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TALL TIMBER BUILDINGS: EMERGING TRENDS AND TYPOLOGIES

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ABSTRACT: The last decade has seen the global proliferation of engineered timber technology in the construction of multi-storey buildings. Due to the relative infancy of mass timber building techniques (particularly in the construction of tall buildings) the trajectory of this new and evolving architectural typology has not been widely studied. Recently, several market reviews have investigated the advantages, disadvantages and best practice for mass timber as a structural material and construction strategy. However, existing literature lacks an overview of the wider market context with particular emphasis on the architectural qualities and ramifications of the emerging tall wood building typology. This paper aims to provide a qualitative analysis of this market context to identify trends within mass timber construction. The study is particularly concerned with the potential for architectural variety (spatial and aesthetic) afforded by tall timber structural techniques, envelope systems, and fabrication methods. The research presented in this paper is the first step towards defining the prevailing architectural strategies within this mode of building that might help to understand how tall timber architecture is evolving.

KEYWORDS: Engineered timber, mass timber construction, timber towers, tall wood, survey, future trends

1 INTRODUCTION

Timber building technology has recently experienced a resurgence in the construction industry. The development of a range of new engineered timber products like glulam, laminated veneer lumber (LVL) and cross laminated timber (CLT) has seen this natural and renewable material become a viable solution for multi-storey construction, which has, until now, been dominated by steel and reinforced concrete. It is now well understood that the concrete and steel industries which have built much of modern cities are highly energy intensive and contribute to a significant portion of global carbon emissions. Within this current landscape of mounting environmental concerns and rapidly growing global populations where increasing numbers of people are living in urban centres, mass timber solutions (which sequester carbon instead) emerge as an attractive alternative.

Recent forward-looking design proposals capturing the optimism of this new building approach have painted visions of cities with 350m tall timber towers in the near future [1]. Although current timber technology cannot yet rival the heights of steel and concrete skyscrapers, over the next two several 18-24 storey timber towers are planned for construction. As engineered timber technology evolves and ongoing research shines new light onto structural solutions, fire safety strategies and construction methodologies, timber tower design will continue to push the limits of height. It will be important to understand mass timber construction, not only as a series of technical problems to be solved, but also as a new architectural typology that can exploit the opportunities afforded by its material properties, rather than simply mimicking the brick, steel and concrete construction that has come before it. [2]

This paper builds upon several market surveys of current [3, 4] and proposed [5] mass timber buildings in order to understand the market trends and identify their trajectory in the evolving architectural typology of tall wood buildings.

1.1 AIM AND SCOPE

The study presented in this paper aims to capture trends in contemporary tall mass timber construction, in order to define and understand emerging strategies within multiple frameworks, including, material, structural and construction methodologies. The study is limited to existing mass timber buildings and those which will be completed in the coming two years. While the speculative schemes projecting 10+ years into the future are interesting for their evocative depiction of future timber high-rise, they are typically not highly resolved in terms of spatial configuration, constructability or compliance to local codes, and therefore not necessarily indicative of current emerging trends.

For the purposes of this study, mass or solid timber refers to engineered timber products such as glulam, LVL and CLT. It is worth mentioning that in some parts of the world, lightweight timber framed housing up to 4 or 5 storeys is the dominant paradigm. The research is

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Figure 1: *Global distribution of case studies.*

not concerned with this type of construction.

While the definition of 'tall' in the context of timber structures is arguable [6], this study has adopted the Wood Solutions Technical Design Guide's definition of mass timber high-rise, which includes any building with an effective height of 25 meters or more above the ground line, or, where this information is not available, buildings of 8 storeys or more. [7] This height limitation is the current maximum allowable height for 'Deemed to Satisfy' solutions for mass timber construction in Australia as specified by the National Construction Code. This paper is chiefly interested in *contemporary* timber construction techniques, and therefore only considers projects which have been built in the last decade – the era of tall timber construction ushered in by the development of engineered timber products.

2 METHODOLOGY: SURVEY OF GLOBAL TRENDS IN TALL TIMBER BUILDINGS

2.1 SURVEY METHODOLOGY

The research has been conducted in the form of a comparative survey examining 46 buildings from 2009 to present, in a variety of countries across the continents of Europe, North America and Australia (depicted in Figure 1.) As many projects as possible have been selected for inclusion based on those listed in existing surveys and those discovered through internet searches. Websites such as Arch Daily, Dezeen and DesignBoom actively report developments in the proliferation of tall timber construction, and as a result, emerging typologies can be understood by studying the kinds of buildings that receive media attention on these platforms. It is worth noting that although we have tried to cover as many different buildings in varying locations, the survey may not be completely comprehensive. It is possible that there are international groups working on proposals that haven't been published or widely publicised in English. This might be an explanation for the lack of case studies in Asia.

Qualitative data about each building was sourced from existing literature such as mass timber surveys, academic papers, feasibility reports and news articles. In addition to this, building information was collected from the project descriptions and documentation (plans, sections, elevations, structural diagrams, visualisation renders), as well as photographs and construction videos available on the websites of the architects, engineers, builders, developers and/or clients involved in each project. Only projects with a significant proportion of the required information available online have been included in the study.

2.2 MASS TIMBER SURVEY LITERATURE REVIEW

Increasing interest in mass timber structural systems and the substantial growth of the market in the last decade has recently spurred several market reviews focused on mass timber construction methods. Perkins+Will's 2014 report [8] commissioned by Forestry Investment Innovations and BSLC summarised learnings from the experiences of main stakeholders involved in ten early projects. The report and subsequent journal paper [3] focus on the processes and challenges involved in the design and delivery of buildings using what was then still a relatively new construction methodology. In 2015 the Solid Timber Construction Report [4] summarised findings from eighteen case studies regarding the cost and schedule savings offered by the mass timber construction methodologies. Neither report exclusively deals with tall mass timber buildings. A list of existing and proposed tall timber buildings was published in the CTBUH Journal in 2017 [5], however this survey makes no comparison or analysis of the projects. Salvadori's 2017 Masters Thesis [9] contains a survey of 40 built and unbuilt mass timber buildings over 22m in height (including some speculative schemes) describing the structural, facade and fire safety strategies used in each. The survey is primarily used to make the case for the viability of timber high rise and while it states the most common structural, material and facade strategies, it does not attempt to derive emerging trends or typologies.

2.3 CATEGORISATION FOR ANALYSIS

In order to understand emerging trends, the collected data has been structured according to two different category frameworks, based on chronological sequence and height, which have been used to facilitate two separate statistical analyses. In both, an attempt has been made to keep the categories as similar in size as possible for consistency in the weighting of each individual building in the final results.

2.3.1 Chronology: Trends over time

In order to determine emerging trends over time, the selected buildings have been grouped into four categories based on what we consider to describe generational phases of tall timber buildings:

- G1: 2009 – 2013.
- G2: 2014 – 2016
- G3: 2017 to present
- G4: To be delivered by 2020

The first category (G1) covers all projects between the emergence of the first tall mass timber building in 2009 and the release of the first US and Canadian CLT Handbooks in 2013. These are considered to be the pioneering buildings which helped to establish a global context for engineered timber structures and construction techniques. There are eight projects in this category. The second (G2) and third (G3) generations have been defined by the waves of projects to follow which benefited from the learnings of their predecessors. In 2017 there was a spike in the number of projects completed so the remaining buildings from 2014 to present have been grouped into two categories: 2014-2016 (containing eleven projects) and 2017 to present (containing twelve projects.) The last category (G4) contains fourteen incomplete projects, either already under construction or to be constructed by 2020.

2.3.2 Trends by height

The study is also concerned with understanding whether there are emerging trends related to the steadily increasing heights of mass timber buildings. Buildings were grouped into five categories describing the number of stories. These categories are as follows:

- 6 + 7 storeys
- 8 storeys
- 9 storeys
- 10-15 storeys
- 16+ storeys

The last two categories cover a wider range of heights than the first three because these kinds of heights are relatively new for engineered timber construction. The categories have been defined so that they are approximately similar in size for consistency.

2.3.3 Limitations

It is worth mentioning that as the survey does not include every tall timber building in the world, the trends inferred from the results of the study may not be absolutely comprehensive.

Figure 2 and *Figure 3* have been developed to visually illustrate the statistical findings of the survey, but they are not able to depict the relationships between the various factors studied. As a result, only some results can be inferred from this kind of graphic.

Finally, a potential limitation of the analysis framework based on height by number of storeys might arise from the fact that residential buildings containing 6-7 storeys most likely do not pass the 25m height threshold and are therefore excluded from the study. This could have the effect of skewing trend results on the lower end of the spectrum, as only non-residential buildings with a greater floor to floor dimension will feature.

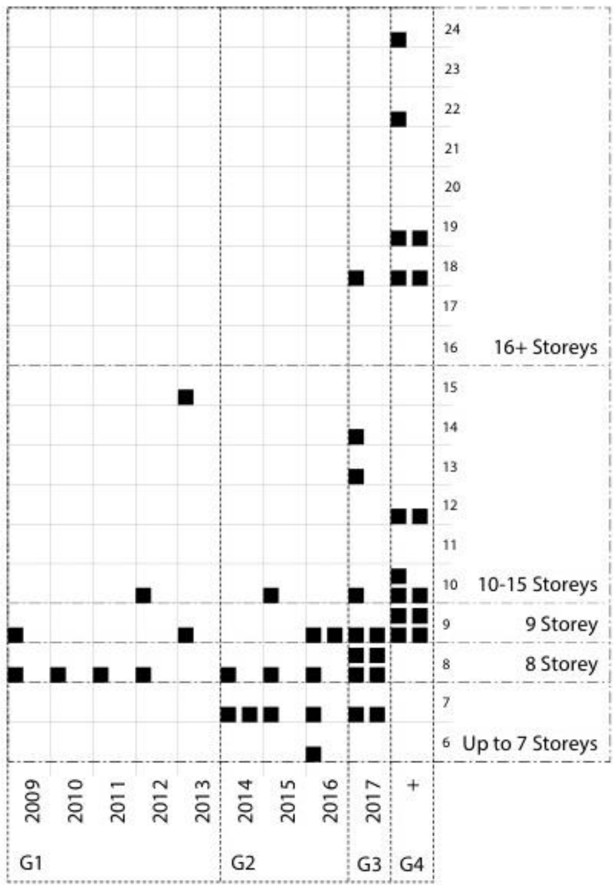

Figure 2: *Distribution of case studies within the survey analysis frameworks.*

2.4 SURVEY LENSES

General information such as height, location and program has been collected for each of the projects. For the purposes of this paper, the scope of the study has been limited by using three main lenses: Structural System, Envelope System, and Architectural Massing. These analytical lenses enable key insights into the emerging trends in tall timber construction.

2.4.1 Structural Limitations

There are currently many different engineered timber products on the market (LVL, Glulam, CLT, hybrids) which can be combined in various ways, resulting in different structural systems which have their own architectural and construction implications. Factors considered in the study are as follows:

a. *Horizontal and Vertical Strategies.* The structural strategy of the selected buildings was categorised into horizontal and vertical construction element types as per Kaufman's *Timber Architecture, Design and Construction.* [10] Vertical structural members were defined as either 1D (columns), 2D (load bearing walls) or hybrid. The architectural implications of the chosen system are reflected in the resulting spatial strategies: column based, cellular or alternatively a combination of both. Horizontal structural members were similarly categorised as 1D (beams), 2D (slabs) or hybrid.
b. *Core.* The structural core was identified by material and location (whether it was centrally located in the building mass or positioned on the periphery of the plan.)
c. *Podium.* For the purposes of this study, a podium has been defined as the lower portion of a building which is distinct from the building mass of the tower above. The survey noted whether buildings featured a podium and/or incorporated a base constructed out of a different material (such as concrete or steel). If this base was not articulated in the mass of the building, it was noted but did not register as a podium.
d. *Articulation of structural system.* Fire safety is currently one of the biggest concerns with mass timber construction. Building codes regulate fire protection requirements differently around the world (indeed within different national jurisdictions), which inevitably has an effect on the material expression both internally and externally. As material expression plays an important role in the spatial experience of a building, this will be a critical issue to address if the mass timber building typology is to fully exploit its architectural potential. Exposed columns and beams, as well as the use of timber on ceiling surfaces (sometimes exposed CLT, other times a timber ceiling) was noted in each project. Although local building codes have not been taken into consideration in this study, it has been noted for future research.

2.4.2 Envelope System

Mass timber construction offers the promise of shorter construction times, which inevitably challenges other aspects of construction, such as the system of building enclosure, to keep up with the increased construction speed [11]. A range of prefabricated facade solutions have emerged which are able to match the speed of mass timber structural cores. These systems have many advantages, such as reducing construction time and removing the need for scaffolding. But these envelope systems also have important implications for architectural expression. This study is interested in understanding how façade systems have evolved over the four generations of timber buildings as building height has increased. The factors considered include: structural and prefabrication strategies; type of envelope technology involved; and, aesthetic issues with respect to facade modularity and cladding materials. More specifically, each of these factors was investigated by examining specific features:

a. *Structural Strategy.* Facades were categorised as either load bearing or non-load bearing groups. This feature is highly influential to both the structural strategy and the construction sequence. It can also affect future use in terms of building adaptability. Material choice for the structure of the envelope was also noted to better understand its relationship with other selected features.
b. *Transparency.* Facades were divided into three main groups, according to their opaque/transparent ratio degree: (1) Opaque walls with punched windows, (2) Completely glazed and (3) Façade systems with alternating elements either fully transparent or fully opaque. Technologies such as unitized glass facades or window walls can fall under category (2) (even if they may include small spandrel sections at floor edges) or (3). Some of the case study projects have used different technologies on different elevations or building parts. In this case, all applicable options have been selected and analysed. The presence of an external screening device was also noted. Although it was outside the scope of this study, in future research we note that it is relevant to understand whether the choice to use a screen was determined by the need for shading (passive strategy with respect to radiation) or, perhaps, dictated by the desire to create a more dynamic effect on the facades.
c. *Prefabrication level.* The adoption of a prefabricated strategy for external walls was investigated. The use of mobile or fixed scaffolding was noted, in order to infer the system's degree of prefabrication. If no action is required from outside during the installation of the façade, the prefabricated envelope system can be defined as factory finished. However, when external access to the façade is necessary (e.g. to complete part of the cladding or the joints at the interface of elements) the external wall elements can be defined as be semi-finished assemblies. In this case, mobile scaffolding is typically used.
d. *Architectural Expression.* Articulation of the façade was investigated with respect to the degree to which the pattern of the structural system featured in the envelope aesthetic. The use of irregularity in façade to generate architectural variation was noted. The presence of timber-based cladding and vegetation was also noted. Apart from wider associations with the introduction of more greenery into urban areas, it

is also a potential indicator of the desire to portray an image of "sustainability".

2.4.3 Architectural Massing

The spatial configuration and general massing of tall buildings is inevitably tied to the structural strategy, and driven by things like the shape, size and location of the core and primary horizontal circulation. In the most basic sense, the form of most tall buildings is derived from the extrusion of the plan and the repetition of floor plates. Variation can be achieved through an: extension, distortion or breaking of the structural grid in plan; irregular extrusion generated by varying floor plates; and, the use of balcony features as geometric recesses or protrusions. Therefore, factors taken into account in this study are:

a. *Building volume.* Buildings have been organised by overall geometric strategies such as rectilinear or irregular plan, and regular or irregular extrusion.
b. *Balcony Strategy.* A wide range of configurations from protruding balcony to no balcony at all, as well as the use of timber as a finish were noted.
c. *Circulation.* Central and peripheral options were identified. Cross ventilation was introduced in this subtopic as a marker of the nature of these circulation spaces: totally airtight or with some degree of natural ventilation.

2.4.4 Mapping Trends

The results of the survey for the two analysis frameworks have been represented in Figure 3. Results in which more than one project was missing data are shown in light grey (the project was omitted in those calculations meaning that the result is not comprehensive.) Subcategories in which more than half of the projects were missing data are indicated with a cross, meaning results were inconclusive.

3 FINDINGS AND DISCUSSION

3.1 TRENDS IN HEIGHT, PROGRAM AND LOCATION

The average height of tall timber buildings is increasing across the generations, and can be expected to continue into the future. Across the 3 generations of built projects and into the generation of proposed projects, there has been a move away from purely residential program, with an increasing tendency towards a mixed program (residential spaces stacked above lower floors housing commercial, retail or community facilities.) This kind of mixed-use typology, which is also common in many non-timber high-rise buildings, appears to be prevalent in the taller timber case studies. There were no instances of residential or mixed-use residential buildings in the 6-7 storey height category. It is likely that these kinds of buildings would not reach the 25m threshold and would therefore be excluded from the study.

The survey case studies were concentrated in Europe, Canada, the United States and Australia. As mentioned previously, the search returned no Asian case studies. While outside of the scope of this paper, further research could involve mapping the locations of case studies against locations in which state of the art research in this field is being conducted in order to provide an additional layer of analysis.

3.2 TRENDS IN STRUCTURAL STRATEGY

Since 2009 there has been a clear shift in the dominant structural strategy of tall timber buildings. While 2D load bearing wall and slab systems (typically using CLT) are most common in the first generation, the last generation presents mostly post and beam structures, often combined with CLT slab floors. Cellular structural systems make up 75% of first generation buildings and only 21% of the fourth generation buildings, while column based structures featuring post and beam, post and slab, or some kind of hybrid column based strategy experienced a rise from 13% to 67% across the four generations. As the residential and mixed-use residential typologies are the most common across all four generations, this shift in structural strategy can likely be attributed to the challenges of increasing building heights, rather than the spatial implications of programmatic requirements.

Interestingly, the analysis by height category indicates that the use of cellular 2D structural systems peaks at the 9 storey mark, tapering off on either side, while the post and beam systems feature highly at the lower and higher ends of the spectrum, tapering off at 9 storeys. This result is unexpected and counterintuitive. CLT floor slabs in 2D cellular systems typically tend to experience compression perpendicular to grain with the increased design loads of taller buildings, [12] and as such, are less appropriate for use in the upper end of the height spectrum. One would expect a higher concentration of 2D load bearing structural systems in the 6-7 storey category, mirrored by a higher concentration of post and beam in the 16+ category, with both systems tapering off towards the other end of the height spectrum respectively. The peak and valley at the 9 storey mark indicated in the survey results could be a consequence of the study's definition of scope. Due to the typically lower floor to floor height, residential buildings below 9 storeys are likely to be excluded from the study as they might not pass the 25m height threshold. This is reflected in the fact that majority of the case studies in the 6-7 category are office buildings, with no residential or mixed-use residential featuring in this category. Post and beam systems lend themselves quite well to commercial programs, and are typically used in office buildings. This is reflected in the dominance of post and beam systems in the 6-7 and 8 storey categories shown in the results.

The use of a concrete core has increased across the generations (38% in G1 to 57% in G4) and is the most common in buildings over 16 storeys. Conversely, the use of a CLT core has decreased across time (63% in G1 to 43% in G4). Again, the 9 storey category presents an anomaly, with a peak in CLT cores and a drop in concrete cores. In G3 we can see the emergence of a steel framed core. This is suggestive of a move towards hybrid systems as the technology evolves. It is unclear from the results of the study whether the increase in the use of a concrete core is directly related to the increase in building height, the increase in the use of the post and beam strategy (which may require a core with more mass than CLT can provide), the emerging trend of hybridisation or a combination of all of the above. There are no apparent trends in the central or peripheral positioning of the core, however it seems that later generations are less likely to use both strategies in the same building.

There is an increasing tendency over time to use a podium strategy in the building mass (25% in G1 to 60% in G4). Interestingly, the choice seems to have no correlation to building height, nor to program.

The post and beam structure appears to be increasingly expressed inside the building across the generations, as is the use of timber on the ceiling surfaces. The timber ceilings are not exposed CLT in all cases (sometimes they take the form of timber slats or boards, potentially due to local fire codes). This could be indicative of an increasing desire to celebrate the timber structure, perhaps due to increasing acceptance of this structural system. The curve of the results regarding beam and column articulation by building height matches that of the use of a column spatial strategy, so the dramatic drop at the 9 storey mark is not surprising.

3.3 TRENDS IN ENVELOPE SYSTEM

Much like the evolution of façade strategy in the early development of steel framed high-rise in Chicago, the use of load bearing external walls in tall timber buildings is expected to consistently decrease into the future, making way for non-load bearing technologies. *Figure 3* shows the steady decline in the use of load bearing facades from 75% in the G1 to 35% in G4. Similarly, the use of timber as a structural external wall material is also declining, giving way to other technologies. This may be ascribed to fact that the average building height is increasing across the generations, resulting in an increasing need for façade systems able to be installed quickly and safely. Several highly industrialised non-load bearing facade systems are already available on the market, and commonly used in steel and concrete high-rise. In particular, fully prefabricated systems such as unitized glass facades have demonstrated their exceptional construction effectiveness and are often the first choice for the realization of high-rise building envelopes. This is evidenced by the survey findings with respect to façade transparency. There appears to be a shift away from opaque external walls with punched openings (100% in G1 to 67% in G4) towards partially or completely glazed technologies (0% in G1 to 30% in G4).

The analysis of the degree of prefabrication of the facade, at a first glance, offers contrasting results with respect to the above statement. In fact, where the prefabrication degree is expected to constantly increase over time, it seems to be rapidly decreasing with respect to height. 50% of the 6-7 storey buildings used a prefabricated façade, compared to only 13% of the 10-15 storey buildings. This tendency may be a consequence the scope of the study, as mentioned earlier, resulting in the 6+7 and 8 storey categories in the survey being dominated by offices. In this case, the presence of highly prefabricated glazed facades in the 6-8 storey buildings

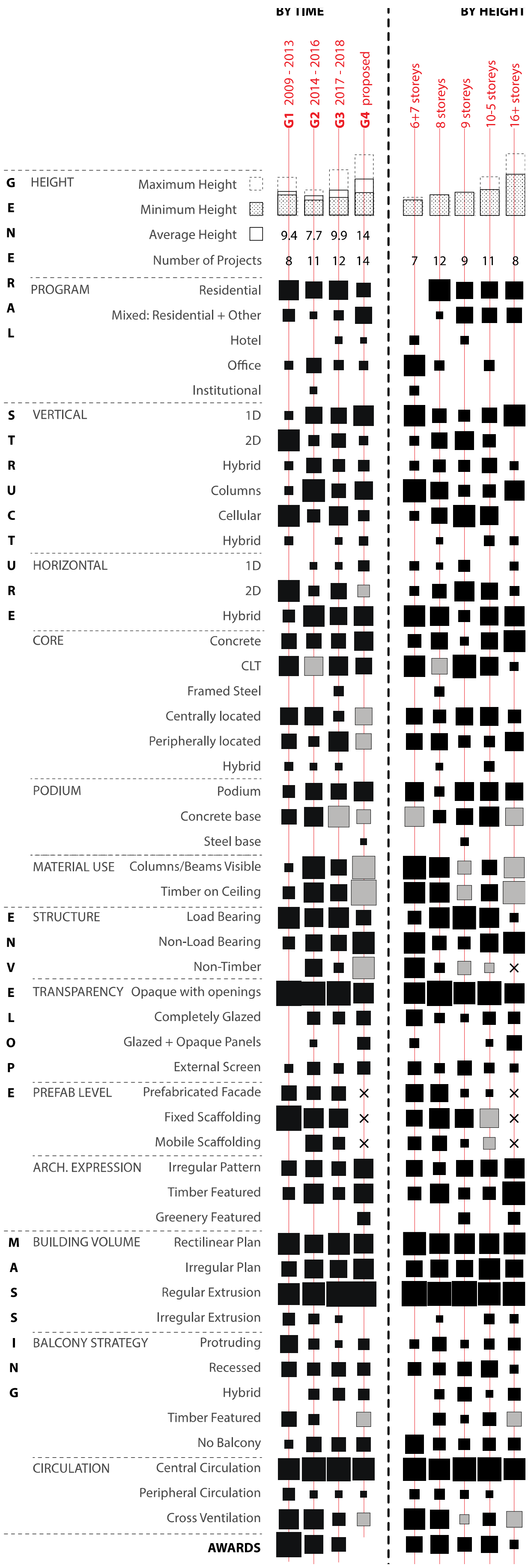

Figure 3: *Study findings – emerging trends in tall timber buildings.*

is mainly due to the building type rather than to the need for efficient site logistics and safety (e.g. elimination of scaffold). On the contrary, the 9 storey height category, which had 14% use of prefabricated facades, presents a high percentage of residential buildings, where opaque envelopes are more likely to be used for several reasons (e.g. cultural views, visual privacy, energy performance and cost). The market offering of opaque envelopes is far less advanced than the glazed facades in terms of an industrialised approach towards manufacture and installation.

Additionally, although G4 had inconclusive results with respect to prefabrication level, we can expect the last generation buildings to mainly use partially and fully glazed envelopes based on observations made from the renderings of these buildings. Most of these buildings fall under the 16+ storey category but since they are not yet built, there is no confirmation or photographic evidence available online of the use of a prefabricated envelope system, unless explicitly stated on the websites of the architects, engineers, and/or developers. However, prefabrication of façade elements can be inferred from the use of fully glazed systems. Buildings already completed or currently under construction in this category all present prefabricated facades.

The use of an external screen in tall timber buildings is shown as fluctuating across generational and height categories, so at this stage the results do not offer any relevant insights. The use of irregular patterning on the façade also appears to fluctuate over the four generations, however there is an obvious increase in the use of irregularity in façade aesthetic with increasing building heights, perhaps driven by a desire to reduce the visual impact of size. The use of vegetation as a façade element only appears in the last generation of case studies, perhaps indicative of the desire to portray these projects as representative of some kind of ‘sustainable’ agenda. As these projects are not yet completed, information for the study has been gathered from renders which often portray the design in an evocative way. As these buildings are completed over the next two years it will be interesting to see whether the promise of green façade holds true.

3.4 TRENDS IN ARCHITECTURAL MASSING

Unlike current trends in high-end concrete or steel tall building typologies, [13] the results of the survey show a dominance of rectilinear plans and regular extrusions, where simply the use of timber, rather than its expression as the main material, is an architectural and marketing feature in itself. Almost all the cases with irregular plans are an adaptation to the higher geometrical constraints of mid- to high-density urban locations, and there is no correlation between irregular plans and a higher degree of timber exposure. The use of protruding balconies is a declining trend across the four generations especially in cases where timber is visually exposed. We find a majority of central circulation schemes, which, despite the peripheral core location in around half of the case studies, show that circulation location is a solution that is rather independent of the position of the vertical communications core. This is perhaps something that is not yet being questioned by the market. It is also potentially enhanced by a geographic factor: for the majority of projects are located in relatively cold climates, where there is an existing tradition of centrally located horizontal circulation.

It is important to point out that the visual documents available for the buildings studied, especially the plans, do not show a huge degree of innovation in terms of how these buildings are actually lived in and used. While flexibility and adaptability of space for future use seems to be a design driver for some of the case studies, typically those that stress innovations in the marketing material focus on technological developments in structural engineering and/or the buildings’ energy-efficiency qualities, rather than innovation in spatial design. Apart from the inherent value of this emphasis on building energy performance, it also perhaps illustrates the changing values and expectations of the potential users of these places.

The decrease in the use of cross ventilation in recent years is quite paradoxical in this regard. In taller structures there is a need for mechanical ventilation due to the excessive air pressure in the highest floors, so the generational decline in cross ventilation could be attributed to a move towards taller buildings.

Overall, the findings from the study suggest that if mass timber technologies are to result in specific tall-timber architectural typologies that are informed by material, structural or enclosure properties, such typologies are yet to reveal themselves.

3.5 EMERGING CLASSIFICATIONS AND FUTURE RESEARCH

This study has provided the first step towards identifying trends which shine light on how tall timber buildings are typologically evolving. Based on this preliminary study, and using the 3 lenses of structure, envelope and massing, there seem to be some prevailing architectural strategies emerging:

- *Bones schemes*. Buildings primarily concerned with a structural grid of columns, which is used to mediate circulation, interior space and façade. Regularity is a common feature, though sometimes this is broken by skewing or removing some grid lines. Timber is celebrated as a structural choice.
- *Threshold schemes*. Buildings very much interested in the inside/outside relationship, making use of screens, balcony protrusions and/or greenery in various combinations to articulate a threshold. Irregularity in pattern seems to be a common feature. Timber may or may not be expressed as a construction material.
- *Articulated mass schemes*. Typically cellular in structure, these buildings try to dissolve their outline with a combination of protruding and recessed balconies, irregular boundary in plan and irregular extrusion heights for various parts of the building in elevation. These buildings trade-off the singular logic in architectural expression of the bones and threshold strategies, and are perhaps somewhat driven by jurisdictional design guidelines.

- *Context schemes*. These buildings tend to make use of simple geometry in plan and elevation. Material choice and façade articulation tends to be heavily context based, in an attempt to blend into the streetscape. Timber as a structural material is generally not exposed, articulated or celebrated in any way.

It is important to point out that these classifications are not inherently linked to the use of timber (as opposed to steel or concrete) as a structural material. We see the first two schemes, bones and threshold, as potentially offering opportunity for timber-specific typologies for evolve, but as the study has shown, this has not yet happened. While local jurisdictional codes and prevalent traditional construction methods in the locations of the case studies have not been included in the scope of this paper, future research could take into consideration the effect that these factors have had on the way that the building typology is evolving.

Future research could involve testing and verifying the strategies listed above through more detailed investigations of spatial configuration, response to context and response to climate, as well as an investigation as to whether any of these typologies can shed light on ways in which mass timber technology can offer architectural innovation. Widening the scope to include the speculative 'plyscraper' schemes mentioned in the introduction can perhaps reveal that nature of the projected trajectory of tall timber construction as envisioned by the architectural and engineering teams responsible.

It has become apparent through the study that the 25m height or 8 storey threshold is perhaps not completely suitable for an analysis across multiple building programs, as the residential sector is mostly excluded from the 6-8 story side of the spectrum. Future research could investigate trends based on individual building programme to better identify the nuances. It is possible that the inherent challenges of high-rise construction (regardless of structural material) may prevent the development of a truly timber-specific architectural typology in buildings above a certain height, in which case the study could be opened up to include low to mid rise construction as well.

4 CONCLUSIONS

The research presented in this paper has examined 46 tall timber buildings from 2009 to present with the aim of analysing emerging typologies within this new mode of construction. With respect to the three study lenses of structure, envelope and architectural massing, the study found that there are some clear trends emerging in tall timber construction. These include: the move away from cellular 2D structural strategies towards post and beam/slab systems despite program; a shift towards the hybridisation of structural materials; increasing articulation and expression of timber structural elements and timber ceilings; the increasing use of non-load bearing envelope systems; increasing use of fully glazed facades and, potentially a shift towards increasing envelope prefabrication.

As a relatively new medium, the rules and expectations around tall mass-timber buildings are not yet set. Like any technological or societal change, initial roll-outs almost always involve a nod to what has come before. In the same way that the first automobiles looked like carriages without horses, so too have many early tall timber buildings mimicked the modes and methods of steel and reinforced concrete buildings. This is a familiar pattern in the history of architecture. Here, it is apt to remember that the first skyscapers, such as Burnham and Root's Reliance Building (1890-95), still carried the fluting and ornament of earlier 19th century buildings, before Mies van der Rohe's Friedrichstrasse Skyscaper Project (1921), ushered in an architectural typology that has persisted to the present day.

The themes raised in this paper inherently relate to broader questions regarding the ways in which new technologies manifest themselves as typologies of use. The evolution of a mass timber structural system for tall buildings has not yet evidently resulted in the development of an innovative architectural typology germane to timber construction: that is, an unambiguous statement of the potential advantages and unique qualities of tall timber buildings. The study presented in this paper has identified four prevalent architectural strategies used in the case studies: bones schemes, threshold schemes, articulated mass schemes and context schemes. Although none of these are inherently specific to use of engineered timber as a building system, further research towards better understanding these building types may help to illuminate opportunities for architectural innovation in this field.

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