DEVELOPMENT OF MULTI-STOREY TIMBER BUILDINGS AND FUTURE TRENDS

DESARROLLO DE EDIFICIOS DE MADERA Y TENDENCIAS FUTURAS

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Abstract

Extensive research has shown that material-neutral building regulations are preferable and, for over a decade, function-based regulations have been common in many European countries, and this have contributed to an increase in the construction of multi-storey timber buildings. As one example, in the Scandinavia the development since mid-1990th of multi-storey timber buildings can be described as a success story, but there is also many other countries that have a positive development in timber construction. There is a great market potential for the use of wood in all types of buildings employing a combination of digital design and CNC (computer numerical control) processing. The construction engineers know how to make use of the digital tools; they have geometric imagination capabilities and construction know-how while the architects have ambitious ideas for building extraordinary projects. Digital design and production using CAE (computer-aided engineering), CAD (computer-aided design) and CAM (computer-aided manufacturing) have allowed timber construction to forge ahead into new dimensions of design. Innovative connections, modern wood-based materials and cutting-edge CNC milling offer entirely new possibilities and shape wood into almost any conceivable form. This paper gives an overview of the development of multi-storey timber building with a special focus on future trends in combination of digital design as flexible planning and design tools in combination with CNC processing to design and build extraordinary projects.

Keywords: Architecture; timber construction; digital design; wood processing

Resumen

La investigación ha demostrado que son preferibles las regulaciones de construcción que no tienen en cuenta el material y, por más de una década, regulaciones basadas en la función han sido comunes en muchos países europeos, y esto ha contribuido al incremento de la construcción en madera de edificios de varias plantas. Como ejemplo, en Escandinavia el desarrollo desde mediados de la década de los noventa de edificios de madera puede ser descrito como una historia de éxito, pero hay muchos otros países que han tenido un desarrollo positivo en construcción con madera. Hay un gran potencial comercial para el uso de madera en todo tipo de edificaciones utilizando una combinación de diseño digital y procesado con CNC (control numérico computarizado). Los ingenieros de la construcción saben cómo utilizar esas herramientas digitales; tienen la capacidad imaginativa geométrica y las habilidades constructivas mientras que los arquitectos tienen ideas ambiciosas para construir proyectos extraordinarios. El diseño digital y la producción usando CAE (ingeniería asistida por computador), CAD (diseño asistido por computador) y CAM (producción asistida por computador) han permitido que la construcción en madera avance hacia nuevas dimensiones de diseño. Conexiones innovadoras, modernos materiales basados en madera y el fresado CNC vanguardista ofrecen posibilidades totalmente nuevas y dan a la madera casi cualquier forma concebible. Este artículo da una visión general del desarrollo en construcción de edificios de madera centrándose en las tendencias futuras que combinan diseño digital flexible, herramientas de planificación de diseño y procesamiento CNC para diseñar y construir proyectos extraordinarios.

***Pablas clave**: Arquitectura; construcción con madera; diseño digital; procesado de madera*

1. INTRODUCTION

Up to the 19th century, wood was irreplaceable as the most important fuel and raw material for all types of construction. However, due to large city fires in Europe, fire protection measures including legislative measures were introduced in several European countries during the late 19th century to discourage or restricted the use of timber frames for the construction of multi-storey buildings. Multi-storey constructions of wood are not a new invention. In Japan, there is the more than 1400 year old Buddhist temple complex Hōryū-ji, including a five-storey pagoda, with a height of 32metres and approximately 20 x 20 metres in the basal area. The wood used in the central pillar of the pagoda is estimated through a dendrochronological analysis to have been felled in 594, so that this is one of the oldest wooden buildings in the world (Figure 1).

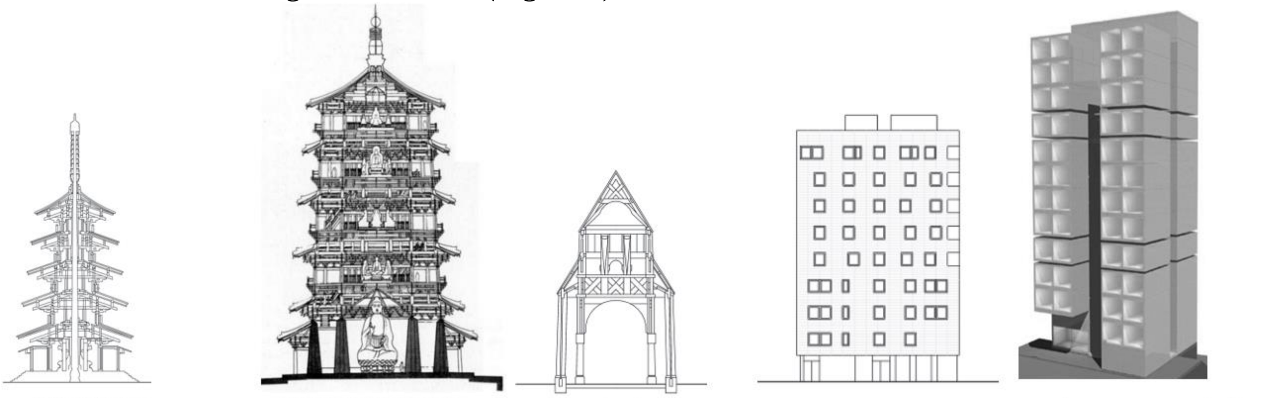

Figure 1: Examples of wood structures throughout history

The construction of multi-storey wood-framed buildings was re-introduced in the early 1990s in several western European countries. Many countries refrained from using flammable materials because of uncertainty about fire risks in the buildings. This helped the concrete industry to dominate the building market in Europe, particularly in Central Europe with a market share of 70-80% [1]. In the early 21st century, less than 10% of one- and two-family houses in Germany, France or the Netherlands were being built with wood, but more than 85% of such houses in Nordic countries [2]. However, extensive research has shown that material-neutral building regulations are preferable and, for over a decade, function-based regulations have been common in many European countries. This has resulted in a considerable increase in wooden multi-storeys buildings (Figure 2).

Figure 2: Development of multi-storey buildings from 1995 to 2015 [3]

In the late 1980s, a construction product directive from the European Commission stipulated functional based requirements for the use of products in building construction with the aim to remove technical barriers to trade in construction products between member states in the European Union [3]. This means that any material, wood, concrete or steel, that fulfils the functional requirements as specified in the national building regulations can be used for the construction of multi-family buildings. It has been nearly three decades since this European Commission construction product directive was issued, but the use of wood frames in the construction of multi-storey buildings is still low, even in the Nordic countries where it is about 10% of new multi-storey buildings.

Modern building regulations have however contributed to an increase in the construction of multi-storey timber buildings of up to eight storeys (Table 1).

Table 1: Present stage and future suggestions for multi-storey buildings

1995-2005	3-5 storey buildings
2008	8-storey condominiums, Växjö, Sweden
2009	9-storey condominiums, London, UK
2011	7-storey multi-family house, Berlin, Germany
2012	8-storey condominiums, Bad Aibing, Germany
2013	9-storey apartment building, Milan, Italy
013	10-storey building in Melbourne, Australia
2014	14-storey apartment building, Bergen, Norway
2020?	30-storey building, Canada
2025?	34-storey building, Stockholm, Sweden
?	80-storey building, London, UK

Multi-storey buildings made of timber can be given an outer architectural design that suits the location where the building is erected. There are different regulations regarding the permissible height of a wood building, mostly for fire-safety reasons (Figure 3).

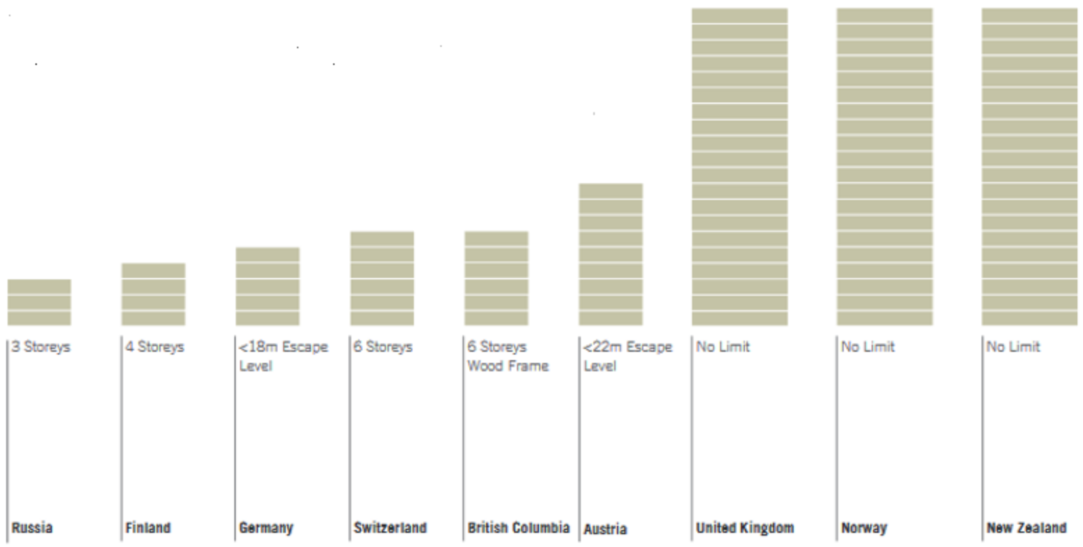

Figure 3: Max building height by regulation in different countries [4]

The increase can be attributed to several important factors such as a lower cost of building compared with wood than with other materials, and advantages of using wood in industrial building, together with a growing environmental awareness, where the choice is motivated by the fact that wood is a renewable material and that its use reduces CO_2 emissions, provided that the timber is harvested in forests where sustainable forestry, with replanting and management plans, is practiced.

Although the development and implementation of timber constructions in multi-storey buildings is on different levels in different European countries, the trend towards an increasing use of wood is clear. The main reasons are that wood used for building is renewable and locally available; it is beautiful, sensuous and has superb technical characteristics. Timber construction leads the way in terms of energy-efficient building. Many responsible contractors, architects and businesses now choose a timber construction because of its efficient use of both resources and money.

2. A COMBINATION OF VISIBLE WOOD, DIGITAL DESIGN AND ADVANCED PROCESSING AS FUTURE TRENDS

The development potential and obstacles in multi-storey building is employing a combination of digital design and computer numerical control (CNC) processing. The construction engineers know-how to make use of the digital tools; they have geometric imagination capabilities and construction know-how while the architects have ambitious ideas for building extraordinary projects.

Digital design and production using CAE (computer-aided engineering), CAD (computer-aided design) and CAM (computer-aided manufacturing) have allowed timber construction to forge ahead into new dimensions of design. Innovative connections, modern wood-based materials and cutting-edge CNC milling offer entirely new possibilities and shape wood into almost any conceivable form. Nowadays, there are flexible planning-design tools and CNC processes that allow us to design and build extraordinary architectural structures (Figure 4). The producers already offer all the stages of the construction process: from technical development to construction, service and maintenance.

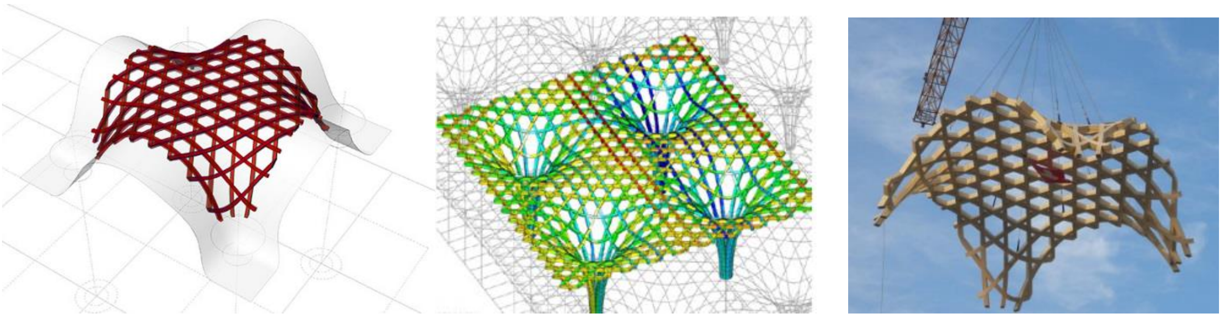

Figure 4: The Yeoju golf clubhouse in Republic of Korea; digital simulation of the construction and a part of the roof during assembly

The coordination of the various steps, such as architectural design based on geometric structures, structural engineering, production, logistics, site facilities, installation and follow-up work, is a core element of contemporary project management.

In the new planning process, the production companies are becoming IT specialists, providing services and solving interfaces, while carpenters coordinate the building processes. There are intelligent machines: software components, machine technology, knowledge, production space, logistics concepts and available engineered raw material. The digital planning process (CAD-interface CAE and CAM) still needs a lot of detailed planning (Figure 5).

Complex timber constructions can compete with traditional constructions but this requires a new modern production philosophy where components are planned and produced quickly, flexibly and precisely with digital processes in the factory: complete 3D modeling, static evaluation of complex building design, solving complexity within the factory, and pre-assembly of parts of the whole structure close to production. This will result in the rapid erection of the building on the building site with a low degree of complementary work.

In contemporary timber structural architecture, the structure remains visible. The structure is the dominant factor of the architectural expression, and is often based on the principles of nature. It shows a perfect match for timber and its variety of advanced possibilities.

Creating exceptional free-form structures requires an intensive and close cooperation between specialists. Developing the geometry, designing the supporting framework and generating production data are all decentralized, yet interconnected, processes. An integrated exchange of data with clearly defined interfaces makes seamless project management possible.

Figure 5: Digital planning process CAD-CAE-CAM interfaces: New dimensions in complexity in timber construction [5]

2.1 New modern production philosophy - production with minimum tolerances and maximum flexibility - free-form structures

The framework for producing components is full of mathematically exact, parameterized models of the structure and its components, which ensure that tolerances are kept to a minimum in the construction, processing and installation phases. 3D modeling, high-quality code and error-free information for CNC machines are also critical for prototyping parts and in the management of 3D printing. These models are part of the entire process from project development, feasibility studies and design, over the CAD/CAM processes, to the construction in service life.

Depending on the type and complexity of the structure, specialists on CAD and CAM software are needed to convert graphical data into machine codes, in general for steering of 5-axis CNC joinery machines. Programming expertise and skill in handling this equipment are needed to ensure the flexible and precise production of double-curvature timber structures (Figure 6).

Modern design and production methods open up many possibilities where complex structures and buildings become real. Free-form structures are distinguished by their cellular supporting structures and the unique nature of each component. They are exceptional – from the initial idea through to the design, production and installation with the required quality, in the specified time frame and on cost-effectiveness from the perspective of the investor and builders.


Figure 6: The wooden Wave as a free Form, Kristiansand, Norway, Tamedia office building: 5-storey building in Zürich, Switzerland [6]

Advanced timber structures save money at the construction site because they allow exact planning and quick assembly as a result of prefabrication. This is also an economic benefit for builders when the time between new construction and rental is short. For investors, it is important that advanced financing and the marketing of the property take less time and are accompanied by assured on-time completion. One of the main advantages of a modern production concept, in-factory rather than on-site, for timber structures is that the construction method is primarily dry, and there is a reduced risk of damage to the structure as a result of moisture.

3. CONCLUSION

A transition from traditional building practices to multi-storey timber buildings depends on several factors. Many different players such as architects, consultant engineers, constructors, contractors, subcontractors, and suppliers are involved in the processes of design, engineering, construction, material supply, and activity coordination. The action of these actors, their beliefs and perceptions, knowledge and skills, and above all the institutional set up influence the development of construction system.

Timber multi-storey building in recent years has gathered momentum in European countries. Construction of the first experimental buildings was completed and today the trust in new timber building is growing. The number of projects, quality and importance, as well as the rising interest from different groups and customers show this trend. The reasons are two: economy and ecology. European timber multi-storey building is progressing with regard to building performance, construction methods and building costs. It is becoming increasingly widespread, and the number, quality and types of timber buildings indicate progress towards their becoming a common construction practice in the middle-rise building environment of European countries. The use of wood for multi-storey building construction varies widely however among the European countries. Positive aspects of wood as a structural material include its strength, environment-friendliness, simple handling and appropriateness for industrial use, but knowledge gaps have led to a reduction in the use of wood by structural engineers and architects [7].

We see opportunities for further development and future trends in high prefabrication, partnership and increased responsibilities for planning and construction, improved and systematic feedback of experiences, and team cooperation. Demonstration projects are vital to show the various actors, e.g. the wood industry, architects, builders, and housing associations, the technical and business potential of wood as a multi-purpose building material.

There are numerous challenges associated with the construction of wooden buildings; as an architect, you design for the present, with an awareness of the past, for a future which is essentially unknown. These challenges are best met through further research and more pilot projects to increase the knowledge of life cycle costs, construction costs, maintenance costs, sound and vibrations, through the general increase in the number of wooden buildings that are being erected.

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REFERENCES

[1] Winter, W., 'Wood is the material of the 21st century' (Holz ist der Werkstoff des 21. Jahrhunderts). *Holz-Zentralblatt* 121(2/3) (1995) 13,16,20.

[2] Eliasson, L., Berg, S. and Sandberg, D., 'Some aspects on the more efficient use of wood in the industrial manufacture of single-family timber houses', *ProLigno* 11(4) (2015) 418-425.

[3] Schickhofer, G., 'CLT structural engineering research in Europe, Solid Timber Construction (STC)– Cross Laminated Timber (CLT) '. Institute of Timber Engineering and Wood Technology, Graz University of Technology, Austria (2013).

[4] 'The construction products directive', European Commission, Council Directive 89/106/EEC, 21 December (1988).

[5] http://www.blumer-lehmann

[6] 'The case for tall wood buildings' (How mass timber offers a safe, economical, and environmentally friendly alternative for tall building structures, mgb ARCHITECTURE + DESIGN). http://www.cwc.ca

[7] Kitek Kuzman, M. and Sandberg, D., 'A new Era for Multi-Storey Timber Buildings in Europe' In: 70^{th} FPS International convention June 27-29, Portland, US (2016).