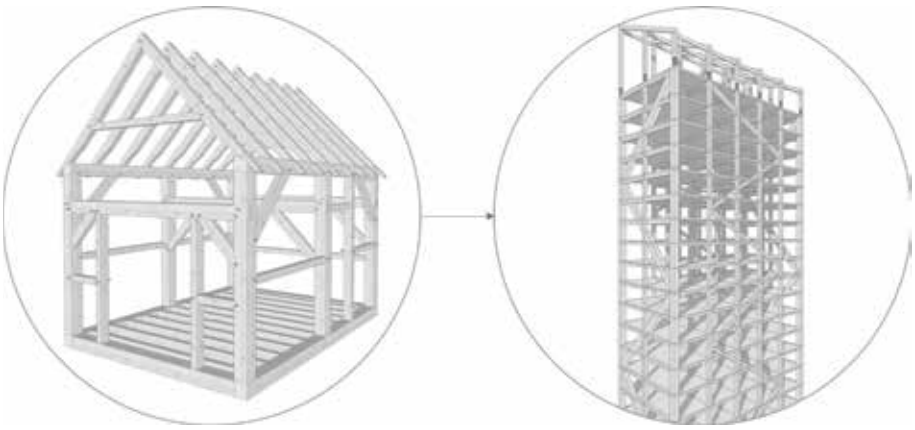

Figure 2. Principles used to construct single-family houses in timber framing have been transferred to modern high-rise structures, such as Mjøstårnet, the world's tallest all-timber building, in Brumunddal, Norway.

Rank	Country	Score	Performance by Sustainable Development Goal (SDG)
1	Finland	86.51	
2	Denmark	85.63	
3	Sweden	85.19	
4	Norway	82.35	

Table 1. The overall performance of Scandinavian countries against United Nations Sustainable Development Goals (SDG). Source: SDG Report, Cambridge 2022

Current Trends

Towers, skyscrapers, or high-rise buildings have been surging in the last century as a way of using dense urban lands more efficiently (Zahiri, Dezhdar & Foroutan 2017). Bearing in mind that approximately one third of global greenhouse gas (GHG) emissions are attributable to the construction and operation of buildings (Green & Taggart 2017), the exchange of concrete for wood gives considerable environmental advantages. Most timber buildings "require less energy during manufacturing of the elements and during the construction stage. In addition, wood is the only building material with a negative CO_2 balance" (van de Kuilen et al. 2011). Its local availability in moderate climate zones makes the material particularly suitable for the development of more sustainable construction methods (Correa, Krieg & Meyboom 2019).

Market Conditions

Does it make sense to push the limit of height of timber buildings, and to what extent, and in which geographical or social area? Wood is a commonly available material in northern Europe, which is generally regarded as a place with low population density, except in dense urban city centers.

Even so, simply by examining the market for single-family houses in Scandinavia, it is clear that wood construction is not evenly distributed. Even though building starts of wooden houses are increasing in Denmark, for example, the market share for such buildings being constructed in timber just exceeds 10 percent (see Figure 3). In Norway, Sweden and Finland, the market share of wooden houses accounts for approximately 90 percent. There is clearly greater access to timber supplies in these countries, compared to Denmark. The ready availability of wood contributes to cost-effective usage, which can explain the long tradition of high utilization of wood in the Norwegian, Swedish, and Finnish construction sectors. (Schauerte 2010). For the purpose of this study, due to the scarcity of wood suppliers in Iceland, and relatively low share of timber use in Denmark, these two Scandinavian countries are excluded from this investigation.

Despite the availability of wood in these countries, its application in multi-story timber construction is relatively low, compared to concrete and steel. While steel and concrete have to date dominated the tall building scene, wood framing has dominated single-family and low-rise residential construction (Bowyer et al. 2016). Multifamily housing ranging from two to eight stories has been identified as the biggest potential market for increased use of timber in Norway (Nygaard et al. 2019).

Obstacles to Adoption

Despite the long precedent of wood construction in conventional housing, the topic of high-rises is relatively complex and new, so constructors tend to opt for other structural systems with which they are more experienced. Despite increasing receptivity

Figure 3. Percentage of housing stock constructed in timber in five Nordic countries.

to the use of timber in multistory buildings, there are persistent contradictory viewpoints, embodied by these selected observations:

"One of the reasons for a lower share of high-rise timber buildings lies in the complexity of their design, where the architectural design, the selection of a suitable structural system, and the energy efficiency concept strongly depend on the specific features of the location, particularly climate conditions, wind exposure, and seismic hazard" (Leskovar & Premrov 2021).

"The fear of fire is probably the single largest contributor to the abandonment of wood as a construction material [for high-rises] and to its replacement by non-combustible materials. Nevertheless, some of the materials used to replace wood, although non-flammable, may ironically perform worse in cases of fire (for example, steel usually fails faster than wood and can expand, triggering faster collapse), a fact that has been largely ignored by the construction industry, building owners and regulators" (Wimmers 2017).

"Despite the many positive attributes, timber is often viewed negatively, due to the perception of an increased fire hazard, which continues to be reinforced by some model building codes" (Barber 2015).

Another issue pertaining to timber frames, which is more intense in in multistory buildings, is sound transmission between floors. This issue can be mitigated by adding insulation or sound-deadening materials to timber frames to muffle sound transmission.

Sustainability and Forest Management

In the contemporary era, there are more reasons to build taller wooden buildings for reasons of both sustainability and economic efficiency in construction (Svilans et al. 2019). Respecting solely the ecological benefits of wood as a load-bearing material in high-rise construction, the usage of timber would be even more rational in Nordic countries, with their abundance of wood resources, than steel or concrete. Wood's "renewability as a natural resource and ability to store relatively large amounts of carbon have also contributed to its [favorable] reception in a social climate sensitive to environmental concerns and the effects of global climate change" (Svilans et al. 2019). Steel accounts for about 4 percent of global energy use (Green & Taggart 2017), whereas the renewable material of wood is naturally "manufactured" by the sun.

Sustainable Forest Management (SFM)

protocols ensure that "the quantity of wood fiber harvested does not exceed the quantity of wood fiber produced by tree growth on an annual basis, nor compromises the ecological services the forest provides" (Green & Taggart 2017). This is despite the fact that associated wood in construction reduces GHG emissions. In Scandinavia, timber is a resource that grows faster than it is consumed.

Regulation

As of now, there is no common and specific regulation regarding wooden load-bearing structures in Scandinavia, though these countries are generally moving in the direction of allowing higher structures. Sweden was the first of the Scandinavian countries to change regulations in 1994, allowing unrestricted use of wood in bearing structures, as long as the functional requirements are fulfilled (see Table 2). In 1997, Norway introduced regulation changes, requiring that high-rise buildings can use timber so long as fire-resistance requirements are met. Denmark followed in 1999 by implementing changes allowing for four-story houses to be built in wood, and from 2004, without limitation on the number of stories (Schauerte 2010). Finnish building regulations have permitted the erection of tall timber buildings since 2011. Timber buildings up to eight stories high can be constructed according to standard Finnish fire regulations; buildings taller than that require a functional fire design analysis (Karjalainen, Ilgın & Tulonen 2021). The fire safety provisions basically increased the

growth of high-rise construction in the past. Each Nordic country has introduced its own regulation, and thus, there is an inconsistency of requirements and standards across the region. Table 2 shows the number of stories allowed with wood as bearing material in Scandinavian countries over the course of time. Nevertheless, practical concerns have limited construction higher than eight stories in most cases (Schauerte 2010).

It is notable that "multistory" implies "more than one story," but in the context of timber buildings discussed in this paper, "multistory" is defined as "having more than four stories," and "high-rise" refers to buildings surpassing 24 meters. These divisions are categorized in Table 3.

As of now, many building codes allow for the use of timber as a load-bearing material in high-rises; but most are hybrid structures, using concrete for the core and foundation, and steel for connections. The most typical arrangement will be one story in another structural system and the rest in timber; using concrete strategically can significantly increase the horizontal stability of high-rise structures. "Concrete and timber work well together, typically with the concrete as a thin floor slab supported by shear-linked laminated veneer lumber (LVL) or glued laminated timber (GLT) beams beneath.

	Until 1993	1994	1997	2004	2011
Sweden	2	∞	∞	∞	∞
Norway	2	3	∞	∞	∞
Finland	3	2	4	4	∞
Denmark	1–2	1–2	1–2	∞	∞

Table 2. Number of stories allowed for buildings with wood as load-bearing material in Scandinavia.

	Divisions	Stories	Height
Multistory Building	Low-rise	1 to 3 stories	Up to 12 meters
	Mid-rise	4 to 8 stories	Between 12 and 24 meters
	High-rise	More than 8 stories	Higher than 24 meters

Table 3. Classifications of multistory buildings used in this paper.

System	Subsystem	Products
All-Timber	CLT Platform FFTT Short Post & beam Stud framing	CLT CLT, GLT, LVL, GLT, LVL, Parallam Dimension Lumber, Plywood, OSB
Concrete-Timber Hybrid	CREE solutions Concrete-joined frame Core braced system	GLT, TCC GLT, TCC CLT, GLT, LVL, TCC
Steel-Timber Hybrid	Pre-stressed cable Steel bracing Steel core FFTT Tall	GLT, CLT CLT, GLT, LVL GLT GLT, CLT

Key:
CLT = Cross-laminated timber
CREE = Proprietary concrete-timber prefabricated system
FFTT = Proprietary all-timber core and post-and-beam system
GLT = Glued laminatedtimber
LVL = Laminated veneer lumber
OSB = Oriented strand board
TCC = Timber-concrete composite

Table 4. Three primary structural systems and subsystems cited in this paper.

Several prefabricated floor panel versions of this timber-concrete combination have been used in recent multistory buildings (Arup 2019).

There are three primary structural approaches to taller wood structures; All-Timber, Concrete-Timber Hybrid, and Steel-Timber Hybrid. An outline of these construction systems is detailed in Table 4.

Timeline and Future Progress

Many of the pioneering wood high-rises have been constructed in Sweden and Norway. In Sweden, Limnologen, Växjö (2009) and outstanding pilot projects in Norway, including Pentagon II (2013) in Oslo, Treet (2014) in Bergen, and Mjøstårnet (2019) in Brumunddal, are amongst the pioneer tallest wood buildings. Figure 4 illustrates the location of these buildings on a map.

Table 5 shows the chronological progression of the tallest timber buildings in Scandinavia, all of which employ extensive use of LVL, GLT or and cross-laminated timber (CLT) elements.

> "There is no common and specific regulation regarding wooden load-bearing structures in Scandinavia, though these countries are generally moving in the direction of allowing higher structures."

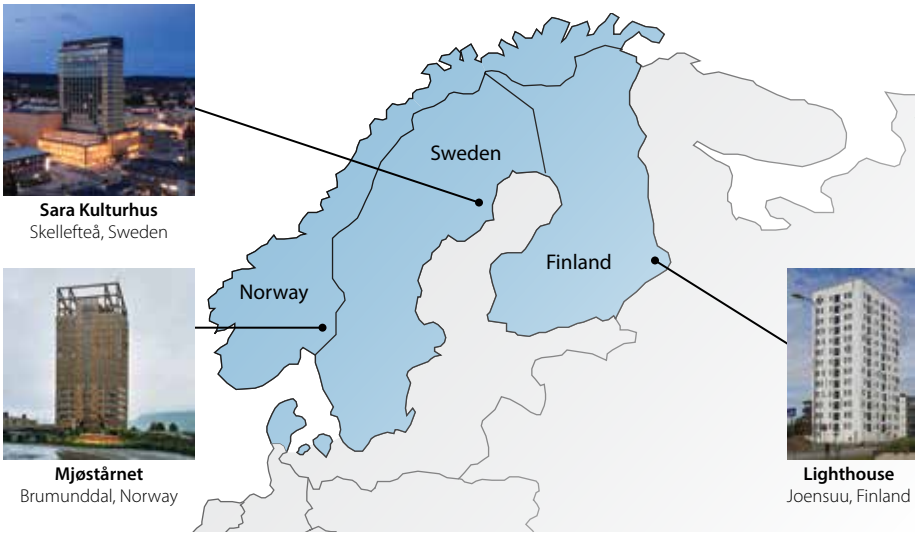

Figure 4. Pioneer instances of high-rise timber construction in Norway, Sweden, and Finland.

Building Name	City, Country	Stories	Height	Year	Structural System
Lagerhuset	Eslov, Sweden	10	31 m	1918*	All-Timber
Limnologen	Växjö, Sweden	8	27 m	2009	Concrete-Timber Hybrid
Pentagon II	Ås, Norway	8	24 m	2013	All-Timber
Treet	Bergen, Norway	14	49 m	2014	All-Timber
Moholt 50/50	Trondheim, Norway	9	28 m	2016	Concrete-Timber Hybrid
Puukuokka	Jyväskylä, Finland	8	27 m	2018	All-Timber
Lighthouse	Joensuu, Finland	14	48 m	2019	Steel-Timber Hybrid
Mjøstårnet	Brumunddal, Norway	18	85 m	2019	All-Timber
Sara Kulturhus	Skellefteå, Sweden	20	73 m	2021	Steel-Timber Hybrid

(*) Retrofitted in 2008, converted from industrial to residential use

Table 5. Selected list of pioneering tall wood buildings in Nordic countries.

The higher buildings tend to use a hybrid construction with concrete and/or steel.

Looking to the near future of timber technology, several exemplary projects can inspire the design of next-generation timber towers. Arup completed HAUT, a 21-story tower in Amsterdam, in 2020 (see Figure 5). Meanwhile, C.F. Moller and Anders Berensson Architects plan 34-story and 40-story skyscrapers respectively, both in Stockholm. Figure 6 shows Tham & Videgård's Wooden High-Rise Housing proposal for Stockholm.

Also, PLP Architecture and Cambridge University's proposal for an 80-story, 300-meter high wooden building integrated within London's Barbican Centre" (Buffi & Angelini 2019) (see Figure 7).

This positive trend of timber construction achieving new height parameters appears to be sustainable. There are national projects initiatives encouraging mass timber construction, such as "Norwegian Wood," initialized in 2008 within Norway's Stavanger region, "Modern Wooden Town," launched in 1999 in Finland (see Figure 8), and a national strategy called "More Wood in Construction," implemented in 2004 in Sweden. Moreover, a larger project, "Nordic Wooden Cities," intended to foster cross-region collaboration in timber construction in Denmark, Norway, Sweden, Finland, and Iceland, has been

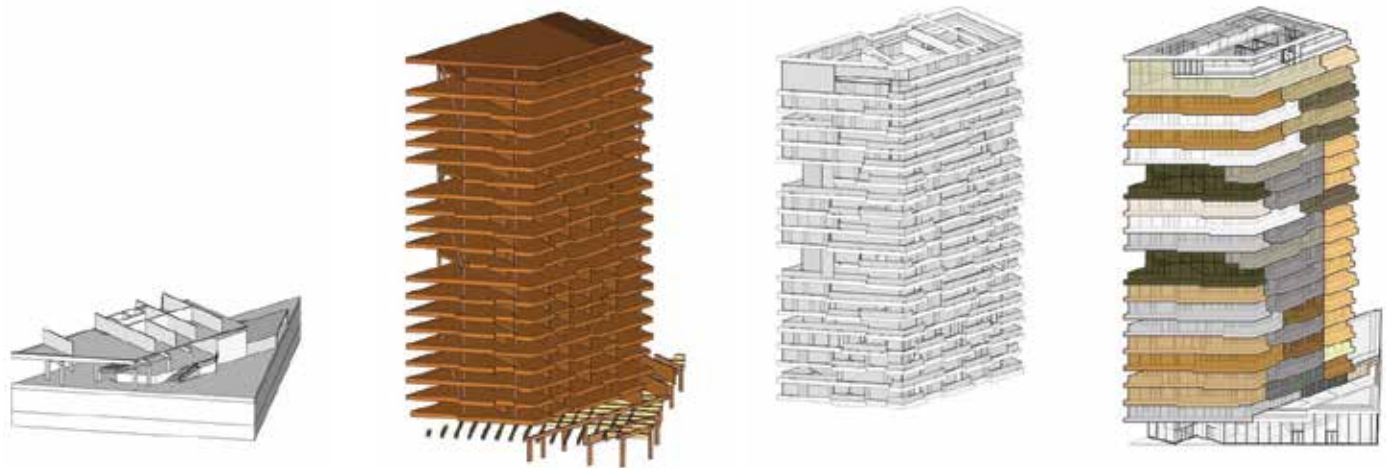

Figure 5. Haut, a 21-story tower in Amsterdam. From left to right: concrete base, load-bearing timber structure, glass façade, multiple apartment layouts. © Jannes Linders/Team V Architecture

Figure 6. Tham & Videgård proposed a wooden high-rise housing project, Stel Torn En, for Folkhem in Stockholm. © Tham & Videgård Arkitekter

Figure 7. Oakwood Tower, London, PLP Architecture and Cambridge University's 80-story proposal. © PLP Architecture

Figure 8. "Modern Wooden Town" (Wood City), Helsinki. © Daniel Safarik

operating since 2010 in the region (Schauerte 2010). These series of linked projects have the power to move multiple disciplines and sectors in wood construction in the same direction.

Discussion and Conclusion

The Nordic countries in the current investigation: Norway, Sweden, and Finland, have a rich tradition of wood-based construction. Timber high-rises in the region embrace a regional expression that reflects cultural heritage, design aesthetics, and harmonious integration with the surrounding natural environment. Nordic timber high-rises often feature clean lines, minimalist design, and a blend of traditional craftsmanship with contemporary architectural techniques. This regional expression not only showcases the unique identity of the Nordic countries, but also emphasizes sustainability and connection to nature.

The Nordic countries possess advanced manufacturing capabilities, making them ideal for producing timber-based construction systems. Nordic manufacturing industries emphasize technological innovation, precision engineering, and sustainable practices. They have developed cutting-edge techniques for timber processing, including CLT and GLT, enabling the efficient production of prefabricated components for high-rise construction. The manufacturing expertise in the Nordic region facilitates the scalability and cost-effectiveness of timber high-rise projects, while adhering to stringent quality standards and sustainability principles.

Timber as a building material offers significant environmental advantages, which align with the sustainability goals of the Nordic countries. Timber is renewable, recyclable, and has a lower carbon footprint compared to traditional construction materials like concrete and steel. Timber high-rises act as carbon sinks, sequestering carbon dioxide throughout their lifecycle, thereby mitigating climate change. The use of sustainably sourced timber in Nordic countries promotes responsible forest

management and supports the preservation of biodiversity. The environmental benefits of timber high-rises contribute to the region's commitment to sustainable development and the achievement of national and international environmental targets.

The current trends of multistory timber buildings in the Nordic region could be summarized as below:

1. *Prefabrication and Modular Construction*
   Nordic countries have embraced prefabrication and modular construction techniques for timber high-rises. Off-site fabrication allows for precise manufacturing, quality control, and reduced construction time. This trend enables efficient resource utilization and minimizes waste generation.

2. *Integration of Technology*
   The Nordic region has been at the forefront of integrating technology into timber construction. Building Information Modeling (BIM) and advanced digital design tools aid in the optimization of structural performance, energy efficiency, and construction processes. Robotics and automation are also being employed for efficient manufacturing and assembly.

3. *Tall Timber Structures*
   Nordic countries have been pushing the boundaries of timber construction by creating taller and more ambitious timber high-rises. Technological advancements, such as CLT and GLT, have made it possible to achieve greater heights and structural integrity. The construction of tall timber structures demonstrates the region's commitment to innovation and sustainable urban development.

4. *Multi-Functional and Sustainable Design*
   Nordic timber high-rises often incorporate multi-functional design features, such as green roofs, solar panels, and rainwater harvesting systems. These sustainable design elements contribute to energy efficiency, enhance occupant well-being, and promote a holistic approach to sustainable development.

Several factors have contributed to the rise of timber high-rises in the Nordic countries:

- Strong wood-based construction traditions and expertise in the region.
- Government support through regulations, incentives, and funding for sustainable construction.
- Growing public awareness and demand for sustainable and environmentally friendly buildings.
- Collaboration between architects, engineers, researchers, and manufacturers to innovate and advance timber construction techniques.
- Knowledge sharing and international recognition of successful timber high-rise projects, inspiring further development, and investment in the sector.

The regional expression and current trends of timber high-rises in Nordic countries exemplify a harmonious blend of design, cultural identity, and environmental stewardship. Through their unique architectural characteristics, environmental advantages, and embrace of technological advancements, Nordic timber high-rises are redefining the urban landscape and setting a global benchmark for sustainable vertical construction. ■

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