Innovative Structural Systems in Timber

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1. Introduction

This paper examines the background to new types of engineered timber structure being built in the UK and presents examples.

The UK is one of the world's largest net importers of timber and timber products[1]. Whilst wood-based panels, including oriented strand board (OSB), wood chipboard and cement bonded particleboard and medium density fibreboard (MDF) and other fibreboard are all manufactured in UK, laminated timber products are largely imported. In some ways this is an advantage; there are many manufacturers of wood products and there are competing suppliers for projects. On the other hand, the UK market is reliant on suppliers from outside the country providing sales and support services and products carry the burden of high transport costs.

Innovation of timber systems is essential to maintain the competiveness of timber as a construction material. With creativity and ingenuity, the use of timber will grow and the opportunities for UK growers of timber to sell their wood into a higher value market will increase. In particular, the use of timber for taller buildings and longer spans offers the opportunity to increase the market share of timber in the commercial sector of UK Construction, currently dominated by the use of steel and concrete.

2. How tall can we go with timber?

2.1 Historical Precedent

The tall timber buildings of the Fareast, particularly the temples of China and Japan established the use of timber for tall buildings many centuries ago. The Sakyamuni Pagoda of the Fogong Temple, built in 1056, is a 67 metre tall timber structure[2], equivalent to more than 20 stories of a modern tower block. The spire of Salisbury Cathedral, more than 60 metres tall, was built on top of a 64 metre tower. The spire is a masonry shell in its permanent structure but still contains the timber temporary timber structure constructed in 1258 used for its construction. A remarkable series of timber radio masts were constructed in Germany during the 1930s. At Ismaning in Bavaria, a 156 metre tall mast was built in 1934. It was used until 1977 when it was replaced by a 100-metre-high guyed steel framework. The wooden tower was nicknamed the "Bavarian Eiffel Tower" and was protected as a monument. Unfortunately repairs were not feasible and on March 16, 1983 explosives were used to demolish it. The tallest timber tower was the Mühlacker Transmission Tower (built 1933/34; destroyed 1945) at a height of 190 metres.

2.2 Why build tall with timber?

The strength:weight and stiffness:weight ratios of timber match those of steel and exceed those of concrete (Figure 1).

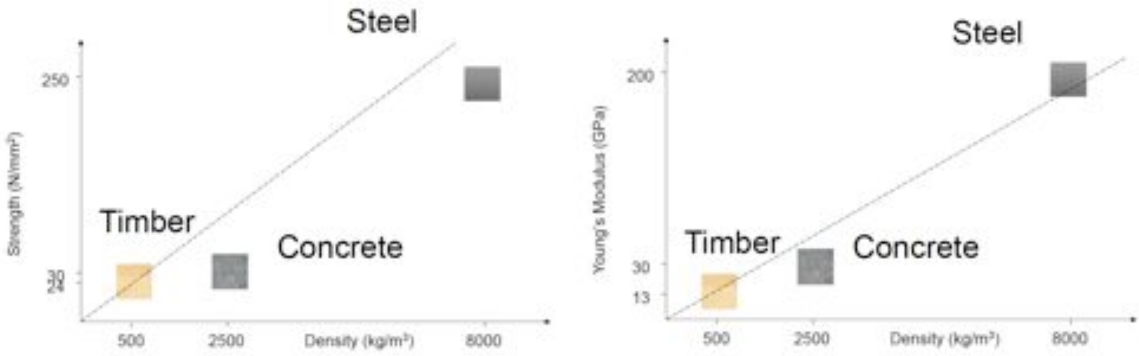

Figure 1: Strength:Weight and Stiffness:Weight for Timber, Steel and Concrete

This makes timber attractive for use in tall buildings. As the number of stories increases the weight of the structure (known as the "self-weight") becomes the predominant load. At 20 stories the self-weight is very significant and good strength:weight and stiffness:weight ratios are necessary for efficient and economic design

With the memories of disastrous fires in tightly packed medieval cities many countries used prescriptive regulations to limit the height of timber buildings. As recently as 1990 all countries of Europe restricted timber buildings to two stories[3]. The move away from prescriptive regulation to performance regulation has removed these blanket restrictions, opening up the opportunity for timber in higher rise building construction.

2.3 Platform Timber Frame

Timber Frame 2000 (TF2000) was one of the most significant timber research projects undertaken in recent years (Figure 2). A collaborative project between the UK Government, TRADA Technology, TRADA, the Building Research Establishment (BRE) and the timber industry, it involved the construction of a six storey, timber frame building – the tallest of its type in the world at the time.

Figure 2: Timber Frame 2000. *Platform timber frame incorporating engineered wood products. Image copyright TRADA*

This research helped to establish multi-storey timber frame construction in the UK. The work was published as design guidance, addressing, structural stability and robustness, fire safety, differential movement as well as construction process and procedures[4].

Having completed this major project, the market was opened to the use of timber frame[4] and, in terms of volume, the platform timber frame is now the most established part of the timber industry in UK. It is used extensively in private and social housing, student accommodation, hotels, medical facilities and care homes. Multi-storey construction, of six floors, is common.

2.4 Cross Laminated Timber

Just as the work of TF200 transformed the UK platform timber frame industry, the introduction of cross-laminated timber has released a series of projects that benefit from its special advantages. It is also uses off-site prefabrication; in this case precision engineered panels, using CAD/CAM technology and CNC machinery.

In the US cross-laminated timber is promoted as “Jumbo-Ply” (Figure 3). This gives a good indication of its make-up. Just as with plywood, it uses timber laid up in alternating gran direction but instead of veneers it uses sawn structural size elements.

Figure 3: Cross Laminated Timber (CLT)

CLT has provided the impetus for increasing the height of timber buildings[6]. (Figure 4)

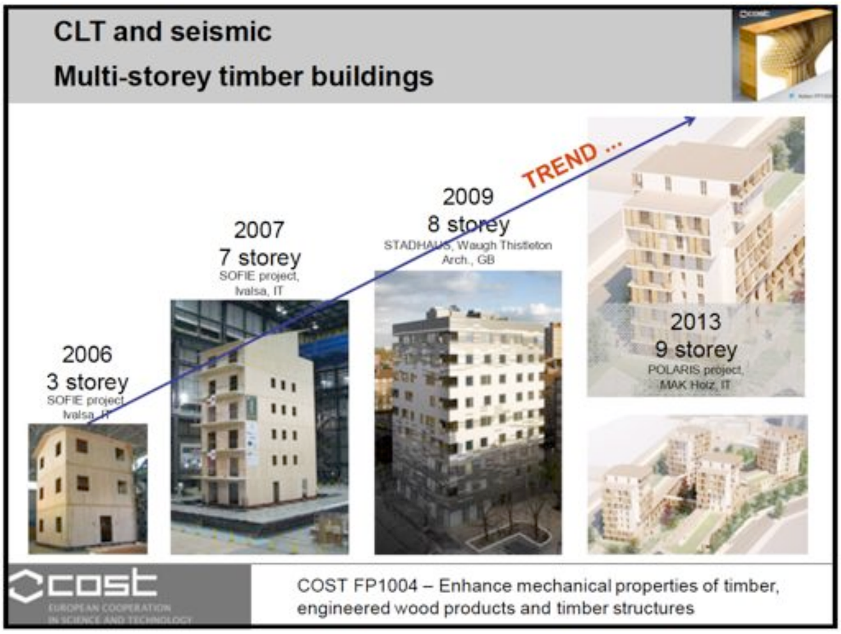

***Figure 4: The increasing height of timber buildings**. Iztok Šušteršič R&D Project Manager, CBD & University of Ljubljana Slovenia "Use of CLT in Slovenia in seismically active areas"*

3.0 Innovation to enable improved performance

There can be a negative perception of timber. The fear of its combustibility as demonstrated by prescriptive regulations has been overcome by the use of fire engineering applied using the more modern approach of performance-based regulations. But there are clearly technical challenges to be overcome to address the indisputable facts that it is a natural product that is generally available in modest size and length. It shrinks and creeps, particularly perpendicular to the grain. It is relatively weak and flexible, again, particularly perpendicular to the grain. And, importantly, connections are relatively weak and flexible.

With increasing demands on performance, research and development has addressed these issues.

3.1 The advantages of Glued Laminated Timber

Glued Laminated timber (Glulam) (Figure 5) is the main product used in customised engineered timber solutions. It often competes directly with steel, providing solutions for long span. Some of the most exciting buildings recently completed or underway at present in the UK make use of customised glued-laminated timber.

Lamination enables structural timber elements to be made in any size and length, only limited by transport constraints. As with all engineered timber products, it also enables a proportion of the natural defects to be removed during manufacture and the anomalies and variation that remains is better distributed trough the product. Thus the material of an engineered wood product is more homogeneous than natural sawn wood.

In the UK, there are only small scale manufacturing facilities for glued-laminated timber. For special structures, such as the Scottish Parliament roof, laminated in oak, by Cowley Timberwork[7,] in a factory set up in Lincoln, the industry is capable of creating special facilities. At present the UK relies, almost exclusively, on glued laminated imported from outside the country and the case studies shown in this paper all use imported timber. UK expertise comes from the architectural and engineering design community, as well as the constructors. Within a regulatory environment, which has performance as its fundamental basis[8], the UK is a great place for innovation and the establishment of a new Glulam manufacturer, Buckland Timber (www.bucklandtimber.co.uk/) is a very welcome addition to the UK industry.

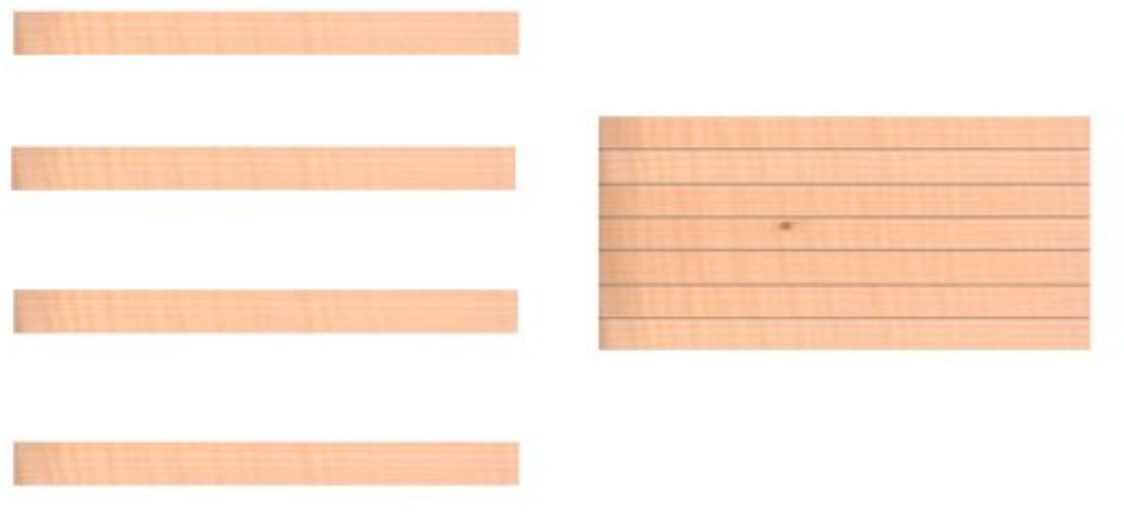

Figure 5: Glued Laminated Timber (Glulam)

3.2 The advantages of CLT

The orthotropic properties of timber are well known – strong and stable along the grain, weak and susceptible to movement across the grain. By placing laminations across the grain, Cross Laminated Timber uses this anisotropy to advantage, enhancing the mechanical properties of wood, by using wood.

This elegant solution has led to Cross Laminated Timber being the most significant recent innovation in timber engineering. It has opened the potential for new construction types, including tall timber buildings. It provides a solution to the difficulties presented by shrinkage and creep perpendicular to the grain.

In design of tall buildings using CLT, castellated connections have been used to eliminate cross-grain loading at floor levels (Figure 6).

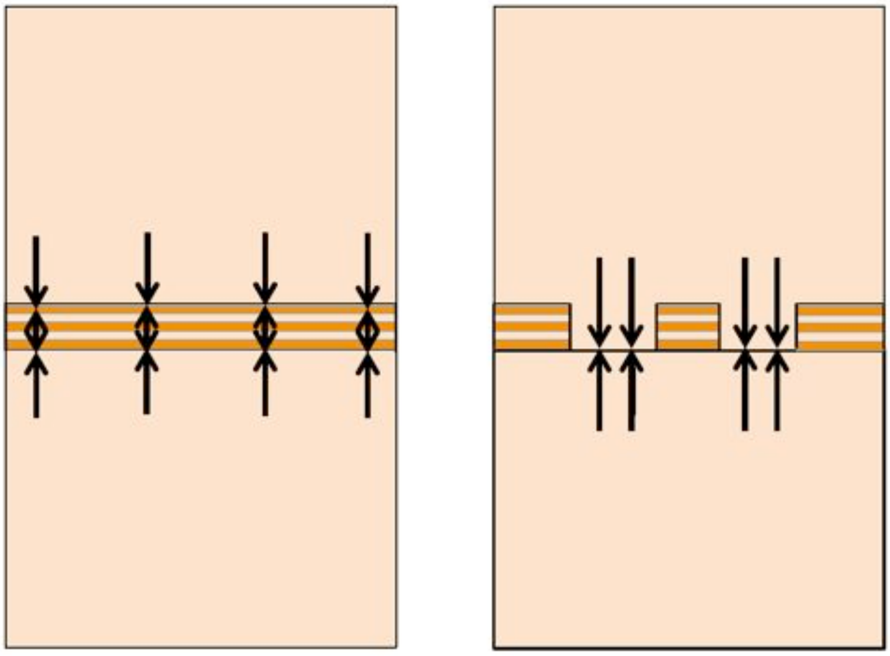

***Figure 6: Example of castellated wall connection**. In left-hand diagram the load transfers through cross-grain compression of the floor. In the right-hand diagram, load transfers through the stiffer and stronger end grain compression of the CLT*

3.3 Overcoming Connection Challenges

Connections in timber structures are certainly points of weakness. There is insufficient space in this short paper to show a review of the enormous range of ingenious solutions to the design challenge that connection present. Broadly speaking there are two approaches, either place connections at points of lower load within the structure, or increase the capacity of structural elements to enable the reduced capacity of connections to be accommodated.

With good design it is possible to use connections that can be a positive enhancement to the structural performance. A good example is the Earth Sciences Building at the University of British Columbia (Figure 7), where connections have been designed to provide energy dissipation in the event of a serious earthquake. Here small diameter steel dowel connectors with multiple steel plates are used for the diagonal bracing. The use of over-length slots to accommodate the steel plates enables the dowels to be designed to yield and dissipate energy in an earthquake.

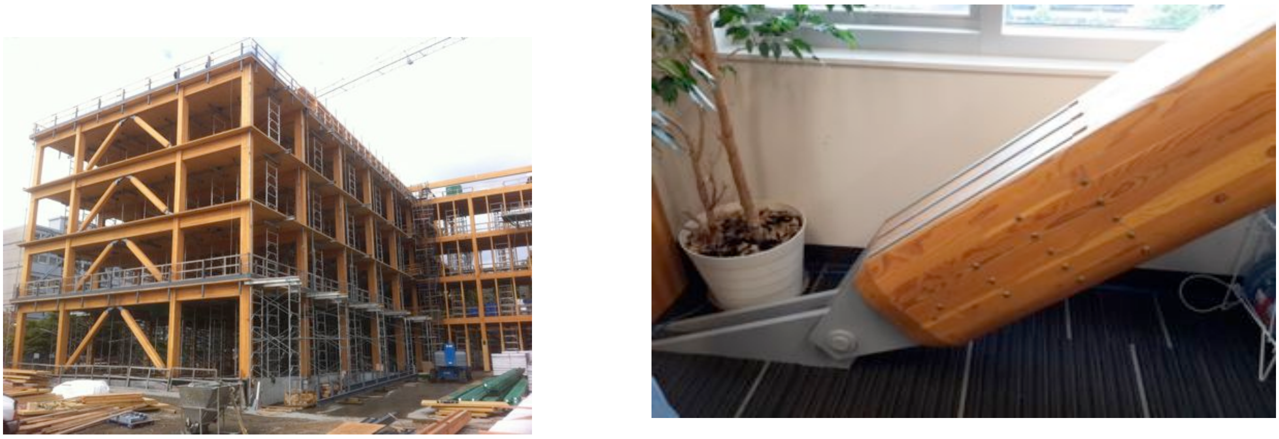

Figure 7: Earth Sciences Building at the University of British Columbia

4.0 Research on lateral stiffness of tall timber buildings

With new proposals for increased height timber buildings being put forward every year, there is essential need for greater understanding of their behaviour. Timber buildings with timber floors are lighter weight than steel buildings, which generally use heavy weight concrete floors. With reduced inertia, timber buildings, particularly those higher than fifteen stories, are susceptible to vibration due to wind load. The cyclic buffeting of wind tends to excite at low frequencies[7], which are close to both the natural frequency of tall timber buildings and the frequency that is most easily sensed by humans.

Whilst it is clear from precedent (see Section 2 above) that tall timber structures are capable of safely sustaining loads without collapse, there is a question over whether or not they will perform adequately in terms of dynamics. Will tall buildings (over 15 storeys[8]) they vibrate to an extent that they upset the building users? Dynamic response does not increase linearly with increasing amplitude and it is unsafe to extrapolate existing knowledge and methods as buildings increase in height.

A project funded by the BRE Trust is currently investigating, through monitoring existing buildings and through a programme of laboratory testing, how dynamic response can be understood (Figure 8).

Figure 8: Limologen Building in Växjö, Sweden. *Monitoring acceleration under ambient wind load*

5.0 Case Studies

5.1 Eton Manor – Long span Glulam

Eton Manor is a sports and leisure venue, which was the northernmost building of the London 2012 Olympic Park and remains as a permanent venue as part of the 2012 Olympic legacy. PJ Steer Consulting Engineers designed the timber structure for the Timber contractor, Wood Newton.

It is a long span structure, built to a tight programme and budget. Glulam was used for the main beans, which are over 39 metres and are constructed from 330 x 2450 GL24h glulam. The glulam manufacturer, James, located in Brécey, France, manufactured the beams in four pieces; they were then glued together to make the full-size bream (Figure 9). Lamination used standard Melamine Urea Formaldehyde (MUF) adhesive. For joining the pieces, a new formulation of gap-filling MUF was used.

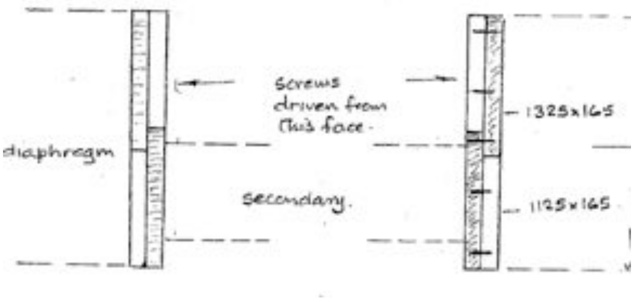

Figure 9: Eton Manor sports facility. Make up of main beam. Image copyright PJ Steer.

Prefabrication of the structural components made delivery and erection of the structure a quick, clean and accurate process (Figure 10)

Figure 10: Eton Manor sports facility. Delivery and installation of main beams. Image copyright PJ Steer.

5.2 High-rise CLT Construction

Excellent examples of clean fast high quality construction made possible by CLT are the two residential buildings constructed in the London Borough of Hackney (Figure 11). The Stadthaus is a nine-storey building (eight of load-bearing CLT over one of concrete) designed by Waugh Thistelton Architects with Techniker Engineers and completed in 2008 (construction by KLH (UK)). In 2010 this building was followed by Bridport House, also eight stories of timber by Karakusevic Carson Architects with engineering and construction by Eurban.

Figure 11: Left: Stadthaus Right: Bridport House under construction.
Both buildings are in London Borough of Hackney

6.0 Conclusion

The UK construction market is very large and engineered timber construction is still in its infancy. The proportion of timber buildings remains small, as a proportion of the total.

When the TF200 project was promoted, the UK medium rise market (4-8 storeys) was dominated by steel and reinforced concrete construction and this is still the case. The same applies now.

Many interrelated factors are now coming together to make timber construction the preferred option for construction clients, designers and contractors. These include environmental issues and government drives on sustainability and efficiency. The TF2000 project was designed to assist in promoting the benefits of timber and in particular timber frame to the whole of the construction industry. Current research initiatives are able to achieve the same outcome, both by directly developing new timber systems but also by providing design expertise to generate customised solutions.

Structural research continues to be essential to enable innovative construction, particularly highrise, to be successfully implemented.

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