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Daniel Safarik is director, research and thought leadership at CTBUH. His responsibilities include providing high-level directional oversight for the Council's research functions, data studies, topical publications, and dedicated tall building database. Additional responsibilities include the development of content for CTBUH publications, particularly the CTBUH Journal. Safarik interfaces directly with the CTBUH President to identify topics and areas in need of detailed exploration and research, then engages analysts, writing staff, and production/digital team members to execute projects using clear operational workflows.

Jake Elbrecht is a research associate at CTBUH. In this role, Elbrecht provides experience both with mass timber structural systems as well as running life cycle analyses. His interest in low-carbon architecture has driven a desire to understand the intersection of cost and carbon in the built environment. Elbrecht is a 2020 graduate of Auburn University and holds a Master of Science in Architecture from Auburn's design-build program, Rural Studio. During his graduate studies, he worked with a team of three other students to test a novel alternative to conventional insulation and heating methods—the Breathing Wall—while utilizing mass timber building enclosures.

William Miranda is the research manager for the CTBUH Headquarters office in Chicago. Previously a research assistant for CTBUH Research Office at the IUAV University of Venice, Italy, he has been involved with a number of CTBUH research activities, including "Creating Industry-Accepted Criteria for Measuring Tall Building Floor Area" sponsored by ArcelorMittal, "Study on the Properties of Composite Megacolumns" sponsored by ArcelorMittal, "A Study on Tall Building Damping Technologies" sponsored by Bouygues Construction, "Cyclone Glazing and Façade Resilience for the Asia-Pacific Region" sponsored by Trosifol, and "Green Living Technologies: What is Missing in the International Standards?" sponsored by Underwriters Laboratories.

Abstract

The past few years have seen tremendous interest in the development of mass timber buildings of increasing height, in urban settings, many of which are hybrid structures with other materials. This study identifies 84 mass timber buildings of eight floors or higher, currently completed or under construction around the world, with analysis by region, function, and structural type. The accumulated knowledge around these projects continues to grow, embracing proposed buildings, and will inform future inquiry for the tall building industry. The data collection is supported by, and related to, research projects currently being conducted by CTBUH, and the network of CTBUH member firms contributing data on their projects.

Keywords: Carbon, High-Rise, Prefabrication, Steel-Timber Hybrid

Introduction

In 2017, the Council on Tall Buildings and Urban Habitat published "Tall Timber: A Global Audit" (CTBUH 2017). This three-page data study accounted for all 48 known mass-timber projects of seven stories or higher that had either been proposed, were under construction, or were completed.

This paper and the accompanying data study (see Tall Buildings in Numbers, page 30) represent the momentum the mass-timber movement has gained over the five years elapsed since the previous study, including the evolution of building codes to allow much higher mass-timber construction. There are now more than 200 mass timber buildings around the world of seven stories or higher, proposed, under construction, or completed, more than a four-fold increase. The tallest in the world is Mjøstårnet, Brumunddal, Norway (see Figure 1) at 85.3 meters and 18 floors, but this building is set to be eclipsed by Ascent, Milwaukee, USA, at 86.5 meters and 25 floors, upon the completion of the latter building in August 2022 (see Figure 2).

Range of Dataset and Survey Methods

The data in this study have been collected over nearly a decade of scholarship, ranging from papers published by CTBUH members in the CTBUH Journal, to volunteer research committees and conference presentations. More recently, CTBUH has undertaken several funded research projects exploring various aspects of mass timber as used in high-rises (see "CTBUH Mass Timber Research Projects," page 29). Virtually all timber projects that come to the attention of the

Figure 1. Mjøstårnet, Brumunddal, Norway, is the current world's tallest timber building, at 85.3 meters and 18 floors. © Nina Rundsveen

Figure 2. Ascent, Milwaukee, USA, 86.5 meters and 25 floors, is expected to become the world's new tallest timber building when it completes in August 2022. © C. D. Smith Construction

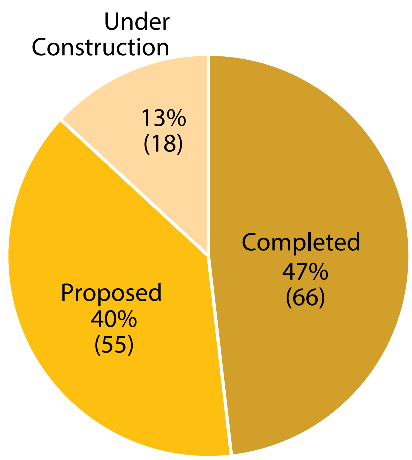

Figure 3. Mass timber high-rise buildings worldwide, 8 stories and higher, grouped by project stage, as of February 2022. Total No. = 139.

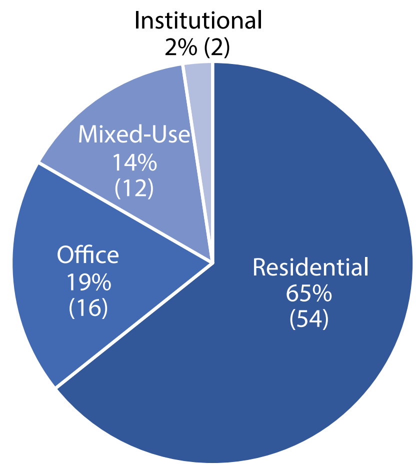

Figure 4. Mass timber high-rise buildings worldwide, built or under construction, 8 stories and higher, as of February 2022, grouped by function. Total No. = 84.

CTBUH Research and Thought Leadership team, via news articles, organizational member interactions, planning submissions, academic publishing, and so on, are entered into a master database.

To maintain a high level of confidence and consistency across the report, the researchers set a minimum height threshold of eight stories above grade. This yields a total of 139 buildings that are either proposed, under construction or completed (see Figure 3).

Limiting the study to buildings under construction or completed reduces the dataset to 84 buildings of at least eight stories' height. The 40 tallest of this group are listed in Table 1.

Summary of Results

The results of the audit are presented in the following paragraphs, in categories that correlate to those used on the CTBUH Tall & Urban Database and in CTBUH annual "Year in Review" data studies.

By Function

The predominant functional use of mass-timber high-rises globally has been residential/hotel, comprising 54 buildings, or 65 percent of the total. This is followed by office use, with 16 buildings (19 percent), mixed-use at 12 (14 percent) and institutional representing just 2 percent (see Figure 4). This correlates with mass timber's well-reported benefits. Many developers choose the material for its aesthetic appeal, exposing structure and paneling inside residential units or common areas. The cellular nature of the cross-laminated timber (CLT) panel systems also correlates strongly with the smaller rooms common to hotels and residential buildings. And the typical heights of multi-family housing in many parts of the world correlate to the maximum allowable building heights of mass timber structures per local fire codes.

The biophilic benefits of timber also reinforce the value of exposing the material in commercial offices, which is expected to be a differentiating factor as companies compete to lure current workers back to the office and recruit new ones. This is driving a leasing premium for mass timber office buildings, whose numbers are expected to increase in the near future.

By Region

As the birthplace of mass timber technology, and home to mature managed forests and some of the most stringent environmental regulations in the world, it is unsurprising that Europe is the leader in terms of regions with the most high-rise timber buildings—some 71 percent of the total (see Figure 5). This is followed by North America, home to the world's largest managed forests and a long history of building with wood (if not mass timber), at 18 percent.

Australia, with 10 percent of the total, has some of the world's best-known and earliest mass-timber high-rise buildings, including Forte, Melbourne, and 25 King, Brisbane (see Figure 5, and page 14), which is all the more remarkable, given that the nation has a

Rank	Building Name	City, Country	Height (m)	Floor Count	Structural System	Function	Status (as of Feb 2022)	Completion Year
1	Ascent	Milwaukee, USA	86.6	25	Concrete-Timber Hybrid	Residential	Under Construction	2022
2	Mjøstårnet	Brumunddal, Norway	85.4	18	All-Timber	Mixed-Use	Completed	2019
3	HoHo	Vienna, Austria	84.0	24	Concrete-Timber Hybrid	Mixed-Use	Completed	2020
4	Haut	Amsterdam, Netherlands	73.0	22	Concrete-Timber Hybrid	Residential	Under Construction	2022
5	Sara Kulturhus	Skellefteå, Sweden	72.8	19	Steel-Timber Hybrid	Mixed-Use	Completed	2021
6	De Karel Doorman	Rotterdam, Netherlands	70.5	22	Concrete-Steel-Timber Hybrid	Mixed-Use	Completed	2012
7	55 Southbank	Melbourne, Australia	69.7	19	Concrete-Steel-Timber Hybrid	Mixed-Use	Completed	2020
= 8	Roots Tower	Hamburg, Germany	65.0*	19	Concrete-Timber Hybrid	Residential	Under Construction	2023
= 8	Wellington	Melbourne, Australia	65.0*	15	Concrete-Timber Hybrid	Office	Under Construction	2023
= 10	Baufeld 1 Suurstoffi Abro	Risch-Rotkreuz, Switzerland	60.0	15	Concrete-Timber Hybrid	Mixed-Use	Completed	2019
= 10	Kromet	Gothenburg, Sweden	60.0*	15	Concrete-Timber Hybrid	Mixed-Use	Under Construction	2022
12	Brock Commons Tallwood House	Vancouver, Canada	57.9	18	Concrete-Timber Hybrid	Residential	Completed	2017
13	Eunoia Junior College	Singapore, Singapore	56.0	12	Concrete-Timber Hybrid	Institutional	Completed	2019
= 14	Hyperion	Bordeaux, France	55.0	16	Concrete-Steel-Timber Hybrid	Residential	Completed	2021
= 14	Rundeskogen Hus B	Sandnes, Norway	55.0*	16	Concrete-Timber Hybrid	Residential	Completed	2013
16	Albizzia	Lyon, France	53.0	17	Concrete-Timber Hybrid	Mixed-Use	Under Construction	2023
17	Ngytan Koriayo Geelong Civic Precinct	Greater Geelong, Australia	52.0*	12	Concrete-Timber Hybrid	Office	Under Construction	2022
18	503 on Tenth	Portland, USA	50.0	10	All-Timber	Office	Under Construction	2023
19	Treet	Bergen, Norway	49.0	14	All-Timber	Residential	Completed	2015
20	Lighthouse Joensuu	Joensuu, Finland	48.0	14	Steel-Timber Hybrid	Residential	Completed	2019
21	25 King	Brisbane, Australia	46.8	11	All-Timber	Office	Completed	2018
22	2150 Keith Drive	Vancouver, Canada	45.0	10	Concrete-Timber Hybrid	Office	Under Construction	2022
= 23	Cederhusen	Stockholm, Sweden	44.0*	13	All-Timber	Residential	Under Construction	2023
= 23	Hoas Tuuliniitty	Espoo, Finland	44.0*	13	All-Timber	Residential	Completed	2021
= 23	Palazzo Nice Meridia	Nice, France	44.0*	10	Concrete-Timber Hybrid	Office	Completed	2019
26	T3 Bayside	Toronto, Canada	42.0	10	All-Timber	Office	Under Construction	2023
27	Tallwood 1 at District 56	Langford, Canada	41.6	12	Steel-Timber Hybrid	Residential	Under Construction	2022
28	Origine	Quebec, Canada	40.9	13	All-Timber	Residential	Completed	2017
29	T3 Sterling Road Building 5A	Toronto, Canada	39.8	8	Steel-Timber Hybrid	Office	Under Construction	2023
30	INTRO Residential Tower	Cleveland, USA	39.6	9	Concrete-Timber Hybrid	Mixed-Use	Under Construction	2022
31	77 Wade	Toronto, Canada	38.2	8	Concrete-Steel-Timber Hybrid	Office	Under Construction	2022
32	Sensations	Strasbourg, France	38.0	11	All-Timber	Mixed-Use	Completed	2018
= 33	Monterey	Brisbane, Australia	37.0	11	Concrete-Steel-Timber Hybrid	Residential	Under Construction	2022
= 33	Rundeskogen Hus C	Sandnes, Norway	37.0*	11	Concrete-Timber Hybrid	Residential	Completed	2013
35	Trafalgar Place	London, UK	36.3	10	All-Timber	Residential	Completed	2015
= 36	Aveo Bella Vista	Sydney, Australia	36.0	11	Concrete-Timber Hybrid	Residential	Completed	2018
= 36	Suurstoffi 22	Risch-Rotkreuz, Switzerland	36.0	10	Concrete-Timber Hybrid	Office	Completed	2018
= 38	Green Office Enjoy	Paris, France	35.0*	8	Concrete-Steel-Timber Hybrid	Office	Completed	2018
= 38	Opalia	Saint-Ouen-sur-Seine, France	35.0*	8	Concrete-Steel-Timber Hybrid	Office	Completed	2017
= 38	Pont de Flandres Batiment 007	Paris, France	35.0*	8	Concrete-Steel-Timber Hybrid	Office	Completed	2019
= 38	Wood and Innovation Design Centre	Prince George, Canada	35.0*	8	All-Timber	Office	Completed	2014

Table 1. The tallest 40 mass timber buildings worldwide, completed or under construction, as of February 2022. Please note that heights marked with an (*) are estimated, based on the floor count of the building. The estimate has been arrived at by analyzing thousands of other buildings of the same function on the CTBUH database that do have confirmed heights. See height calculator at skyscrapercenter.com/height-calculator. For the full list of 84 mass timber buildings, eight stories and higher, go to ctbuh.org/mass-timber-buildings.

relatively small timber industry. Most materials are shipped tens of thousands of kilometers overseas from Europe. Asia brings up the rear with only two buildings in the dataset, though this can be expected to grow significantly in coming years.

By Structural Material

It was equally important to define the structural materials used in each of the buildings in the audit. The major categories are defined as All-Timber, Concrete-Timber Hybrid, Steel-Timber Hybrid, and Concrete-Steel-Timber Hybrid structures. In Figure 6, the pie chart illustrates the breakdown of the dataset, grouped by structural material combination.

- *All-Timber Structures*
  To qualify as an "all-timber" structure, both the main vertical and lateral structural elements must be constructed from timber. An "all-timber" structure may include the use of localized non-timber connections between timber elements. A building of timber construction with a floor system of concrete planks, or concrete slab on top of timber beams, is still considered a "timber" structure, as the concrete elements are not acting as the primary structure (CTBUH 2019). A well-known example is Treet, Bergen, Norway (see Figure 7).

- *Concrete-Timber Hybrid Structures*
  In these buildings, a significant element of the vertical or lateral load-bearing system is made of concrete, often presented as a concrete core supporting a timber frame. Other commonly seen examples include buildings that use lateral spanning elements, such as beams, and vertical load bearing columns made of concrete, with timber serving as the main floor decking system. Several of the factory-prefabricated systems on the market integrate concrete frames with timber inlay panels for walls or flooring, or timber-framed modules with pre-poured concrete flooring. The current tallest concrete-timber hybrid building is HoHo, Vienna, Austria, at 84 meters and 24 floors (see Figure 8).

- *Steel-Timber Hybrid Structures*
  In buildings with timber-steel hybrid structures, a significant element of the vertical or lateral load-bearing system is made of steel. Most typically, this will be a lateral force resisting system such as steel-framed cores, buckling-restrained braces, perimeter-frame or exoskeleton

Figure 7. Treet, Bergen, Norway, is the second-tallest all-timber building in the world currently, standing at 49 meters and 14 floors. © Sparrow (cc by-sa)

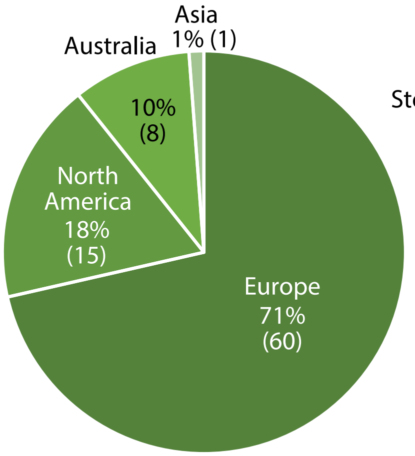

Figure 5. Mass timber high-rise buildings worldwide, 8 stories and higher, built or under construction, as of February 2022, grouped by region. Total No. = 84.

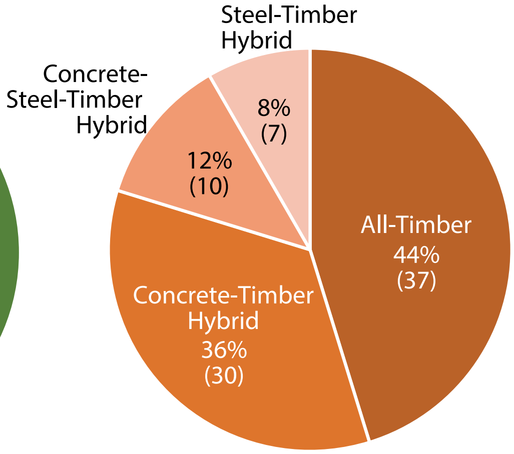

Figure 6. Mass timber high-rise buildings worldwide, 8 stories and higher, built or under construction, as of February 2022, grouped by structural type. Total No. = 84.

Figure 8. HoHo, Vienna, Austria (84 meters, 24 floors), completed in 2018, is the world's current tallest concrete-timber hybrid building. © DERFRITZ - Fotograf (cc by-sa)

Figure 9. Sara Kulturhus, Skellefteå, Sweden (73 meters, 19 floors), is the world's current tallest steel-timber hybrid building.© White Arkitekter / Åke Eson Lindman

Figure 10. De Karel Doorman, Rotterdam, Netherlands (70.5 meters, 22 floors), is the world's current tallest concrete-steel-timber hybrid structure. The design approach was chosen to facilitate a new residential tower atop an existing 1948 department store. © Fred Romero (cc by-sa)

steel bracing systems and a gravity system composed of columns and beams that interact with a timber floor or wall system. Generally, this structural classification is meant to reflect a substantial use of steel, beyond the fasteners and connectors used in typical mass timber and wood-frame construction. The current tallest steel-timber hybrid building is Sara Kulturhus, a mixed-use building in Skellefteå, Sweden (see Figure 9).

- *Concrete-Steel-Timber Hybrid Structures* These buildings use a combination of all three materials to carry primary loads. The most typical combination would be a concrete core working in tandem with steel beams and columns, with timber flooring and partition walls, but many variations exist. The current tallest concrete-steel-timber hybrid building is De Karel Doorman, Rotterdam, Netherlands, at 71 meters and 22 floors—the majority of which are included in a lightweight hybrid tower constructed on top of an existing 1951 department store (see Figure 10).

In terms of the structural material combinations identified previously, some interesting patterns emerge. The largest group of the buildings, 37 of the 84 in the eight-story-and-higher range, have an all-timber structure, followed by timber-concrete, timber-steel-concrete and timber-steel hybrids. On its face, this can seem surprising, because it is generally assumed that the flexural tendencies and light weight of timber relative to other materials would be an inhibitor to height, and that some kind of hybrid or composite structure would be necessary to achieve greater heights. A breakdown of the distribution of the various structural material combinations is shown in Figure 11.

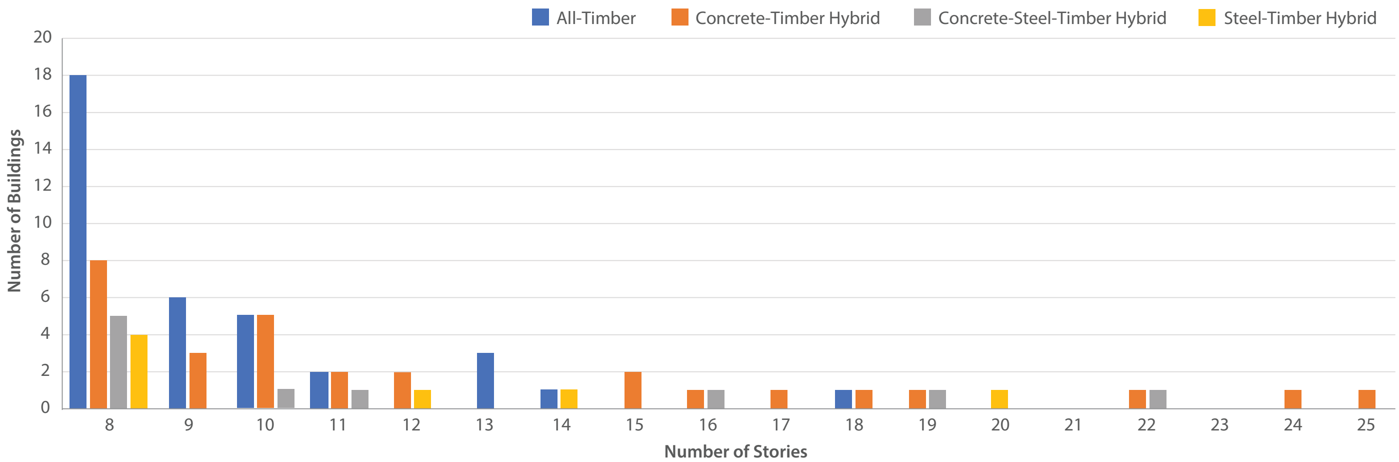

Figure 11. Distribution of mass timber buildings, eight stories and higher, worldwide, by number of floors and structural material combination. Data is accurate as of February 2022.

Structural Material	No. of Buildings	Framing Type	No. of Buildings	% Buildings per Framing Type
All-Timber	37	Load-Bearing Wall	26	30.9%
		Post and Beam	8	9.5%
		Preassembled	3	3.6%
Concrete-Timber Hybrid	30	Load-Bearing Wall	8	9.5%
		Post and Beam	18	21.4%
		Preassembled	4	4.8%
Concrete-Steel-Timber Hybrid	10	Load-Bearing Wall	1	1.2%
		Post and Beam	9	10.7%
		Preassembled	0	0%
Steel-Timber Hybrid	7	Load-Bearing Wall	3	3.6%
		Post and Beam	3	3.6%
		Preassembled	1	1.2%
Total			**84**	**100%**

Table 2. Distribution of framing types across structural material combinations, under-construction, or completed mass timber buildings, eight stories and higher, worldwide as of February 2022.

Structural Material Combinations by Framing Type

Each of the four structural material combinations can be further broken down into three framing types, based on whether loads are distributed through walls, a post-and-beam system, or a modular system composed of prefabricated units.

As the highly versatile CLT panel is very commonly used in mass timber construction generally, it is perhaps unsurprising that, of the 39 all-timber structures of eight stories or higher, 26 are load-bearing wall systems. A total of 30.9 percent of all the projects in the dataset are all-timber load-bearing wall systems (see Table 2).

The second-most common framing type is the post-and-beam system, representing 21.4 percent of the timber-concrete hybrid systems, 90 percent of the timber-steel-concrete hybrid systems. In all, 16.7 percent of the dataset consists of timber-concrete hybrid systems with post-and-beam framing.

Cross-Comparisons by Region

Some illuminating comparisons can be made across the modes of analysis cited above, illustrating the somewhat different development of high-rise mass timber in regional markets.

Europe has the greatest number of completed projects (54), with a further 22 proposed. In North America, there are far more proposed and under construction projects (26 and nine, respectively) than completed (six). In Australia, there are five proposed, three under construction, and five completed buildings of eight stories and higher. In Asia, there are two

> “A total of 31 percent of all the buildings in the 84-building dataset are all-timber load-bearing wall systems.”

completed buildings, only one proposed, and none currently under construction. There is no mass-timber construction activity to speak of in Africa or South America (see Figure 12).

In Figure 12, the statistics generally reflect the maturity of the market in each region, as the technology for mass timber originated in Austria in the 1990s and spread throughout Europe, with a few pioneering projects of note in Australia in the first decade of the 2000s, followed by North America, and most recently Asia.

With respect to materials used in the primary structure, the same pattern holds. Europe has the greatest number (29) and proportion (49 percent) of all-timber structures, while North America comes out quite evenly between all-timber, timber-concrete, and timber-steel solutions (see Tall Buildings in Numbers, page 30). Each individual project will have its own set of circumstances that dictate the most economical and practical choice of materials, subject to the economics of steel, timber and concrete in each city, let alone region. But some generalizations can be made.

The prevalence of all-timber structures in Europe may be partly due to the proximity of timber forests to project sites; environmental objectives, such as demonstrating adherence to carbon footprint-reduction goals; or a preponderance of projects near the lower end of the height range studied.

The higher proportion of steel-timber hybrid structures in North America may be partly reflective of the flexibility and performance of steel under seismic conditions, which prevail in areas that also have a significant timber economy, such as the Pacific Northwest in the United States and British Columbia in Canada.

The lower number of projects in Australia should raise caution around making sweeping generalizations, but it is

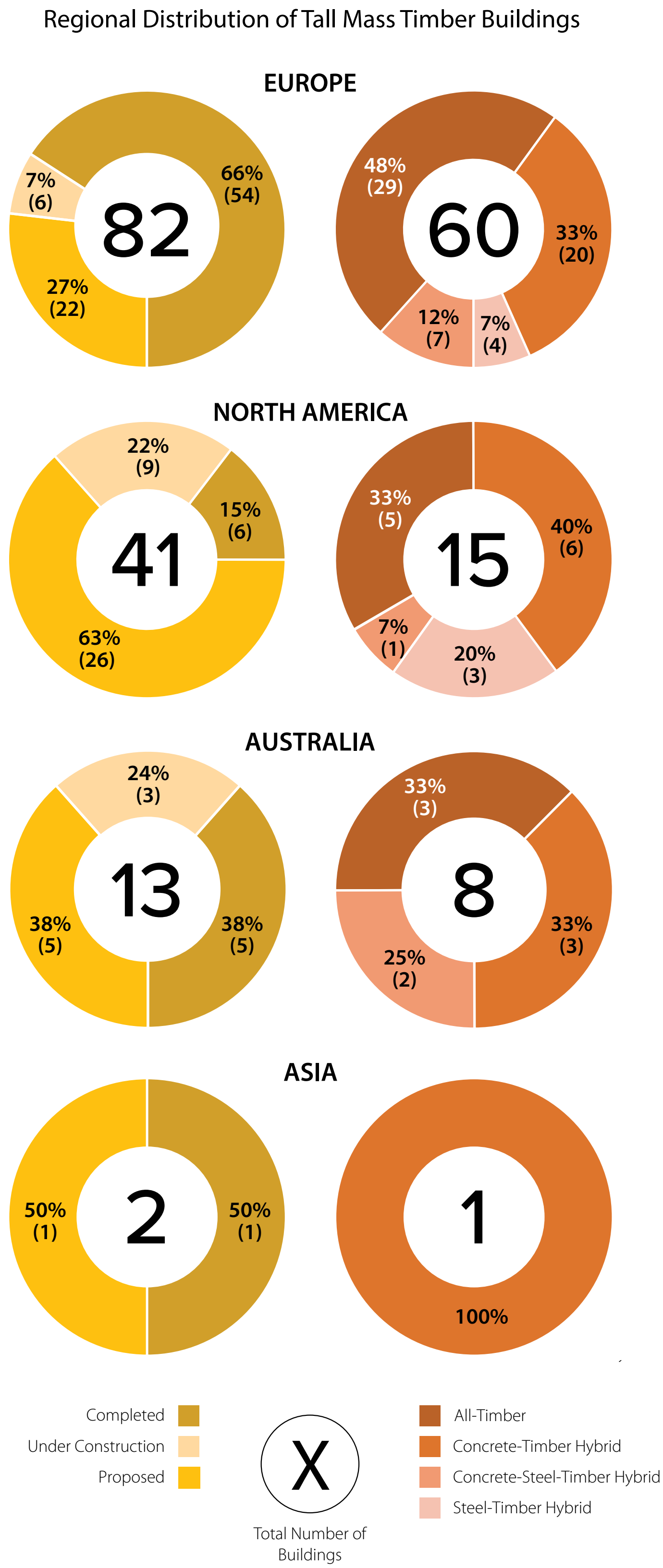

Figure 12. Left column: number of proposed, complete or under construction mass timber buildings, 8 stories or higher, per region. Right column: structural composition of complete or under-construction buildings, 8 stories or higher, per region.

remarkable that the largest group is all-timber structures, when considering that nearly all timber used for construction is imported.

> “The higher proportion of steel-timber hybrid structures in North America may be partly reflective of the flexibility and performance of steel under seismic conditions, which prevail in areas that also have a significant timber economy.”

What’s Next

The near future of high-rise mass timber appears bright. Worldwide, there are currently 70 buildings of eight stories or greater that are under construction or proposed. Many are in cities that already contain at least one tall timber building and are in countries with an existing tall timber economy, but many are also new. And it does appear that new height thresholds will be broken, going beyond the 25-story (circa 90-meter height) currently.

These projects will likely only achieve these lofty goals by taking advantage of timber hybrid construction, in conjunction with steel and concrete. It is for this reason that CTBUH is conducting the research project “The Future Potential of Steel-Timber Hybrid Buildings”, (see inset below) including convening a research conference on the same at Illinois Institute of Technology in May 2022 (see advertisement on page 7 or visit ctbuhsteeltimber.com). The optimal interaction of timber with these materials is essential to achieving several critical outcomes: reduced carbon footprint, improved construction efficiency and faster production of much-needed accommodation for the world’s rapidly urbanizing population. ■

Unless otherwise noted, all image credits in this paper are to CTBUH.

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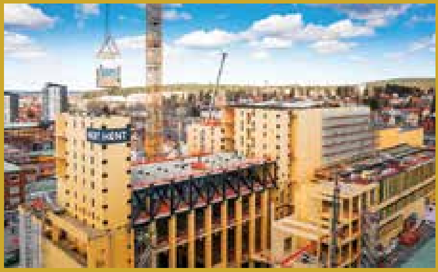
CTBUH Timber Research Projects

The accumulation of data in this report is the result of the following research projects undertaken by CTBUH.

Timber Rising: Mass Timber Engagement Program
Project years: 2019–2020
Funder: USDA Forest Service
Principal Investigators: Daniel Safarik & Will Miranda
ctbuh.org/timber-rising

Future Timber City: An Awareness and Educational Program for Future, Sustainable, Dense Cities
Project years: 2020–2022
Funders: USDA Forest Service & Binational Softwood Lumber Council (BSLC)
Principal Investigators: Antony Wood, Will Miranda & Daniel Safarik
ctbuh.org/future-timber-city



The Future Potential of Steel-Timber Hybrid Buildings
Project years: 2021–2023
Funders: constructsteel & Softwood Lumber Board (SLB)
Principal Investigators: Antony Wood, Daniel Safarik & Jake Elbrecht
ctbuh.org/steel-timber-hybrid