

Biobased materials and technologies for a new architecture

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ABSTRACT

High-rise timber construction projects multiply at a fast rate all over the planet. Among projects in progress and those in the process of conception, we can find different types of buildings. Nowadays countries seem to be racing to build the most innovative timber project. This article suggests a review of the construction solutions available, but also of the future solutions for timber construction.

PLATFORM-FRAME

Let's start by debating about a constructive system typical of North America, the platform-frame system. It is used extensively in the construction of mono and multifamily homes. Its use is allowed in Canada for constructions up to six storeys high. Most of its success lies on the fact that existing building codes in Canada and the USA propose a series of perceptive solutions allowing anyone with manual skills and knowledge of carpentry and masonry to be able to build their project on their own without needing the intervention of a structural engineer.

The development of a process of prefabricated construction of a platform-frame has allowed single family buildings of 200 m² in less than three days. The system is so popular in Canada that it is the most used for residential constructions (single family and multifamily houses of some units) with a rate of 90 per cent adoption. In addition to the fact that it is fast to build, it is a much optimised system. Its platform frames and its platforms use very little raw material while creating large volume buildings.

The platform-frame system is also known for its resilience in case of an earthquake because of the ductility provided by the joints driven into the structural elements. When the enveloping is installed adequately, it provides great energy efficiency. However, the big optimization of materials of the system has the effect of a low thermal mass. Observations of twin buildings, one of platform-frame and the other of cross laminated timber (CLT) have shown that comparing them, their energy consumption was not significantly higher in summer nor in winter (Ramallo-González, Gosselin, Blanchet, & Natarajan, 2017).

The platform-frame system is so common in North America that it is often left aside in the construction of non-residential buildings. However, it is also possible to use it in this context, as the STGM Canadian firm did for its own study (Figure 1). When they were inspired by the platform-frame system, they came up with a clever system of

small triangular beams in sight which has a double function, structural as well as aesthetic, inside the building.

It must be understood that the small beams are a product of wood engineering that supposes a key element in the platform-frame system, allowing the creation of structural boxes and, at the same time, compartments that prevent the propagation of flames in the case of fire. Engineered wood has well known properties; therefore, when following the recommendations of the building codes, we can adjust their dimensions confidently in order to comply with safety requirements in each circumstance. However, in spite of the popularity of the platform-frame system, it is not possible to predict a development of high-rise buildings with this system.

The elements that have made timber high-rise building to emerge are the natural aspect of this material and the will of architects to implement projects with a minimum environmental impact. Materials developers like to think that the availability of a material regarding another has invigorated the construction of timber high-rise buildings, but it is rather the will of the practitioner. Gosselin et al. (2017) showed that the main motivation architects have to use wood in non-residential and multifamily constructions is their environmental value for the project. Diagram 1 shows the conclusions of Gosselin et al. (2017) about the study of 13 international projects implemented in the last decade.

This environmental context has favoured a bigger use of large elements such as glulam and CLT panels.

GLUED LAMINATED TIMBER

Glued laminated timber has been used for several decades in different projects of great significance. However, the growing interest in wood shown by architects has meant an increase in its use. While its simplest use tends to create orthogonal building typologies, it has also been used in more open formats. For example, the French architectural study X-TU has designed in Bordeaux, France, an exhibition centre called Cité du Vin (Wine City). In this project, the use of glulam was favoured as a structure because of a concern for the complexity and also for an aesthetic interest (Figure 2).

The complexity of this building shows the potential of this material for large projects. However, the metal connectors used in the glulam structures continue to be the weakest point from the point of view of structural safety because of the loss of continuity they imply and because of concerns about fire risk. Besides, metal connectors do not integrate properly into some architectural concepts. Therefore, there is a need to develop invisible connectors like, for example, glued plugs which allow completely hidden connexions. In this last case, the metal plugs and the adhesive are protected in case of fire by wood itself. However, the long term behaviour of this type of connectors must be observed, particularly if the inspection of carrying out the joints is limited due to the configuration of the connexions. For aesthetic reasons as well as for safety in case of fire, the metal plates are often inserted in the wood, where they

are hidden and protected from fire.

Big construction projects that use glulam imply a high precision mechanisation of structural elements. This mechanisation is frequently done in factories using numerically controlled machines (CNC). This takes us to the next question: would normalisation agencies accept the reintroduction of wood-to-wood joints like the ones used in old Japanese temples and in old European constructions? Numerically controlled machines could, undoubtedly, become a first order tool for carrying out such complex assemblies in high-rise constructions. Therefore, it is legitimate to wonder whether this technology is being used to its full potential in timber constructions today. The fabrication potential of complex architectural concepts is immense thanks to prefabrication. Here is a possibility to take wood out of the limitations imposed by orthogonal shapes.

Regarding materials, cross laminated timber (CLT) have largely contributed to the development of high-rise timber construction. Architects have chosen this material for its technical properties, but above all, for its low intrinsic energy (compared to reinforced concrete and steel) and its capacity to store biogenic carbon at a rate of 1,1 tons of CO₂ per cubic meter of wood (Frühwald, 2007). In addition, CLT panels offer a full series of advantages for its use in timber constructions, mainly its lightness, which gives the possibility of high-rise building on soils with limited geological properties. A notable example is Bridport House, designed by Karakusevic Carson Architects and completed in 2011. It is an eight storey complex built with CLT panels over the

main rainwater way in London.

Speed is another advantage of timber constructions; in several projects it has been shown that it is possible to build one storey per week when this is done with CLT panels. This was the case of the Forté building in Australia, built in 2013, and, more recently, the construction of Brock Commons building in Vancouver, Canada. Finally, the Origine project, built in Québec, Canada, also showed this speed of construction, as well as other safety elements of CLT constructions.

In fact, the Origine project, designed by Nordic Structures (Figure 3), proposes a construction totally built with CLT panels, including stairwells and lift shafts. Regulating authorities in the province of Quebec demanded technical proofs before they allowed this construction. Regarding fire safety, tests were done at a 1:1 scale: a flat was built on a floor next to a stairwell that was also constructed with CLT panels, without any sort of fire prevention covering such as plasterboard. The test consisted in artificially lighting a normalized heat load in a section of the flat; the behaviour showed that resistance to fire was higher than two hours and that there was practically no temperature rise in the contiguous stairwell. The test was done in the presence of firemen from main cities East of Canada: a good way of informing the parties involved about safety in case of fire of constructions made with CLT panels (Figure 4).

Although we frequently classify structural systems by their main material, it seems that constructions increasingly take advantage of different materials available in hybrid

systems. Thus, we can often see pillar and beam structures made with CLT panels, as in Brock Commons and Origine projects. The use of a technical cubicle (lifts, stairs and services) is also frequent. This last one generally allows a simpler technical conception to solve lateral loads (wind and seism). It is also frequent to see structures made with a wood-concrete mix, like the ones used in the UMass Design Building project, completed in the USA in 2016. In that project, designers – Leers Weinzapfel Associates – tried to make wood work collaborate with concrete to obtain higher structural properties than the ones represented by each material individually.

This is a wide field of research and it is reasonable to think that there will be developments regarding hybrid structures. Auclair et al (2016) proposed an economic connector of reinforced concrete with a high resistance fibre (BFUP) which allowed control of ductility of wood-concrete compound structures. The economy of that connector is due to the possibility of prefabrication and to the fact that it limits the time of intervention of workers, a resource that may be important as could be seen in the UMass Design Building (Figure 5) project.

Regarding occupant safety, the designer will be satisfied with the possibility of creating and controlling the final behaviour of the structure. Here is another technical progress that democratizes the use of wood. In the near future, we can foresee the development of hybrid systems with other types of materials, such as steel and aluminium. The timber construction industry must, from now on, assert its leadership

proposing hybrid solutions focused on prefabrication, favouring fast construction of complex architectural concepts.

In relation to this, there is a structural system that has been neglected: the grid shell (Figure 6). There are few projects built with this structural concept; the last one is the reception pavilion of the Macallan distillery in Scotland (Rogers, Stirk, Harbour + Partners). There was an empty lapse of fifteen years in the use of the system for a significant project at international level (since the completion of Weald and Downland Museum in England). The system allows for a great optimization of the material/volume relationship between footings; however, building these structures is slow and this tends to discourage developers. In order for the system to be democratized, it must be industrialized and achieve a faster process of construction.

The future of construction also implies the transformation of wood, shifting from being a material of traditional engineering to being a modern material. Here, the possibilities of development are immense. But, how can we modernize a material created by nature? The development of several strategies is in progress and these will increase in order to adapt themselves to the challenges proposed by architects. Some modifications can be done to material, like the chemical modification of the structure of wood (at cellular scale), or thermo-hygro-mechanical modifications. There is also the possibility of injecting synthetic materials into the wood mass to give it properties it would not have otherwise. More simply, you can resort to the application of functional coverings on

its surface, or even to the disposition of successive materials that would allow reaching the highest standards of construction.

What can advanced materials allow in timber construction? Lafond et al (2016) show this through an example. An injection of a small quantity of polymer into the whole of a screwed joint allowed increasing the carrying capacity of the bolts, reducing the section of the structural element, creating a better distribution of the efforts inside the wood and reducing the variability observed in the mechanical capacity of the connectors (Diagram 2).

The dimensional stability of wood is a problem that might be the subject of advanced materials research. Among the more promising approaches is the acetylation of wood and the impregnation with ester of citric acid-glycerol. The benefits of these treatments apply particularly to the exterior use of wood, such as façade coverings, but also to structural elements that imply continuity between the exterior and the interior of a building.

The impregnation of functional encapsulated materials in the mass of wood might, in short, allow the increase of the thermal mass thanks to the use of phase change materials. Likewise, the impregnation of functional materials would protect wood from ultraviolet rays (thanks to capsules sensitive to solar energy), protect wood from flame propagation (with flame retardant thermosensitive capsules) or favour the absorption or reflection of infrared radiation depending on environmental temperature (with the use of thermochromic materials, like

vanadium dioxide). There are few limitations to the new functions that can be integrated into wood based material, provided the end advantages justify the production efforts required for its integration.


CONCLUSION

In order to evolve, timber construction will need a good number of technical developments. Some of them are directly linked to the study of timber engineering, particularly all the developments associated to the assembly of structures and joints. These must evolve towards more aesthetic solutions and offer more varied architectural options. They must reach beyond metal screw or nail connectors and an option is to offer hidden joints thanks to glued plugs or by means of wood-to-wood joints.

But timber construction must also offer advantages in the system itself. If the speed of assembly of buildings is the number one advantage for the constructor, the designer will appreciate the possibility of personalization. Steel offers few possibilities of personalization. Reinforced concrete, however, allows certain personalization, but it is limited by the possibilities offered by the formwork. Wood, thanks to its facility to mechanize, should be placed as the champion of personalization. Structural elements that are round, eccentric or curved should be the spearhead of large innovative projects.

In any case, it is important for architects to maintain the rate of use of wood for high-rise constructions, particularly in projects of great visibility. Although these represent a limited part of all the possible timber construction, visible projects are a

window for technical solutions. The major wealth of these projects, from the point of view of the elaboration of construction solutions that can be replicated in conventional projects, is that they push engineers and materials producers to abandon their models.

Finally, the evidence of environmental advantages, prime mover in the selection of wood by architects, must continue informing itself, undoubtedly, with the purpose of positioning construction systems based on wood as the champions in the fight against climate change. Besides, we must not forget the physical environments created by wood materials. These are long term benefits for the occupants and they ensure quality of light, warmth of spaces and a feeling of comfort. For the workplace, these qualities may mean increased productivity and reduction of absenteeism. There are, then, multiple, wide and complex advantages in timber construction. It is up to the scientific community to feed the reflection of architects and engineers, who have a key role in the execution of large projects of timber construction. 

REFERENCES

- AUCLAIR, S. C., SORELLI, L., & SALENIKOVICH, A. (2016). A new composite connector for timber-concrete composite structures. *Construction and Building Materials*, 112, 84-92.
- FRÜHWALD, A. (2007). *The Ecology of Timber Utilization Life Cycle Assessment Carbon Management, etc.* Probos Foundation. Kick off meeting CSR (Doorn November 15, 2007).
- GOSSELIN, A., BLANCHET, P., LEHOUX, N., & CIMON, Y. (2017). Main Motivations and Barriers for Using Wood in Multi-Story and Non-Residential Construction Projects. *BioResources*, 12(1), 546-570.
- LAFOND, C., BLANCHET, P., LANDRY, V., GALIMARD, P., & MÉNARD, S. (2016). Effect of acrylate wood impregnation on mechanical properties of wood structure connector's zone. *BioResources*, 11(1), 1753-1764.
- RAMALLO-GONZÁLEZ, A., GOSSELIN, L., BLANCHET, P., & NATARAJAN, S. (2017). Stochastic non-adaptive occupant behavior models in dwellings: Review and development of a unified tool. Submitted to *Applied Energy*, APEN-D-17-04115.