Wood Design FOCUS

A JOURNAL OF CONTEMPORARY WOOD ENGINEERING

Volume 26, Number 4 Winter 2016

In This Issue:

2016 World Conference on Timber Engineering

In The Next Issue:

Revisions to the Load-Resistance Factor Design for Wood Standard

Editorial

The 2016 World Conference on Timber Engineering (WCTE) was held in Vienna, Austria on August 22-25, 2016. If you are not familiar with the WCTE, this is the premier international conference on wood design and construction. WCTE 2016 had over 600 individual presentations - almost too many to absorb.

As you can guess, many of the talks focused on the area of massive timber, particularly tall buildings. Being located in Austria, the birthplace of cross-laminated timber, this was expected. However, almost every other aspect of wood design was also featured, from centuries old time frames to contemporary light frame design.

This issue of Wood Design Focus contains five articles from the WCTE 2016 reprinted with author permission to give the readers a flavor of the types of discussions and topics covered.

Gerald Epp discusses the current growth of mass timber in the United States.

Vijaya Gopu talks about non-destructive methods to identify decay in bridges.

Gary Williams discusses the historical aspects of how European design and engineering was brought to the North American continent.

(NOTE: I would also like to mention a recent article on the impact of the Hungarian refugee waves which formed the nucleus of wood design at the University of British Columbia. It is a fascinating read! http://www.vancourier.com/news/the-hungarian-refugees-who-helped-shape-canada-s-forests-1.2466189)

Alfred Teischinger discusses the future of wood design and innovation concepts.

Hermann Kaufmann discusses particular challenges for architects as we look forward to more timber buildings.

I hope you enjoy this issue and hope to see you at a future WCTE conference!

I would also like to announce that I am stepping down from the Editorial Board Chair of Wood Design Focus. It has been an enjoyable time communicating with all the authors and readers. Buddy Showalter will be taking over as Editorial Board Chair.

Thanks,

Daniel Hindman, PE

Editorial Board Chair, *Wood Design Focus*

dhindman@vt.edu

WOOD DESIGN FOCUS

Published by the
Forest Products Society

Wood Design Focus
(ISSN 1066-5757)
is published quarterly by:
Forest Products Society
15 Technology Parkway South
Peachtree Corners, GA 30092
Phone: (855) 475-0291
Fax: (301) 604-0158
www.forestprod.org

The annual subscription rate is free to members of the Forest Products Society and $125 USD for Institutions who are members. For nonmembers, the subscription rate is $155USD for individuals and $199USD for institutions and libraries. The Forest Products Society and its agents are not responsible for the views expressed by the authors. Individual readers of this journal, and nonprofit libraries acting for them, are permitted to make fair use of the material in it, such as copying an article for use in teaching or research. Permission is granted to quote from this journal with the customary acknowledgement of the source.

Timber Awakening in America

Gerald A. Epp, P.E.

Abstract

Being endowed with a wealth of timber, America has a long history of its use in construction. By the end of the nineteenth century, cities were building multi-storey commercial buildings using heavy timber, and, because of fire concerns, were building large floor plates out of what we would now call mass timber. With advances in structural steel and then reinforced concrete, such use died out. However, the recent development in Europe of prefabricated mass wood panels, along with wood's natural aesthetics and sustainability features, has led to renewed interest in North America. With the 2008-2014 recession behind us, American developers and architects are now pursuing mass timber with vigour.

Introduction

The wood revolution, involving mass timber on a broader commercial basis, is only now being experienced in a significant way in North America. The trend which began in Europe several decades ago has "caught on", and now a significant body of domestic research and "proving" is behind us, which, along with the aesthetic and sustainability features of wood, is paving the way for greater acceptance. Canada was the first to embrace mass wood, but one can begin to hear the thunder of the American economic engine warming up to this also. A resource which was once restricted largely to the domain of residential wood frame construction and historical timber frame techniques is now of interest for the broader category of office, institutional, and other commercial buildings, even relatively tall wood structures in America.

Keywords: Mass timber; mass wood; CLT; NLT; heavy timber; prefabrication; panels; commercial buildings

History of Massive Timber in The United States

The history of wood use for buildings in North America is somewhat different than in Europe and other parts of the world. In some ways it is quite unique. Pioneers and settlers coming from Europe needed to erect their buildings quickly in an unsettled environment, and the large tracts of virgin forests were a very handy provision for such needs.

The "pioneer" mind-set has remained very much a part of the North American way, particularly in the West and Mid-west. Wood frame became the mainstay and normal way of construction, not only for single family houses, but also and more recently for apartment blocks.

In this form of construction, the wood frame was protected against fire by non-combustible sheathing, and thus was concealed from view.

Mass Timber Buildings of the Past

On the commercial side, as the west became more settled, the wealth of available old growth Douglas Fir timber led to the development of economical tall (up to 9 storeys) wood mercantile buildings, using large cross-section beams and columns to carry the load, and a heavy brick outer shell to protect it. There are many examples of such buildings in the late 19th century warehouse districts of cities like Seattle, Portland, San Francisco, Vancouver, even reaching as far east as places like Chicago and Minneapolis.

The famous fire of 1871 in Chicago had taught some lessons about building in wood, and the building type described above involved the use of what we would now call mass timber. Not only were large timbers used for the frame, but the floors and even interior walls were built of fire-resistant solid wood construction, made simply by laminating 2" thick lumber together with nails. It was found that these heavy wood floors were also very resilient, and became ideal for carrying heavy materials like sugar and rice, stacked nearly to the ceiling!

The 19th century and the industrial revolution also saw the rise of the new structural materials, starting first with structural steel, and then later with concrete. These innovative, strong, non-combustible materials soon took over from timber, and thus the tall wood buildings of that era became a piece of history – quaint relics of the past that more recently have been fitted out for use as trendy offices and condominiums, located, as they are, adjacent to downtown cores of large cities.

However, timber construction remained strong in the residential sector. There were also technological advancements with wood, and the early twentieth century saw the smart utilization of wood fibre in the invention of glulam. Building codes which began to develop allowed the use of wood in commercial buildings under certain conditions, and glulam was used for such structures as medium span roofs (particularly as arches, because the process of laminating thin pieces could be adapted easily to curves). Some architects and engineers knew how to work with wood, but many more became enamoured with the possibilities of steel and concrete. Naturally these became the materials of choice for mid and high-rise buildings.

Modern Architecture / Exposed Structures

The twentieth century was the era of the modern movement in architecture, involving minimalism and later the honest expression of structural materials, culminating in the high tech architectural movement of the latter part of the century.

In the 1980’s and1990’s in the Pacific Northwest of North America (British Columbia, Washington, and Oregon), architects who identified with this trend sought uses of their beloved native material timber which went beyond traditional uses and spans.

Thus we as engineers and builders became engaged in the pursuit of what could be possible using this highly aesthetic material expressed as part of the architecture, and yet honestly, efficiently using its properties to carry out its structural function. We became involved in a long string of experimental projects which exploited the non-traditional use of timber in highly public architectural structures. Often these involved other materials like steel and concrete, combined sensibly with the wood. Why not use each of the materials in the way that utilizes their best properties?

While on the radar because of European developments, mass timber used for buildings in the broader markets was, in both the US and Canada, not yet viable.

So we and others in our part of the world continued to be fascinated with unique opportunities to use wood - both engineered wood, and dimensional lumber - in exploratory ways or unusual applications. Such projects became “demonstration projects” and promoted the use of wood on a broader scale, raising awareness that this material was capable of far more than what people had come to expect. The important thing is to understand timber’s unique properties and capitalize on them. These projects also proved how brilliantly wood lent itself to concepts of prefabrication and the new architectural forms that were rapidly becoming possible through the use of parametric 3D software .

Dimensional Lumber

British Columbia contains one of the richest concentrations of softwood lumber in the world. It is the primary source of what North Americans call “two by” material (2x4’s, 2x6’s, 2x8’s, and so on), i.e. ordinary dimensional lumber that is used to feed the vast housing market in the US, Canada, and, increasingly, around the world. The local BC economy is heavily dependent on this product, but the market is quite volatile. Many in the industry were seeking to increase market share by finding new markets for the numerous mills of the British Columbia interior, which primarily produce SPF (Spruce Pine Fir) species of lumber, the mainstay of wood frame residential construction.

Around the year 2000, a phenomenon developed which had a significant effect on these mills, and on the small communities which are very dependent on them. The Mountain Pine Beetle is an insect which thrives on the pine species, but is normally controlled by very cold weather. A lack of cold winters during this period led to the proliferation of the beetle, which was killing the trees on a massive scale. Huge forests would turn red, and then brown, and then black. (pictures)

While the structural properties of the wood are not affected, the forests needed to be harvested within 3 years of the trees dying, in order to be useful.

This fueled the need to find new markets, and industry stakeholders began to research the viability of mass wood for the North American market, particularly non-residential. Organizations like the Canadian Wood Council, FP Innovations, and others were instrumental in promoting this initiative, which began by seeking to raise the allowable height for wood frame apartment buildings to six storeys.

However, the primary focus was to promote the use of wood in the commercial sector – office, recreational, and institutional buildings, a sector which traditionally built with steel and concrete. Trying to get a bigger piece of the pie. And, of course, promoting possibilities of constructing mid-rise wood buildings in all sectors.

Demonstration Project For The World

In 2010, Vancouver was to host the Winter Olympics, and provincial and local governments were very keen on showcasing the use of wood, especially pine beetle-killed wood, and what better way to do that than on the largest, longest span roof for these Games, the roof for the Speed Skating Oval? The world, for three weeks, would be getting prime TV footage of what BC wood can do, both structurally and architecturally, in a large, unconventional application. Could the 95 metre span be elegantly achieved using glulam arches. Further, could ordinary 2x lumber, even pine beetle-killed lumber, be used to span over 13m between the arches on a roof area of over 25,000 m2, satisfying structural, aesthetic, scheduling requirements, and the very significant fire and acoustic issues?

Here was an opportunity, a "demonstration project", for the world stage, which could help pave the way for greater use of BC's primary resource.

The desire was to use 2x lumber. Our company StructureCraft became aware of this desire, and puzzled over an efficient response. We were familiar with European *brettstapel*, or a similar product we call nail-laminated timber (NLT), stacking the lumber pieces in a vertical orientation (show pic), and nailing them together. But this was inefficient for the 13m span, requiring lumber too deep, and costing too much. Further, acoustical absorption would be required to allow amplified sound to be heard in the finished facility.

So was it possible to lay up an arrangement of small 2x4's in a way that was both structurally efficient, and could allow for sound absorption and concealment of sprinkler and lighting services, while satisfying the onerous fire requirements of using small dimension lumber in such a large building? We came up with an interesting idea we call the "Wood Wave Panel", and approached the client with it. In plan view, you might think it was *brettstapel*, but in cross-section the lamina cascade into a wave shape resulting in a very light curved shell structure, with mineral wool concealed inside to both suppress fire and absorb sound. You could call it 3D *brettstapel*.

Thus our fun experimentation with wood for special projects was leading us towards a local interpretation of the mass wood idea – hand nailed laminated timber panels.

MASS TIMBER STRUCTURES

Architects and clients liked the look of exposed NLT, and it was not long before opportunities arose to create flat mass wood panels using it. It was about this time that CLT plants were being set up in Canada, and NLT was competitive with CLT, particularly for floors and roofs (as opposed to walls). Many architects were liking mass wood for its aesthetic appeal in buildings like offices and institutions, so the structures were not concealed from view. The Canadian market was taking on its own flavour for the mass timber idea. And we were setting our sights on the massive American market.

The American Market

In 2008, just as we all thought the timber idea was starting to catch on beyond the borders of British Columbia, the economy in the United States took a sharp turn, leading to one of the largest and longest recessions in its history. We all know about it because it affected the lives of every one of us.

We were just completing a project in Washington DC, and were getting some interest for other architectural projects in the United States. However, at this point everything went on hold. One American architect recently told me that this deep recession stripped their industry of a pool of talent that firm leaders are now struggling to replace.

Our company StructureCraft, dependent on a market larger than just BC, at a time when we thought our body of work, including the Speedskating Oval roof, would lead to an influx of new work, was now thrown into uncertainty. This was to continue for a number of years.

During the period of the recession, which was to last at least through 2014, the initiatives promoting the advantages of mass wood construction carried on both in Canada and the US. The US Woodworks program began during the recession, and the magazine Wood Design and Building continued to send pictures of beautiful timber projects into the offices of architects, engineers, and the building industry at large. During these years, architects were hearing about all of the sustainability and aesthetic benefits of wood, as well as seeing what the possibilities were through example projects in every possible building type. They did not have the experience, but were warming up to wood, wanted to try it on new projects. But there were no projects to try it with.

So when in 2014-15 the economy started to wake up, there was a surge of interest, fed by the continuing supportive work of research institutions and educational efforts of the wood industry, making CLT a buzz word. And by fascination with the idea, which was being experimented with in other parts of the world, of tall wood buildings.

Finally architects and clients were able to apply their newfound interest, at least potentially, as they explored the implications for projects that had lain dormant for years. Questions like:

• What are the implications for fire requirements?

• Is it safe for large or tall buildings?

• Would the codes allow the use of wood? For what type and size of building?

• What are the implications for building services.

• What about durability? Especially during construction in rainy climates

• How do we design with wood? Especially for taller buildings

Given that CLT is a relative newcomer to North America, and that the glued assembly required much proving before it could be accepted, there were significant hurdles to overcome. However, Canadian and American researchers have been working very hard with structural and fire testing, as well as bringing European knowledge across the ocean. The Canadian timber code CSA O86 now has a design section on CLT, and America has developed ANSI PRG 320, a standard for the production of CLT. Both countries have their own well-developed "CLT Handbook" to assist designers. CSA O86 is expected to publish a supplement containing a section on design of ductile "rocking wall" CLT shear walls for seismic zones, which will be a world first.

During the past two years, federal initiatives on both sides of the border have sought to "prime the pump" with incentives to developers of several tall wood projects. One of these, the Framework project in Portland, is a 12-storey mixed residential/commercial building we are currently assisting with, and it proposes to be the first tall wood building to incorporate the rocking wall concept.

NLT is also a product of great interest in North America. Possibly because of the historical precedent, and because domestic CLT was not at first available, several notable buildings have been built using NLT in the Pacific Northwest. These include office and institutional buildings up to five storeys tall, such as the CIRS and MEC buildings in Vancouver, the Bullitt Center in Seattle, and a number of other roof-only structures.

Unlike CLT, NLT did not have much barrier to entry, as the earliest codes, building on the experience with the many earlier historical structures, recognized this assembly as heavy timber. This is still the case, and jurisdictions which are as yet unfamiliar with CLT, may be more comfortable allowing NLT. But things are changing rapidly, and the timber revolution is making more and more believers.

It was about this time that CLT plants were being set up in Canada, and NLT became competitive, particularly for floors and roofs (as opposed to walls). Many architects were liking mass wood for its aesthetic appeal in buildings like offices and institutions, so the structures were not concealed. The Canadian market was taking on its own flavour for the mass timber idea.

COMMERCIAL TIMBER STRUCTURES – THE FUTURE

The wood industry in America is not satisfied with demonstration projects. From their perspective, market growth must be sustainable, and for too long this has been uncertain.

Now finally, it can be said that such desires on the supply side are now being met by an appetite, growing by the day, for CLT and mass timber buildings. Developers, building owners, and tenants are becoming conscious of the benefits, and are knocking on doors of people like us to design and deliver such structures, to help them discern whether mass timber is for them, and what the costs are.

As an example of such interest, our company two months ago completed the structure for a six-storey timber office building in Minneapolis called T3, said to be the first tall modern office building in America. This building was developed by one of America's biggest commercial developers, Hines, and they chose to build with timber for market reasons, without any other incentives.

This is a cost-driven project with a grid layout optimized for timber construction. We took great care in the design of the members and connections to ensure speed of construction, as well as a clean, modern look. We chose European glulam for the beams and columns. We also studied options of domestic and European CLT, but chose to use NLT for the floor slabs for reasons of cost and developer's visual preference.

There are now requests from all parts of the country, regarding all kinds of buildings, curious about what can be done with mass timber, desiring education, as well as pricing. Some of these projects will die for cost reasons, others because of resistance from the authorities, or from the design team. But it appears more and more of these projects will follow the lead of projects like T3 and Framework.

With timber buildings, it is evident that the American giant is beginning to awake…

Gerald A. Epp, P.E. is president and chief engineer of Structurecraft Builders Inc. gepp@structurecraft.com

Integration of Composites in Timber Bridge Rehabilitation to Inhibit Decay and Improve Service Life

Vijaya Gopu PhD, P.E.

ABSTRACT

The U.S. has over 50,000 bridges in which timber is utilized in the superstructure and substructure of bridges. These timber bridges are used extensively in secondary roads for a number of reasons. A variety of factors make the use of timber bridges on secondary roads to be attractive to the local authorities with the primary factor being the lower cost. A very significant percentage – over 50 percent – of the timber bridges in the country are either structurally deficient or functionally obsolete. While the service life of a properly constructed and detailed timber bridge can be comparable to or better than that of steel or concrete bridges, a deficiency in these two areas have adversely impacted the durability of timber bridges. This paper discusses details of the study undertaken to assess the condition of in-service timber bridges and identify the key factors adversely impacting the durability and performance of timber bridges. The study led to investigation of the suitability of the application of FRP in timber bridge construction and rehabilitation to improve durability, reduce maintenance costs and maintain the design load rating. Examples of application of the recommended repair/rehabilitation methods using FRP are presented and recommendations for improving the service life of timber bridges are discussed.

INTRODUCTION

In the U.S. wood accounts for over 50 percent of all the construction material used in residential and non-residential buildings. However, its use in non-building related construction is limited for a number of reasons related to the demands of the structures involved. Only ten percent of the bridges in the U.S. use timber in the superstructure and a higher percentage use timber in the substructure. With nearly half of the nation's timber bridges classified as structurally deficient or functionally obsolete, it was important to understand the factors contributing to their durability, service life and performance. The condition of a select group of bridges in four southern states in the U.S. – Alabama, Georgia, Louisiana and North Carolina – which have the most severe decay hazard for wood were assessed with the assistance of the departments of transportation in these state. The factors contributing to the poor performance of some of the bridges and the potential for use of FRP to enhance the durability and service life of these bridges is discussed in the paper.

INSPECTION OF TIIMBER BRIDGES IN SEVERE DECAY ZONES

The bridges inspected in the study represented those subject to harsh environmental service conditions. The bridge clusters selected were located in Alabama, Georgia, Louisiana and North Carolina and in zones classified as Severe or High Decay from a durability perspective. The location of the bridges is shown in Fig. 1 and include the coastal and marsh regions of the Gulf Coast, low lying areas in the lower Mississippi delta plain,

Figure 1. Wood Decay Hazard Map (American Wood Protection Institute)

Keywords: *Timber bridges, FRP, rehabilitation, durability, service life, WCTE 2016*

areas outside major river flood plains, mountainous areas with significant annual rainfall, and areas close to the mid-Atlantic coastline. The blue stars on the map in Fig. 1 represent the states involved in the study.

TYPE OF TIMBER BRIDGES INSPECTED

In order for a bridge to be classified as a timber bridge, it must have timber components in the superstructure. These components are generally either the stringers or decking. A majority of timber bridges have both the stringers and decking made of timber; however, it is not unusual to find the decking to be a cast-in-place concrete type. A small percentage of timber bridges have steel stringers with wood decks spanning these stringers. The presence of wood piles and pile caps does not impact the classification of timber bridges, though it is these piles and pile caps that impact the performance and durability of bridges to a significant degree.

The thirty-one bridges that were inspected in this study represented five different bridge types based on the decking material, stringers, wearing surface, and substructure. The differences in the five bridge types are evident from the information provided in Table 1. Bridges on state highways and major local roads invariably have an asphalt wearing surface over either timber or concrete decks. Bridges with wearing surface of gravel or running planks are usually located in rural areas, national and state parks, and forest service roads with low average daily traffic (ADT).

CONDITION ASSESSMENT PROTOCOL

A protocol for conducting the bridge assessment was established by the USDA Forest Products Laboratory to ensure that the assessment was conducted in a rather uniform fashion by the various teams conducting bridge assessment in different regions of the country. The protocol invoked the use of the standard timber bridge inspection methods used by the various state departments of transportation and coupled them with the use of advanced technology tools.

The various steps involved and required in the inspection were the following:

a. Visual inspection of the condition of all the timber components in the bridge, namely, piles, pile caps, stringers and deck. All observations were documented by written notes and hi- resolution photographs.

b. Hammer sounding of the components to detect areas of concern and marking the suspect areas for further evaluation.

c. Measurement of moisture content in areas where decay was observed or suspected.

d. Measurement of sound velocity using an acoustic tool in areas of decay or suspected decay.

e. Determination of micro-drill resistance of the wood in areas of decay or suspected decay. The micro-drill permits the assessment of the level of internal decay in the wood member. The lower the resistance the higher the level of deterioration/decay in the wood. Documentation of micro-drilling operation with digit videography.

f. Documentation of flawed construction details responsible for triggering decay in timber members through field notes and hi-resolution digital photography.

The following figures illustrate the various steps involved in the inspection protocol. The data collected by the author during the condition assessment of the bridges using this structured protocol has enabled the

Table 1. Bridge Types

Bridge Type	Decking	Wearing Surface	Stringers	Piling
A	Timber	Asphalt	Sawn	Timber
B	Timber	Gravel	Sawn	Timber
C	Timber Plank	Running Plank	Sawn Lumber	Timber
D	Concrete	Asphalt	Sawn Lumber	Timber
E	Timber Plank	Asphalt	Glulam Lumber	Concrete

Figure 2. Labeling of Members and Marking of Decay Areas

Figure 3. Hammer Sounding of Timber Piles

determination of the impact of flawed construction details on the performance of the bridge.

- Hammer sounding is a rapid condition assessment method that the bridge inspectors are familiar with. The inspectors are tuned to detecting the hollow sound from a deteriorated pile that has been struck by their hammer. This capability permitted the use of advanced technology tools in a very efficient manner.
- The detection of high moisture content by the use of moisture meter indicated moisture access and penetration in the member. High moisture content in interior stringers and interior sections of the deck indicated that moisture was moving through the wearing surface to the timber elements in the superstructure.
- The resistance microdrill was utilized to determine the level of deterioration in structural member in the zones where decay was suspected through hammer sounding and moisture content determination. The resistance plots were obtained for each drilling operation and used for additional assessment of the bridge condition. The holes caused by the microdrill machine was so small that it was hard to find them once the drilling operation was completed. The information gained from a microdrill cannot be obtained by conventional methods without inflicting considerable damage to the member.

CHALLENGES IN BRIDGE INSPECTION

The use of the resistance micro-drill in tall bents is extremely difficult because of having to climb the braces to access the superstructure components. Operating the micro-drill while hanging on to a brace is an enormous challenge and quite dangerous.

Figure 4. Determining Moisture Content of Wood

Figure 5. Picture Illustrating the Deployment of

The

Figure 6. Resistance Microdrilling to Assess Condition of Stringer

Figure 7. Resistance Microdrilling to Assess

operation of the micro-drill in very low clearance bridges is also problematic.

The use of advanced technology tools and the documentation of the observations requires an inspection team consisting of at least three members as opposed to two members that are involved in standard bridge inspections.

DETERIORATION FACTORS

Based on the field assessment of the bridges, a number of factors contributing to the deterioration of timber bridges elements were identified. These factors are discussed below:

a. The bridge piles were not protected from decay in the wet-dry zones and this contributed to the decay in the piles. The use of inexpensive treatments to retard or inhibit biological degradation was ignored. Simple measures could have extended the service life of the piles.

b. The failure to seal the end grains of pile caps, decking boards, abutment boards and railing posts permitted moisture penetration into these members. This moisture penetration is the primary cause for the biological degradation of these members.

c. Cracks in the asphalt overlay over the timber decking boards led to the seepage of moisture to the top of the decking boards. The presence of moisture contributed to the decay of the decking boards over a period of time. Given that the deck is flexible, it is expected that the asphalt overlay will crack over time. Moisture seepage through the asphalt overlay could have been prevented by installing a durable vapor barrier between the decking board and the asphalt overlay.

d. Moisture dripping from the decking boards led to the wetting of the top of stringers that suffered decay over a period of time.

The continuous wetting and drying of the timber components that had access to moisture had a negative impact on the durability of the bridge. Construction of timber bridges without consideration of the unique physical properties of wood is a major contributor to the deterioration of the timber bridge components. Disregarding the impact of moisture on the durability of wood in high decay zones is a definite recipe for a reduced life span. Figures 8-14 provide details of the

Figure 8. Decay of Pile in Wet-Dry Zone

Figure 9. Exposure of Pile and Abutment to Moisture

Figure 10. Crushing of a Pile Cap

Figure 11. Deteriorated Boards in Abutment

Figure 12. Deteriorated Pile Cap with Exposed

Figure 13. Crushing Girder at Pile Cap

Figure 14. Deteriorated Decking Boards With Exposed End Grain

Figure 15. FRP Flashing on Stringers to Prevent Moisture Damage

Figure 16. FRP Flashing on Pile Cap for Moisture Protection

decay observed during the inspection. Utilizing FRP material in a strategic way can very effectively retard, and even prevent, decay of the bridge components.

USE OF FRP TO ENHANCE THE DURABILITY AND PERFORMANCE OF TIMBER BRIDGES

The study clearly indicated that there is a tremendous opportunity to utilize advanced materials – in particular, FRP – in both the rehabilitation of decayed timber elements and initial construction of timber bridges. The bridge maintenance personnel need adequate information to accept the deployment of FRP repair techniques and use of this material to improve the timber bridge performance.

The use of FRP in a strategic manner in the repair and rehabilitation of these bridges can significantly enhance the service life while reducing the maintenance costs. The use of FRP material can prevent, and even eliminate, moisture related decay and degradation and thereby make timber bridges an attractive and economical alternate to concrete and steel bridges on secondary roads. FRP can be deployed in the following areas to improve the durability and long-term performance of repaired, rehabilitated and new timber bridges.

a. Top of pile caps and stringers: FRP flashing can prevent moisture access to these two major load carrying members. Figure 13-14 shows the application of the flashing.

b. End-grain of pile caps, decking boards, abutment boards and railing posts: A durable resin impregnated with FRP fibers can be used to seal the end grain to prevent moisture access. Figure 15 shows the sealing of end grain in these members in a timber bridge.

c. Pile wet-dry zone: The timber pile can be wrapped with FRP to prevent moisture access to the pile in the wet-dry zone. Proper preservative treatment using cooper borate rods need to be provided prior to installing the FRP wrap. This wrap and preservative treatment can be used for spliced piles and non-spliced piles. Figures 16 shows the FRP wrap of timber piles in the wet- dry zone.

d. Back side of abutment decking boards: FRP sheets need to be used on the back side of the abutment boards to act as a secondary water- proofing layer to prevent moisture access to these boards.

SUMMARY AND CONCLUSIONS

Figure 17. Decking Boards and Railing Posts Sealed With Resin to Prevent End Grain Moisture

The

Figure 18. FRP Wrapped Pile With FRP Flashing to Prevent Moisture Penetration Through Top of Pile

assessment of timber bridges that have been in service for several decades has clearly shown that these bridges could easily exceed their design life if they were built with the proper design details required of structures built with timber. The lack of these details and the consequent decay of critical elements of the bridge have contributed to current attitude of most of the state transportation agencies to avoid construction of new timber bridges and, if possible, replace those requiring rehabilitation with concrete or steel bridges. The deployment of FRP can change the current situation by enhancing the durability of these bridges. The following conclusions are drawn from the study.

a. The deterioration of the decking board can be halted by introducing a durable vapour barrier between the asphalt overlay and the decking boards.

b. Flashing over the stringers and pile caps is essential to deflect water away from the members.

c. The end grain of all timber members must be sealed to prevent moisture access that can lead to biological degradation of the member.

d. Adequate vapour barriers have to be provided behind the abutment boards to prevent their decay.

e. Timber piles must be protected in the wet-dry zone by both preservative treatment – long-term treatment – and a sealing system that prevents moisture access.

f. Proper construction details must be made available to the designer and bridge owners to render them competitive.

ACKNOWLEDGMENTS

Timber bridge inspections in Louisiana were conducted with the support of the bridge inspection teams of the Departments of Transportation of Alabama, Georgia, Louisiana and North Carolina.

REFERENCES

[1] North American Wood Pole Council, Estimated Service Life of Wood Poles, 2008

[2] American Association of State Highway and Transportation Officials. 1983. Standard specifications for highway bridges. 13th ed. Washington, DC: American Association of State Highway and Transportation Officials.

[3] American Society of Civil Engineers. 1982.

Evaluation, maintenance, and upgrading of wood structures. Freas, A., Ed. New York: American Society of Civil Engineers. 428 p.

[4] American Society of Civil Engineers. 1975. Wood structures, a design guide and commentary. New York: American Society of Civil Engineers. .

Vijaya (VJ) Gopu, Ph.D., P.E. is a Professor at The University of New Orleans and the Associate Director for External Programs at Louisiana Transportation Research Center. v.gopu@la.gov

Gary C. Williams

ABSTRACT

Over the last two decades or so, increasing familiarity with European creativity in building with wood has excited wood designers and constructors world-wide.

This has led to new visions of daring and adventure to change building codes and design standards, establish new manufacturing and distribution channels, all to bring expanded opportunities to work with wood that Vogue Paris describes as "a trendy product…undoubtedly one of the most elegant building materials".

This paper will examine how the North American exposure to European product development and production techniques has contributed to the explosion of interest and vigour to challenge well established barriers to build with materials other than steel or concrete in non-residential construction.

INTRODUCTION

I wish to speak to my experience in understanding how wood was thought of as a more eligible material choice when designers contemplated new non-residential construction in Europe than they did in North America.

My thoughts are based on experiences from my early visits to production facilities and academic institutions in a number of European Countries and the on-going personal contacts established with some involved in the development of wood building standards and various aspects of building with this unique product.

KEYWORDS: European influence, Product development, Production techniques, Cross Laminated Timber, Building Codes, Connections, PRG 320

The paper primarily focuses on how the development of Cross Laminated Timber (CLT) production in Europe fostered independent design material and the eventual establishment of production facilities in the U.S. and Canada.

When speaking at last year's Holzbau Forum in in Garmisch I quoted Senior Technical Director of the American Wood Council, Lisa Podesto. Lisa had spoken about what she saw as a quiet revolution happening in Europe and Canada and suggested that these influences would change the way architects in the U.S. think about wood building systems.

Call it a revolution or not, it is certain that Canada has influenced thinking in the U.S. in a major way and this paper will describe how that a major part of what has energised that influence has its roots in developments and advances in working with wood in Europe.

Of course building with wood in North America is not a new idea. However, what is happening in that field today is very different from efforts in the past.

AWARENESS OF OPPORTUNITIES

Obviously the title of this paper taps into the theme of the 1963 James Bond movie "From Russia with Love". There has always been excitement and adventure in each of the Bond films since the first over 54 years ago.

Similarly, as the influences of achievements of European wood researchers and manufacturers began to migrate to North America, there has been excitement and adventure associated with that too.

Hence I am stretching a point to link some thoughts about recent developments in wood construction there in this way. This is the fourteenth WCTE conference, and since 700 or so attend each, these events have played a significant role themselves in disseminating new wood design and fastener research around the world.

In preparing this paper, I polled a number of my colleagues to ask what had stimulated their thoughts of grander opportunities for building with wood. I acknowledge their contributions.

I was surprised at the number who mentioned that the material presented a "double header" conference held in Las Vegas in 1992 was the early alert to the larger community of the North American timber industry that European practitioners were not only looking at quite different ways of using timber in structures, but in connecting the members together.

The "Conference on Wood Products for Engineered Structures" was paired with the "International Workshop on Wood Connectors".

Changes in the way we think about things do not always happen quickly… but they do happen.

What is the world's tallest wood building (for now) at 18 storeys was topped-off in Vancouver just a few weeks ago.

Let's agree that's a pretty big change when one realizes it is only seven years back that the limit on wood construction in that jurisdiction was just four storeys.

In the same year as the mentioned Las Vegas conference, Professor Borg Madsen (by now at the University of British Columbia) published the first of his two books "Structural Behaviour of Timber" [1] where he focused on the need to recognize the strengths of large timbers by in-grade testing.

He wrote of how the understanding of such timber behaviours could be incorporated into improved design procedures for timber members.

Dr Madsen advocated that "Timber is as different from wood as concrete is from cement" and brought his Danish experience to Canada as an early ambassador for advancing more significant timber structures there.

Borg continued to share many thoughts in code committee work and was opening a window of new thinking.

Figure 1. An Example of the Images of European Wood Construction that Flagged Early North American Interest in More Innovative Wood Designs

In speaking of windows, In calculated that if each European were to look from their window, he or she would see a forest cover equivalent to the area of about 68 tennis courts.

Each American would see a forest cover of about 350 tennis courts. Each Canadian would see that cover to be about 3200 tennis courts.

What do these comparisons suggest?

Since Europe has almost twice the population of North America, in order to support wood construction from their domestic forest resource, the zeal to optimise the use of the relatively smaller per capita availability of fibre across the several countries is understandable.

Canada, with a larger readily available per capita fibre resource, and with manufacturing geared to support light frame construction products domestically and for export to the U.S. had not been driven to develop significant secondary manufactured production because building types had limited demand for it.

On the academic front, Universities in Germany, Austria and Switzerland had established quality programmes to advance research and technical training with a view to optimise and refine design and building approaches to build with wood.

Integrating practical industry experience into those wood syllabuses provided graduates with a broad scope of understanding of both the potential and limitations of using the product.

While basic wood engineering courses have been part of civil engineering programmes at some Canadian and U.S. universities, it remains a rare student that graduates in that discipline with hands-on experience in a manufacturing work place.

The demands of new programmes such as environmental studies have made it difficult to find any more time for wood courses in civil engineering departments. Courses still concentrated on steel and concrete design.

As a result, any efforts to facilitate an increase in wood design and research have had to find a different approach.

NORTH AMERICAN PRACTICE

As mentioned, the preference in both the U.S. and Canada is to use light wood framing for residential buildings.

Almost 70% of the softwood lumber harvest is being used in light wood frame construction. [2].

Not surprisingly then, much of the research on materials and production processes has been directed to supporting these applications.

The summer/fall 2015 Survey of the UCLA Anderson School of Management indicated that changing U.S. lifestyle tastes were showing a shift from single family housing with the associated commuting into the employment centres to a balanced mix between single-family and multi-family housing located closer to workplaces, entertainment and sporting venues.

Given the generally limited available real estate closer to such enterprises, building higher becomes the standard approach.

Building such multi-family accommodation with wood higher than four storeys has been limited by prescriptive building code limitations in many US and Canadian municipalities.

Now that some of these handcuffs are gradually being taken off, the design community is challenged to reach for expertise in different wood design and construction approaches to figure out how to join the dots.

How was this knowledge to be gained?

Even though we have examples of large wood buildings in the U.S. and Canada, such as some six-storey heavy timber framed structures more than 100 years old that still serve office and residential occupancies in Vancouver and Toronto, they are few and far between.

There are a number of landmark glulam structures such as the 525 foot diameter Tacoma Dome built in 1983 still perform well.

Figure 2. Tacoma Dome, Washington, USA

Most designs for the larger wood buildings up to the late 1990's were rather basic; connections were generally made with bolts, split rings, shear plates and most often exposed steel side plates,

These designs had relied on the application of the technologies presented in wood design courses in North American universities and colleges at the time.

IDENTIFYING DIFFERENCES FROM ABROAD

Canadian and American researchers and academics who were attending meetings such as CIB-W18, (now INTER) and other international conferences were recognizing that wood research was being managed differently elsewhere.

These folk were meeting emerging champions who were stimulating new thinking in working with new fasteners and advancing CNC manufacturing processes.

They were becoming aware of larger and more intricate timber structures being constructed in Europe. They also saw the development of the manufacturing of large wood panels at KLH and then at other facilities.

Names such as Natterer, Larsen, Ceccotti, Glos, Blass, Schickhofer, Weirer and others were becoming known in North America as reports of the various conferences and visits were discussed.

With this widening awareness of new products and fasteners from abroad, industry was beginning to see rays of possibilities to promote structural timber as a more viable material option for designers in non-residential work.

There were few North American structural engineers who had reasonable confidence to design more than elementary wood systems.

From a purely practical perspective, many engineers had little reason to propose other than steel and concrete for a new project. They were familiar with the potential and limitations of both materials, and those design processes were well learned.

Their consulting fees would better support work to design with a material they knew how to manage. To commit time to essentially self-train to engage a timber design was not an attractive prospect.

Even those engineers who were prepared to size wood members or even frames were uncomfortable with designing the connections, and spoke of this as the most difficult part of designing with wood. [4].

Understandably, architects were becoming discouraged by the low level of available domestic technical support that they needed if they were tempted to consider designing buildings similar to the more adventurous wood projects they were beginning to see from abroad. Their discontent was expressed to industry associations in focus sessions.

What had to change?

ADDRESSING THE OPPORTUNITY

In the mid 1990's some developments were paving the way to eventually move to engage more focused timber engineering training such as was being recognized abroad.

Figure 3. Forest Sciences Building at University of British Columbia, Vancouver (Timber Systems Limited 1994)

Figure 4. Some of the Participants in the 1999 European Tour

An initiative coming from the Canadian joinery and furniture industries lead to the construction of the new The Forest Sciences building on the University of British Columbia (UBC) Vancouver campus which was completed in 1996, at a cost of fifty million dollars. In this case, locally produced Structural Composite Lumber (SCL), Parallam® was used to frame the structure.

The building housed the Centre for Advanced Wood Processing and Wood Science, Canada's National centre for education, training and technical assistance for those industries and also became the home for the UBC Forestry department as well as accommodating some Civil Engineering programmes.

Even though there was yet no significant structural wood design and construction curriculum in place at the facility, the Centre became the focal point to meet and plan for such a programme.

A body of Canadian West coast educators at the facility were of the opinion that it was time to take a serious look abroad to gain a perspective of what ideas might guide thinking and actions needed to advance the heavy timber industry there.

In late 1999 I was pleased to be a part of the group of 12, made up of those educators, some consulting engineers, and a few manufacturers who set out to Zurich to begin a ten-day tour of Swiss, German and Austrian wood manufacturing plants. The trip included visits to both the FH Rosenheim University of Applied Science and the Berne University of Applied Science in Biel. The group also attended the 5th Holzbau-Forum in Garmisch.

This tour of some 17 years ago was the first organised attempt to find out just what these European wood magicians had conjured, and then to think about what could be integrated into the Canadian landscape.

Over time it has proved out that it was the personal contacts established and nurtured relationships that facilitated a great deal of the information transfer that was key to supporting North American planning for more mass timber work there.

These developing contacts also encouraged a number of Swiss and German students to include U.S. and Canadian schools as a part of their studies. Some later returned to accept employment there which brought another level of technology transfer along with their practical experience to influence the workplaces.

ESTABLISHING FORMAL PROGRAMMES

Canadian industry interest was now driving efforts to create a wood research and education strategy along the lines of what had seen to be the European model.

The vision was to create a world class research and education programme that would place it at the forefront of innovation and knowledge developments in the field of building design and construction.

A Chair was established in 2006 to oversee a programme integrating contributions from each of the Architectural, Civil Engineering and Forestry Departments at UBC in Vancouver.

The mandates of the UBC Chair, Wood Building Design and Construction were to develop world class research and teaching programs. While the individual Faculty members maintain their own research programs, they have also created some joint initiatives, most notably a FII funded project on timber shells. With the addition of Dr. Tannert in 2011, UBC was able to offer the most comprehensive suite of wood design course in North America consisting of two undergraduate and two graduate courses.

More recently, in 2011, the Canadian Government funded the "NEWBuildS" programme which engaged liaison and cooperation between four universities and other research facilities across Canada.

This project was completed in 2015. It supported over 70 graduate and post –doctoral students, and produced more than 60 PhD and MSc theses.

These theses encompassed a broad range of related disciplines. They included structural engineering, fire engineering, building envelope design, durability and product characterisation of North American CLT.

The outcome has been a larger resource of talent to populate engineering offices and industry positions.

A FIRST LOOK AT CROSS LAMINATED TIMBER

As mentioned, it was during our 1999 tour of various glulam and other manufacturing facilities, that our interest was piqued when we saw CLT in its early stages of development and production. Glued, nailed and pegged lamella were all being tested out. It appeared that the primary application at the time was for residential construction.

But homes in Austria and Germany are quite different in design and styling from those in North America.

Greater attention was being paid to energy efficiency and the mass timber assemblies complemented that interest.

An interesting product, but could it find a place in North American home building?

DIFFERING APPROACHES AND PRG 320

Both the American and Canadian Wood Councils are industry-supported associations charged with the development of design standards and support materials for the construction of timber buildings. They also work to coordinate marketing initiatives.

A joint study by these groups concluded that there was a good case for CLT to play a role in North American wood construction, and a decision to develop a manufacturing standard to embrace domestic material properties and adhesive specifications was made.

Individual European manufacturers produce product to their own manufacturing standards and prepare strength and performance values on a proprietary basis. Led by the Wood Councils, at the outset of contemplated North American CLT production, code committees joined forces to prepare a product standard document for the production of CLT there.

The product standard document "Standard for Performance Rated CLT (ANSI/APA PRG320)" to which manufacturers could be certified and to which specifiers could reference for performance expectations was produced in 2012. The Standard was updated in 2015.

The evaluation of CLT products that have not demonstrated conformance to PRG 320 is not as simple as a conversion of design properties published by product suppliers.

The design standards in North America were developed based on an array of performance expectations stipulated in this standard.

Durability in heat, moisture and fire as well as compatibility with design value derivation in North America are parameters to be measured.

Figure 5. Glulam Atrium, Toronto, Canada (Timber Systems Limited)

TECHNICAL DEVELOPMENT

Companies and researchers interested in planning for the first Canadian and U.S. CLT plants were now making regular visits to Austrian and German facilities to gain background to assess the best approaches in beginning domestic production.

Further to the manufacturing aspects of these interests, in considering the best way to introduce CLT to the North American designers, Code committees in both counties were now considering the best way to harmonize the work needed.

As it turned out, Canada and the U.S. took different approaches to developing and publishing initial design data.

The American Wood Council published basic design direction and capacities for CLT manufactured to PRG 320 in its 2015 edition of the "National Design Specification (NDS)".

Rather than publishing rather preliminary CLT design guidelines in the 2014 edition of the Canadian Standards Association design standard "CSA O86, Engineering Design in Wood"), the Technical Committee chose to develop more complete material to include in the standard at a later date.

Committee work then continued for the next two years in order to prepare a substantial supplement which was published in June of 2016. It attended to a broad range of design and performance parameters to guide engineers to engage CLT panels in building systems, not merely panel elements. The inclusion of CLT design clauses in the standard affected more than 150 pages of the document.

NORTH AMERICAN CLT PRODUCTION AND USE

CLT production had begun in 2011 at two Canadian glulam plants with the interest to establish the panel as a complementary product to their current work and expand opportunities for mass timber construction in general.

Approvals for CLT production at a similar U.S. facility were in place as of 2015, so more sources of domestic product were becoming available.

These CLT manufacturers were themselves providing design assistance to consultants to support the integration of the product into new projects.

Technical seminars and presentations mounted by industry associations in both countries were now including examples of domestic successes as well as interesting projects from overseas.

Quite independent of CLT work, more complex glulam structures were being realised in non-residential construction both in the U.S. and in Canada. The promotion of these successes was building confidence in the design and contracting communities.

Also, just as is the case in Europe, there were emerging champions from the Canadian design community.

Figure 6. Installing 25 KLH CLT Panels Per Day. September 2015 (Timber Systems Limited)

Engineers Robert Malczyk and Eric Karsh of Equilibrium Consulting and energetic architect Michael Green were actively promoting interest in building tall with wood at home, in the U.S. and even in Europe.

These and other professionals were planning and designing projects that included glulam, CLT and other products on a much larger scale that had been considered previously.

The early examples of taller wood structures in such landmark buildings as the nine-storey Murray Grove project in London, U.K, and the ten storey Forte project in Melbourne, Australia, both of which were completed less than eight years ago with Austrian expertise and product, served to confirm to global audiences that a new era of wood construction had arrived.

In the U.S., construction is set to begin on a twelve storey glulam and CLT tower in Portland, Oregon.

Newer projects have followed in the U.K. and elsewhere. The largest of a number of tall wood buildings currently underway in Canada is the eighteen storey Brock Commons student residence at UBC in Vancouver.

North America is seeing new timber buildings becoming part of downtown landscapes. Work is currently underway on a seven storey glulam and nail-laminated deck panel structure in Minneapolis, Minnesota.

Construction has begun on a four level glulam and CLT retail store surrounded by high rise office towers at Canada’s busiest intersection in Toronto.

With so many other such innovative projects already in construction being presented at this conference, it is likely that this event in Vienna is one that showcases more that is new in building with wood than any before it.

North American contractors and entrepreneurs have been approaching European manufacturers directly to fill their requests for CLT proposals and quotations to supply product in competition with the newly established domestic plants. Some have been seeking product distribution agreements as well.

Figure 7. Moment Connection Using Tight-Fit

Similarly, European manufactured glulam is now competing with established local production, particularly in Canada.

Current European CLT production may not comply with the requirements of the North American Manufacturing Standard PRG 320. Circumstances may affect its use in North America in that it may require that the project engineer of record assesses the characteristics of the product offered and make a professional judgement as to the appropriateness of its use in the particular project.

As reported, some North American production is now in place. However, until we see demand justifying additional domestic manufacturing capacity, one can expect to see off-shore manufactured CLT to be part of the supply chain for some time.

Relative fibre, manufacturing and shipping costs, as well as currency exchange rates are some of the factors that will determine the competitive position for European manufactured wood products in North America.

Distribution relationships for some European CLT producers for some territories are now in place, whereas other manufactures are choosing to work directly with clients on an ad-hoc job-by-job basis.

MAKING CONNECTIONS

Building with Mass Timber does involve substantial connections to transfer high loads by virtue of typically larger structural configurations.

Connections with small diameter tight-fit dowels are among those that some European designers had been working with to attend to the larger loads. Such connections and the design philosophies behind them were not familiar to designers in North America.

Few designers were equipped to work with the design data available to be able to predict the behaviour of the various fasteners in species other than European spruce, so applications were limited.

Further, the CNC equipment needed to precisely frame glulam and other products to support the use of these and other concealed fasteners was not generally in place until 15 or so years ago. Today, most fabricators have installed this equipment and are better equipped to include such offerings in their timber projects.

The long, course threaded self-tapping screw has been introduced to North America by a number of manufacturers and have been embraced by heavy timber fabricators to provide effective and efficient load transfer mechanisms without the shop drilling required by more traditional alternatives.

When working with these screws in Douglas fir (as is commonly used in solid timber or glulam construction in North America) pre-drilling of lead holes is necessary in some applications.

Screw capacities are not generally published for Douglas fir or Southern Yellow Pine applications.

The lack of generic design data for screws and other connectors makes specifying such products difficult for designers without designating a particular manufacturer.

One distributor has done the homework in presenting capacities for these screws in North American species. Other current literature from some European screw and other connector manufacturers continues to express capacities as characteristic values.

This means adjustment factors need to be applied before their use in a standard Canadian Limit States Design format for example. The present situation presents a risk of unsafe designs if the designer mistakes the basis of the presented data.

Testing of these screws in North American species is underway with an interest in establishing a basis for assessing capacities for specific steel strengths and product diameters that can be included in design standards.

SOFTWARE INNOVATION

It was not until some 20 years ago that North American fabricators began to engage the detailing software programmes that were already being used in Europe to model and detail structural members and connections.

Previous to this, most modelling and detailing work had been managed by AutoCAD® software that each company configured to its particular requirements.

The power and capabilities of this industry specific software was soon recognised as essential to moving forward with more elaborate framing work as well as to prepare machine files to interface with CNC equipment.

These mainly Swiss and German programmes quickly established a hold on the market, and most providers now have on-the-ground technical and support staff in place.

INDUSTRY AND GOVERNMENT RESPONSES

In encouraging designers to become more familiar with the design and construction strategies I have described today, government initiatives in the U.S. included the Tall Building Competition mounted by the Softwood Lumber Council in 2014.

This competition would fund the two award-winning proposals to develop the concepts for the construction of tall wood buildings of twelve storeys or more, potentially with one project to be built on the East coast, the other on the West coast.

The West coast winner was a design proposal for a 12 storey building in Portland Oregon. I mentioned earlier that this project was now ready to begin construction.

The award for the design proposal for the East Coast project was for a 10 storey residential condominium in midtown NYC.

In both countries, actions underway to modify building codes and standards have been very effective in removing some long-standing barriers to expanding the potential to build with wood.

The Government of the Canadian Province of Quebec for example, launched a technical guide in 2015 titled “Construction of Mass Timber Buildings up to twelve storeys”.

NORTH AMERICAN CONTRIBUTIONS

Importantly, North America itself has not been without creative and innovative spirit when it comes to wood research and product development.

Work on seismic loading provisions has provided world-leading direction to designers who promote wood buildings as being well suited to building in earthquake-prone regions.

Structural Insulated Panels (SIPs), Wood I –Joists, Structural Composite Lumber (SCL), Oriented Strand Board (OSB) and other panel products continue to play important roles in everyday construction in both the U.S. and Canada, but have few have seen use in Europe.

Even in these early days of designing with CLT in Canada, design innovations there are showing new directions. The design for the previously mentioned Brock Commons student residences at UBC in Vancouver does not have panels supported by the traditional beam framing between columns, but rather engages two-way bending such that the panels supported only at their corners.

So, as cross-ocean relationships mature and the experience gained from each project leads to optimisation of processes, the potential for North America to reciprocate with its own contributions to

European wood construction may well lead to a future paper “From North America with love”.

CONCLUSIONS

The interest in seeking out the results of recent decades of wood research, product innovations and advances in manufacturing processes in Europe has resulted in many of those achievements being effectively integrated into Canadian and U.S. construction.

The on-going adaptation of building codes to establish a regulatory basis for building larger and higher with wood, the strengthening of domestic manufacturing resources, and an avid interest in considering wood as a viable and desirable building material do herald expectations of growth in the industry to challenge long-held decisions to build with steel or concrete in the short term future.

ACKNOWLEDGEMENT

I thank a number of colleagues who have offered their opinions of how activities in Europe have influenced their own experiences in various aspects of designing and building with wood.

DEDICATION

I wish to dedicate this paper and plenary presentation to the memory of close friend and colleague Dr David Barrett who passed away this year.

Dave encouraged so many of us to share his vision and enthusiasm for what our industry could achieve and was instrumental in alerting us to the value that his European friends could bring to our efforts.

REFERENCES

[1] Masdsen B. Structural Behaviour of Timber. Timber Engineering Ltd. 1992

[2] Beuhlmann U. Virginia Tech. Personal communication. 2016

[3] Summer/Fall 2015 Suvey | UCLA Anderson School of Management.

[4] O‘Connor J. Survey of North American Achitects and Engineers. Forintek. 2003

Gary C. Williams is President, Timber Systems Limited in Ontairio, Canada. gwilliams@timsys.com

Opportunities and Limits of Timber in Construction

Alfred Teischinger

ABSTRACT

Wood has to be seen as a complex biological structure, a composition of various cell types and chemistries acting together to serve the needs of a living tree which are mechanical support, transport of water, storage and the synthesis of bio-chemicals. All fundamental properties of wood, such as physical, mechanical, chemical, biological as well as the technological utilization of wood as a material are derived from the fact that wood is formed to meet the needs of the living tree. Wood as one of the most traditional materials lost track in the new material design of the synthetically produced materials and composites but new approaches in wood modification and Engineered Wood Products paired with environmental benefits pave the way for a wider application in the building sector. Additionally some trade -offs and limits for an increased future use of wood in the construction sector is discussed.

INTRODUCTION

A tree is a perennial, vascular woody plant with a root system and an elongated stem, or trunk, supporting branches which form the crown. The vascular cambium is a narrow layer of cells located between the inner bark and the stemwood, which produces living cells to the bark and the sapwood. The tissue of living cells around the cambium and the physiological active cells of the inner bark and outer xylem (sapwood) is fairly small compared to the full cross-section of the stem. But this small part of the tree is an important active part of the whole metabolism of a tree and the photosynthesis in the leaves/needles. The fascinating photosynthesis process transforms CO2 of the atmosphere into carbohydrate compounds (sugars) as a basis molecule for the further very complex biochemical process of wood formation which is summarized by [1].

Keywords: Timber in construction, biomaterial wood, material selection, wood availability, WCTE 2016

Photosynthesis products as nutrients for the cell metabolism in all living parts of a tree travel downward and are distributed through the inner bark of the stem and water and minerals from the roots are flowing upwards to the crown through the sapwood (Fig. 1).

First of all, wood has to be seen as a complex biological structure, a composition of various cell types and chemistries acting together to serve the needs of a living tree. Wood evolved over the course of millions of years to serve three main functions:

- conduction of water from the roots to the leaves/ needles
- storage and synthesis of bio-chemicals

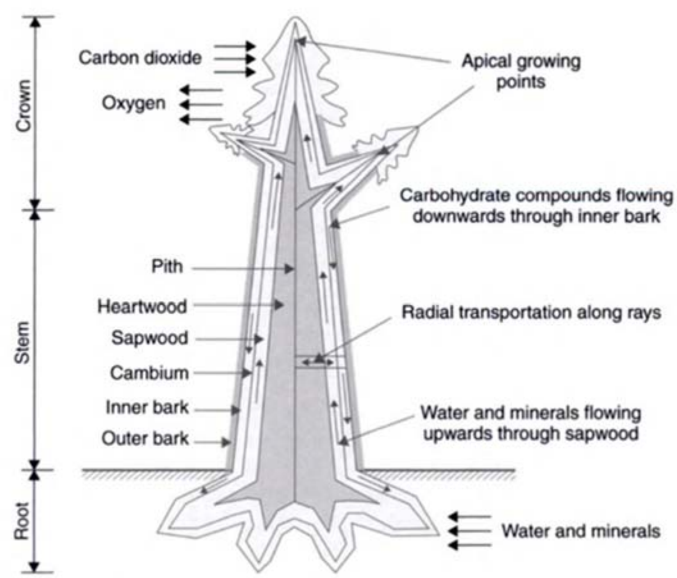

Figure 1. Main Parts of a Tree And Their Function, Where Carbon Dioxide From The Atmosphere is Captured in the Leaves and Needles of the Crown and Oxygen is Released by the Biochemical Process of the Photosynthesis in Order to Produce Carbohydrates as Nutrients for the Metabolism of the Whole Tree (Derived from [2])

- mechanical support of the plant body incorporating the roots and the crown with their many branches and the leaves/needles

But also the function of the outer bark, which provides mechanical protection to the softer and physiological active inner bark, helps to limit evaporative water loss and protects the UV-sensitive lignin from the deteriorating radiation of the sunlight, has to be highlighted.

All fundamental properties of wood, such as physical, mechanical, chemical, biological as well as the techno-logical utilization of wood as a material are derived from the fact that wood is formed to meet the needs of the living tree. By understanding the function of wood in a living tree, one can better understand the strengths and limitations it presents as a material.

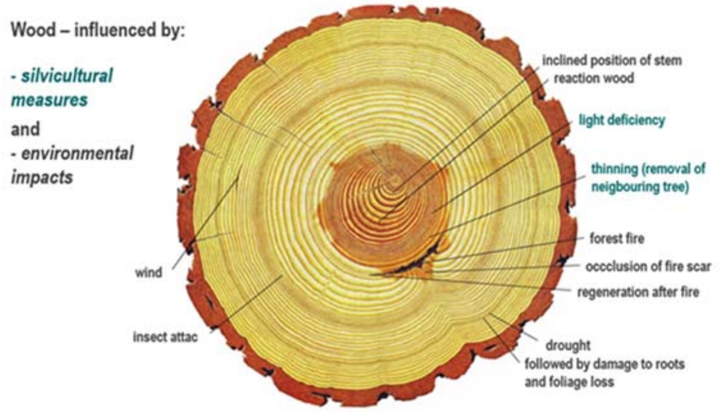

Figure 3. Cross-section of the Stem Exhibiting a History of the Whole Life of the Tree (Source: Eidg. Forschungsantalt für Wald, Schnee und Landschaft WSL, adopted and extended)

HIERARCHICAL STRUCTURES AND CHEMICAL COMPOSITION OF WOOD

Wood is a very efficient structure consisting of a macro-molecular compound of cellulose, hemicellulose and lignin as building blocks for multilayered cell walls in a sophisticated hierarchical structure as shown in Fig. 2. The trunk of a tree is able to push the crown towards the sunlight in order to collect the energy of the sun for the photo-synthesis prcess still connecting the roots in order to stay rooted and to convey water, minerals and nutrients along its axes. In this competition for sunlight on the one hand and the access to water and minerals from the soil on the other hand, the trees have become the most successful plants on earth in the course of the evolution. The tallest trees reach a height of more than 100 meter (Fig. 4) and without human interference, a major part of the earth´s surface would be covered by forests. For a plant to reach such a height, its main wooden structure needs to be light rigid, but to some extent flexible in order to bear the crown against adverse weather conditions.

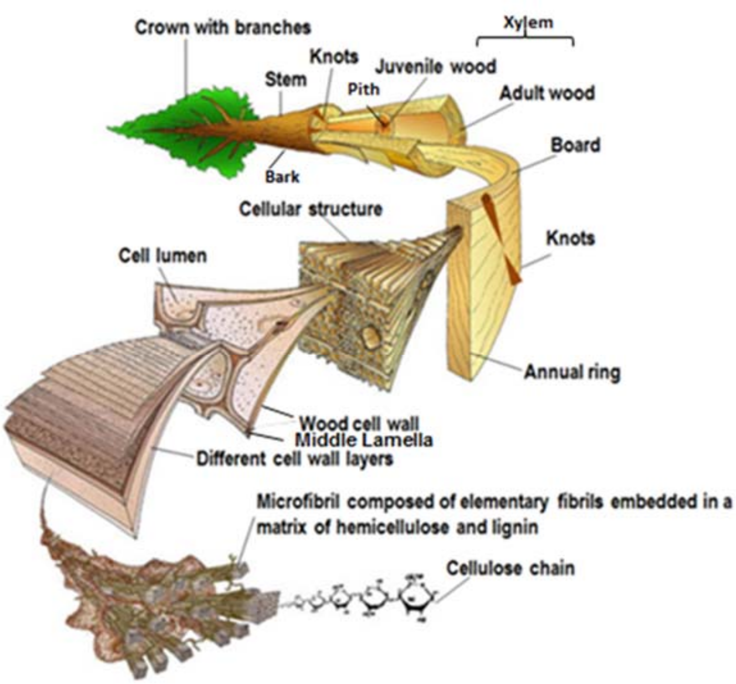

Figure 2. Scheme of the Hierarchical Structure of Coniferous Wood (Softwood) (University of Canterbury, 1996. Design by Mark Harrington, slightly changed and extended)

But the wood structure built up by annual growth increments (annual ring) also has a story to tell, which reflects the seasonal impacts and the environment such as precipitation, temperature, sunlight etc. (Fig. 3). The growth and synthesis of wood in the juvenile and adult phase (Fig. 2) and the different seasonal impacts combined with many other impacts of forest management (tree spacing, branches/knottiness, silvicultural measurements etc.) as discussed by [9], make wood as a material extremely inhomogeneous, which is a big burden for a high-tech material utilization. The consequence in wood utilization is a specific wood raw material disintegration and re-engineering process, as outlined in Fig. 7, in order to produce reliable and reproducible wood based materials and standardized products.

Considering the elements building up the molecules which compose the biopolymer structure of an interconnected network of cellulose and hemicellulose (both considered as carbohydrate polymers) and lignin (amorphous, highly complex, mainly aromatic polymer), as shown in Fig. 2, with minor amounts of extractives and

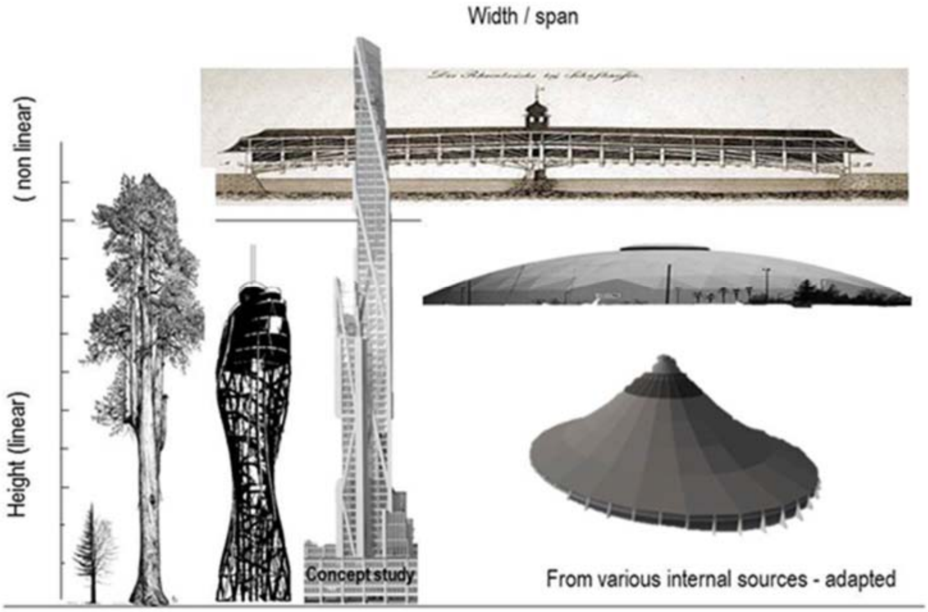

Figure 4. From the Living Tree to Technical High-Rise and Large-Span Wood Structures (partly in scale, up to the horizontal bar at 100 m). Vertical Structures from Left: Usual Tree Height, Highest Tree, Pyramidkogel/Wood Tower in Austria, Concept Study of a High-Rise Building (300 m)
Horizontal Structures from Top to Bottom: Bridge Over the Rhine River (CH by Hans-Ulrich Grubenmann (1758), Tacoma Dome (USA), Rinter

inorganics, carbon, oxygen and hydrogen are the dominating light-weight elements (compare Table 1). Synthesizing wood via the photosynthesis and wood formation process also is a carbon capture process as long as the bio-synthesized wood is a constituent of a living tree or is used as a material in the wide array of wood utilization.

BIO-BASED AND SYNTHETIC MATERIALS—A SHORT COMPARISON

Wood is synthesized by nature, most of the other engineering materials are synthesized and fabricated by man and this makes the big difference between wood and the synthetic materials. Wood is a result of millions of years of evolutionary material optimization in nature to meet the needs of trees and to make the tree one of the most successful plants on earth. Wood is formed in a dynamic, but perennial process of material synthesis according to a recipe stored in the genes, rather than being fabricated according to a technical design by man whereas synthetic fabricated materials are to meet a certain design. This makes a big difference in the design strategies of bio-based materials and technical engineering materials (Table 1).

Plant-based materials derive from plant growth, also in reaction to the changing needs of a growing plant (e.g. juvenile wood, reaction wood as a result of a one-sided load to the tree, adult wood), whereas fabricated technical materials are a result of a designed production process. This leads to differences in the two material types which are discussed thoroughly by many authors [3,4,5,6,7,8].

Besides the material itself, there is also a difference in how to create or fabricate a component part. An engineer selects a material to fabricate a component part according to an exact design whereas nature goes the opposite way and grows both the material and the whole organism (e.g. a tree with components such as the stem and branches) using the principles of (biologically controlled) self -assembly in an approximate design [6].

Using wood as a material in technical applications we have to cope with the history of self-assembly which causes all the features such as annual ring patterns, grain deviation, knots, pitch pockets, density variations and generally spatial variations in the

Table 1. Differences Between Bio-based Materials and Technically Engineered Materials (based on [6])

Biological Materials	Engineering Materials
“Light” Elements are Dominating: H, C, N, O, Ca, P, S, Si	Large Variety of Elements: Fe, Cr, Ni, Al, Si, C, N, O, . . .
Growth by Biologically Controlled Self-Assembly (Approximate Design)	Fabrication from Melts, Powders, Solutions etc. (Exact Design)
Adaption of Form and Structure to the Function (Also According to Changing Environmental Conditions)	Selection of Material According to Function
Healing: Capability of Self-Repair	Secure Design (Considering Possible Maximum Loads as well as Fatigue)
Hierarchal Structure At All Levels	Beyond Micro-structure: Homogenous

wood properties. This huge variety in the raw material wood is a challenge to analyse wood and measure wood properties respectively and to place them along the added value chain in the best possible way as described by [9].

Considering the height of the tallest trees, which also is an indication of the limits of the material wood, we face the limit in the hydraulic and biomechanical system of a tree. A tree as a well-rooted column with a crown (as a functional unit on the top) still could be higher than 100 meters, but obviously there is the limitation of the hydraulic function of the physiologically active cells which transport water and nutrients. Water is transported from soil to the transpiring leaves under negative hydrostatic pressure, requiring high mechanical strength of the water conveying wood cell walls in order to avoid implosion and the breakage of the water column (cavitation) as discussed by [10]. So, besides many other biological and environmental factors, cavitation might be one of the limiting factors for a tree to become higher than the highest trees which have been recorded.

It is up to the architects and engineers to design and calculate the tallest wooden structure possible based on wood material properties so as it is the example of a compelling and visionary concept study of the University of Cambridge with a wooden building of a height of 300 meters [11]. Such a speculative concept study might be discussed; if such a high wooden structure based on dramatically improved and modified wood properties is worthwhile, as the big majority of (residential) buildings rise up to 10 stories. In this dimension of building structure wood can be used as an almost “ready to use” building material, which only needs a minor processing with low energy input and still incorporates all the features of wood as a natural material [12].

According to M. Ramage from the University of Cambridge [11] the new approach to the limits of natural materials includes the utilization of other lignocellulosic materials such as bamboo (tensile strength about five times that of wood) or boosting the material properties by polymeric impregnation etc. “We want to redesign natural materials to carry out different functions that will change the way we construct cities. This starts at the molecular level and continues to engineered solutions to sustainable living. Although the techniques to manipulate manufactured materials are better understood, the potential to generate materials with diverse properties based on plants may be far greater”.

In the current competition about the largest or tallest wooden structures an enormous run can be seen, driven by visionary concepts, concrete realization plans and already performed projects which are highlighted in the various wood construction and architecture journals and other documentations [13,14,15]. Wood technology and building component manufacturing systems have to innovate and provide proper and competitive manufacturing and material solutions for the construction sector. Cross laminated timber (CLT), parallel strand lumber (PSL), laminated veneer lumber (LVL), glued laminated timber (glulam) and various prefabricated paneling and building components systems are among the current products, contributing to a wider range of modern innovative wood building components as they are compiled exemplary by [15,16].

MATERIAL SELECTION PROCESS IN THE DESIGN PROCESS

Clustering the material properties

There are some ten-thousands of materials available to the engineer and the materials are divided into material classes such as metals and alloys, ceramics and glasses, synthetic polymers, natural materials and composites. In designing a structure or device, how is the engineer to choose from this vast menu of materials which best suits the purpose? [17]. Mistakes in selecting the right material can reduce competitiveness and market share but can also cause failures, accidents and even disasters. Material and design failures and the accompanying disasters are some of the most prominent headlines in the newspapers. Not to mention the many everyday little accidents and inconveniences due to wrong material design.

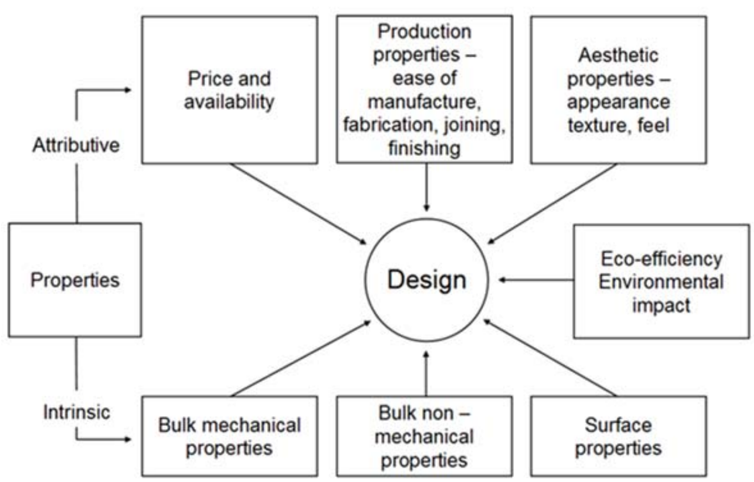

Figure 5. How the Properties of Engineering Materials Affect the Way in Which Products Are Designed (adapted from [17] and further developed)

Besides straight engineering values also “soft facts” such as environmental issues (Fig. 5) are becoming more and more important, however, appropriate decision tools are still missing despite of many environmental assessment methods.

Different classes of materials such as metals and alloys, ceramics and glasses, polymers, natural materials and composites exhibit various classes of properties. These properties encompass general and specific physical and mechanical properties (density, stiffness, strength, conductivity etc.), environment interaction (corrosion, durability), production properties (ease of manufacture, finishing etc.), aesthetic properties (colour, texture) and economic properties (price and availability, recyclability).

Design to minimize adverse impact of engineering products and structures on the environment (“green design”) is assuming an increased importance in all branches of engineering. Eco-impact thus becomes an additional metric to be optimized along with performance and cost but the problem is a complex one: eco-impact can be associated with the extraction and refinement of the material, with the manufacture of a product/structure from it, with the use of that product or structure and with its disposal [19]. Life cycle assessment (LCA) as described by Murphy [20] has become a common system analysis tool for evaluating environmental impacts over the whole life cycle of a product, process or activity from the “cradle” (raw materials acquisition) to the “grave” (disposal or recycling). Meanwhile many LCAs are available for wood as a material and wood in construction and various other uses but also comparisons to other materials [21] and various studies are compiled by [22].

Currently materials and processes to shape them are developing faster than at any previous time and the challenges and opportunities they present are greater than ever before. Wood, as one of the oldest, most commonly available and versatile materials, has not changed its nature during the engineering history of mankind. Is wood therefore an overmature material or still one of the most promising materials of the future?

Material properties chart

As wood and many other competing materials are used in different applications, one has to differentiate between material selection in structural design, engineering design, industrial design etc. For each design different approaches are appropriate and common. This makes a general analysis of a wood material choice very complex and is also a major challenge for the wood industry to provide a proper material portfolio (solid wood, different wood species and grades, wood based materials, wood composites, engineered wood products etc.). Each of the materials within this portfolio has to be described and categorized by material property values and design values. Something which still causes problems for wood as a very versatile, inhomogeneous and anisotropic material based on hundreds or thousands of commercially used wood species, each species exhibiting a large variability of properties.

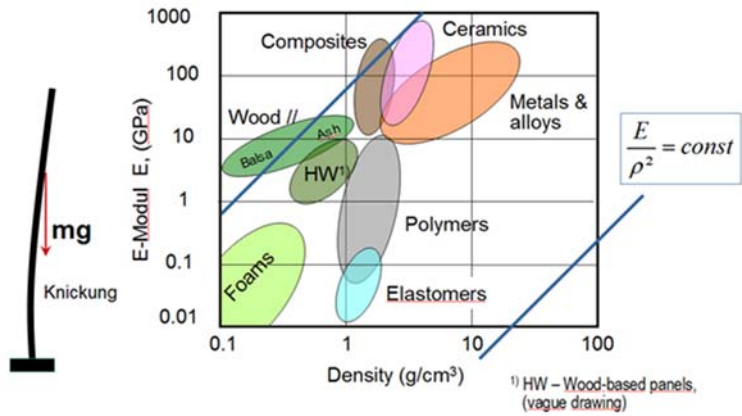

Figure 6. Idea of a Materials Property Chart (derived from [23]): Young’s Modulus, *E*, is Plotted Against the Density, ρ, on a log scale. A Contour Derived from the Issue of an Elastic Column Buckling by E/ρ^2 = Constant Deploys Several Material Clusters to be Selected.

Unfortunately, wood as one of the most traditional materials lost track in this new material design of the synthetically produced materials and composites. Material properties limit performance and a way of surveying properties is needed so as to get a feeling for the values design-limiting properties can have. Seldom the performance of a technical object depends on just one property. More often it is a combination of properties that matter, for instance, of the strength-to-weight ratio (σ_f/ρ), or stiffness-to-weight ratio (E/ρ), which enter lightweight design. This suggested the idea by [23] of plotting one property against another, mapping out field in property space occupied by each material class. The resulting charts are helpful in many ways, as they condense a large body of information into a compact but accessible form (Fig. 6).

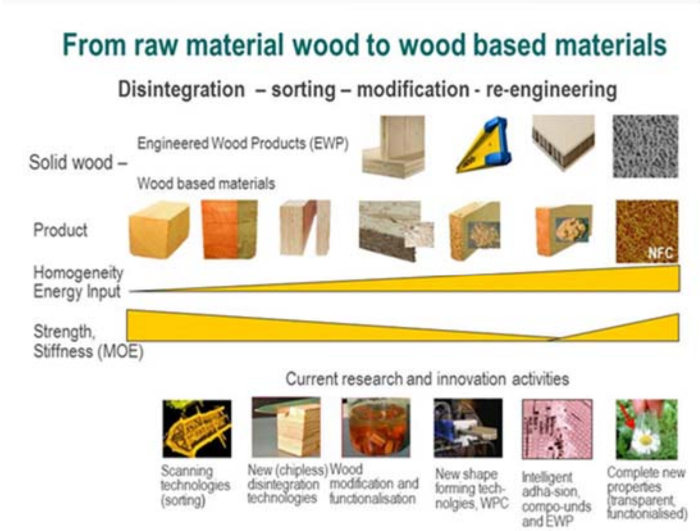

Figure 7. Disintegration, Sorting/Grading and Remanufacturing with Different Consequences Such as Change in Stiffness and Strength Properties Further Developed from [25].

WOOD COMPOSITES AND ENGINEERED WOOD PRODUCTS (EWP)

Wood composites are material derivatives from wood, designed and produced by man. They represent something in between the natural polymer of wood and a technically fabricated and engineered composite consisting of wood particulates (particles) and a glue or matrix material. Glued wood components and wood based materials form a distinctive material class with the idea of fractioning the raw material, sorting and grading the fractionized components and reintegration in order to achieve new and fairly homogeneous material families with new and designable material properties. The extent and the way of disintegration of the roundwood has various consequences such as increasing energy input and material homogeneity and reliability with increasing disintegration but also decreasing strength and stiffness (Fig. 7).

During the last high-tech decades wood has not been acknowledged as a key-material. The engineering image of wood and wood-based materials has been one of "low-tech" or "secondier" material [26]. In opposition to this misperception, however, is the fact that the use of wood and wood-based materials in construction, by weight, exceeds that of steel or concrete each year.

Mainly, two main developments, the increasing environmental consciousness and the emerging of new "Engineered Wood Products" (EWP) combined with more sophisticated grading systems for lumber continue to be developed and successfully introduced into the engineering and construction marketplace. Some of the key advances and trends such as raw material assessment, grading, improvements in the primary and secondary wood processing are reviewed by [7,9,26], where the non-destructive evaluation (NDE) of wood is one of the key-issues. Following the grading process, improvements in assigning appropriate design values for use by both design codes and design engineers has also been a targeted effort.

The current development of wood as an engineered product as well as a commodity mass product is based on several drivers:

- Cost efficiency and competitiveness to other materials
- Raw materials situation for wood, but also for other materials, including renewable resources and/or recyclability etc.
- Ecological aspects, consumer awareness of materials

The driving force behind the development of many wood-based composite materials is many-fold such as the response to the changing wood resource (wood from thinnings, short rotation, by-products from processes etc.), the need to meet increased and/or specific performance demands for the materials, producing larger, two-dimensional elements and cost-efficient processes etc.

One of the major challenges for wood-based materials is the high variability of the natural resource (Fig.8), but modern engineered materials should exhibit a very small variation of properties and at least they have to meet threshold-values given by various standards. Exceeding the threshold values mostly means higher raw material costs, reduced yield, higher process costs etc. and

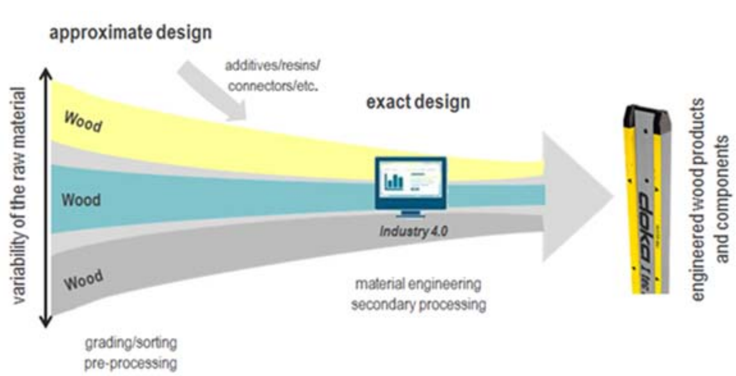

Figure 8. The Challenge of Materials Design and Process Based on Bio-based Raw Materials, Which Have a High Variability

therefore reduced competitiveness. In many applications (they are rarely open for wood materials) such as transport and automotive industries, aeronautics etc. only a small material property slot is allowed in order to meet the restrictions of weight limits in the final product (car, plane, sport equipment etc.).

MATERIALS OF THE FUTURE

In general materials in the huge field of applications, where also wood as a material can be applied (structural design, furniture and indoor design, packaging, specific technical application, mobility sector etc.) will evolve in the next years in order to follow the increasing demand for structural performance and multi-functionality step by step and the environmental and sustainability requirements, too. Resource efficiency in material design and fabrication and the potential for new design solutions will be an important issue. New materials need adequate manufacturing systems including new forming, joining, assembly, surface protecting and painting processes.

Recyclability is another important issue concerning the design and utilization of materials, compounds and technical structures. Yet, wooden components and hybrid structures do not always exhibit the very best performance in recyclability. Therefore a “design for recycling” is necessary as outlined by [27].

Several studies and material roadmaps are already high-lightening the future of materials in general (e.g. European Platform for Advanced Engineering Materials and Technologies, http://www.eumat.org). Can wood and wood-based materials meet these challenges? An answer can be drawn from specific wood related initiatives such as the US Forest Products Industry Technology Roadmap (http://www.agenda2020.org), the strategic research agenda from the European Forest-Based Sector Technology Platform (http://www.forestplatform.org) or specific research programmes such as the Finnish-Swedish “Wood Material Science and Engineering Research Programme”, which is compiled by [28].

Analysing possible ways of shaping the materials of the future, one can also refer to [29]: The cheapening and improvement of iron and steel during the eighteenth and nineteenth centuries was the most important event of its kind in history. … Metals, however, do not have the monopoly of strength. Some of the best combinations of lightness and strength are afforded by non-metals and the strongest substances in existence are the recently discovered “whisker” crystals of carbon and of ceramics. As the subject is developing, it now seems very possible that the coming of new engineering materials will resemble much improved versions of wood and bone more closely than metals.

FOREST RESOURCES AND TIMBER IN CONSTRUCTION

A huge part of the earth is covered by forests and wood is acknowledged as a renewable material from forests and agroforestry plants. In a majority of the industrial countries and many other countries, too, sustainable forestry is granted by certain forest acts in the specific countries, which guarantee sustainable forest management that provides multiple economic, environmental and social benefits today without compromising the needs of future generations. In addition to national forest acts, non-governmental organizations such as FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification Schemes) provide certification systems in order to guarantee wood from sustainable forestry within the forestry wood processing chain in business to business (BtB) and business to customer (BtC) relations. [31]

As shown in Table 2, the annual world harvest of wood amounts to 3.6 billion cubic metres solid volume under bark [32] from which 52 % are used for material purposes and 48 % as fuel wood [33].

Table 3 provides a general overview of the production of materials, which are important to the building sector and it also exhibits the great importance of wood as a raw material. But one has to consider that wood, due the diversity of the raw material, its variety in wood species

Table 2. Total Harvest of Wood in Reference Year 2014 and Share of Material and Energetic Use World-wide and in Europe

	Harvest		Material Use	Energetic Use
	10^6 m^3	10^6 ton^2	%	%
World	3,583	1,792	52	48
Europe	695	348	57	43

Table 3. Material Production Data According to References [32] and [34-38]

	Wood	Cement	Steel	Plastics	Aluminum
	10^6 tons				
World	1,792	3,700	1,649	299	108
Europe	348	260	201	57	10

and properties as well as the geometry and shape of the different parts of a tree, multiple technological potentials and economic demands, is allocated to different utilization tracks including the pulp and paper wood chemistry and energy sector. Based on the high requirements on construction timber and Engineered Wood Products, only a specific share of the overall raw material wood (roundwood supply) can be allocated to the process chain for solid wood and wood composites for construction purposes.

Besides the other forestry wood value chains, the building sector already consumes a significant amount of timber. With respect to the increasing use of the raw material wood as energy from biomass, currently there is a discussion if the increasing demand for the raw material wood from different wood chains such as solid wood, wood based materials, pulp and paper, wood chemistry and biorefinery and the energy sector can be covered by wood from sustainably managed forests [39].

Comparing the total added value generated by the production of various products as modelled by [40], roundwood with specific characteristics regarding diameter and wood material properties, provides the best added value when used as sawn wood as building material (solid wood and glued products) and assigning the side products of this process chain to wood-based materials.

The building sector already consumes a significant amount of timber. In Germany, for example, the current annual input of timber into the building and construction sector amounts to over 10 million cubic meter [41]. Analysing the various studies on wood supply, such as [33,39,41], the competition about the raw material is evident, but also the potential of a significant future increase of timber for construction based on a sustainable wood supply. But also a new approach in a design for recycling [27] (in all applications of wood), and a rigorous logistics for recovered wood for the wood based panel industry and the energy sector has to be pursued.

SUMMARY AND FUTURE OUTLOOK

We are living in a world of ten-thousands of synthetic and natural materials available. Material properties charts are a proper way to identify a material cluster for a specific purpose and design process.

The forestry-wood chain is responsible for one of the most abundant and most versatile renewable materials in the world, which also plays a major role as a building material.

Wood is a highly synthesized material by nature following an adaptive design of the tree. Therefore, it exhibits a high variability of the material properties within a tree and between different trees and wood species. This has to be overcome by a proper sorting, grading, manufacturing system and product design when transferring the raw material wood into wood based materials and building components.

Wood and wood based materials are very efficient engineering and design materials, but huge innovation in material understanding, material design and improved manufacturing systems are necessary in order to stay competitive with other materials.

At the moment highly advanced wood composites and Engineered Wood Products are of minor importance, a huge impact to develop advanced wood based materials and composites is necessary for the future.

Wood and other renewable resources have to match in order to become a new family of renewables-based materials and composites and to emerge as a new material generation (green composites) as outlined by [30].

Various wood process chains with increasing demand are competing about the raw material supply. Despite of this competition, it is feasible to allocate a selective and increasing share of suitable roundwood for the conversion process into building components.

REFERENCES

[1] Plomion C., Leprovost G., Stokes A.: Plant Physiology, 127:4, 1513-1523, 2001.

[2] Smith I., Landis E., Gong M.: Fracture and Fatigue in Wood. John Wiley & Sons Ldt., Chicester, 2003.

[3] Niklas K.J.: Plant Biomechanics. An Engineering Approach to Plant Form and Function. The University of Chicago Press, Chicago, 1992.

[4] Jeronomidis G.: Wood, one of nature's challenging composite. In: Vincent JFV, Currey JD (ed,). The mechanical properties of biological materials. Cambridge Univ. Press, London, pp 169-182, 2008.

[5] Matteck C., Kubler H.: The internal optimization of trees. Springer Berlin, 1995.

[6] Fratzl P.: Biomimetic materials research: what can we really learn from nature`s structural materials?, In J.R. Soc. Interface, 4, 637-642, 2007.

[1]

[7] Teischinger A.: Wood and competing materials. In: IUFRO & The Chinese Forest Products Assoc., Eds., IUFRO, All Division 5 Conference, Forest Products and Environment: A Productive Symbiosis, Taipei, p 10-12. 2007.

[8] Burgert I., Dunlop J.W.C.: Micromechanics of cell walls. In: P. Wojtaszk (ed.): Mechanical Integration of Plant Cells and Plants, Signaling and Communication in Plants 9, Springer-Verlag Berlin Heidelberg, 2011.

[9] Teischinger A.: Wood properties of the raw material: challenges for new processes and products. In Wood research - Knowledge and concepts for future demands, EMPA, Swiss Federal Laboratories for Materials Testing and Research, , 115/50, 95-105; EMPA, Dübendorf, 2003.

[10] Rosner S.: Hydraulic and biomechanical optimization in Norway Spruce trunkwood – a review. IAWA Journal 34:4, 365-390, 2013.

[11] Anon. 2014, Seeds to scycrapers: http://www.cam.ac.uk/research/features/seeds-to-skyscrapers, Creative Commons License, 2014 (access: 25.06.16), 2014.

[12] Anon. 2015, Der Wald kommt in die Stadt zurück. http://orf.at/stories/2257999/2258000/ (access: 25.06.16), 2015.

[13] Green M.: The Case for Tall Wood Building, Creative Commons, Vancouver, 2012.

[14] Fleming P, Smith S, Ramage M.H: Measuring-Up in Timber: a Critical Perspective on Mid- and High-Rise Timber Building Design. Architectural Research Quarterly 18 (01). Cambridge University Press: pp 20 –30, 2014.

[15] Bowyer, J., Bratkovich, S., Howe, J., Fernholz, K,. Frank, M., Hanessian, S., Groot, H., Pepke, E.: Modern tall wood buildings: Opportunities for Innovation. Dovetail Partners, Inc., Minneapolis, 2016.

[16] Kaufmann H., Nerdinger W.: Bauen mit Holz - Wege in die Zukunft. Prestel Verlag München, 2012.

[17] Ashby, M.F., Jones D.R.H.: Engineering Materials 1. An introduction to properties, applications and design. Elsevier Butterworth-Heinemann Oxford, 2005.

[18] Hill C.A.S.: Wood Modification. Chemical, Thermal and other Processes. John Wiley & Sons, Ldt., Chichester, 2006.

[19] Wegst U., Ashby M.F.: Material selection and Design of products with low environmental impact. Adv. Eng. Mater., 4, pages 378-383, 2002.

[20] Murphy R.: Life cycle assessment. In Green composites. Polymer composites and the environment, Baillie C. (Ed.), Woodhead Publishing Limited, Cambridge, 2004.

[21] Lippke B., Wilson J., Perez-Garcia J.P., Bowyer J., Meil J.: CORRIM: Life-Cycle Environmental Performance of Renewable Building Materials. Forest Products Journal, 54:6, 8-19. 2004.

[22] BRE (Building Research Establishment 2004), www.woodforgood.com, 2004.

[23] Teischinger A.: Holztechnologien für die Zukunft (Wood Technologies for the Future). Herausforderung für Forschung und Lehre (1). Holzforschung und Holzverwertung, 53: 1, 12-14, 2001.

[24] Burgert I., Cabane E., Zollfrank C., Berglund L.: Bio-inspired functional wood-based materials – hy- brids and replicants. International Materials Review 60: 8, 431-450, 2015.

[25] Ashby, M.F.: Materials selection in mechanical design. Butterworth Heinemann Oxford, 2003.

[26] Fridley K. F.: Wood and Wood-Based Materials: Current Statute and Future of a Structural Material. Journal of Materials in Civil Engineering, 91-96, 2002.

[27] Teischinger A., Kalcher J., Salzger E., Praxmarer G., Vanek M.: General systematic for a design for recycling – guideline for wooden windows and wood aluminum windows. In WCTE, Vienna 2016.

[28] Poppius-Levlin K., Johansson B. (Eds.): Wood Materials Science and Engineering, Final Report. AoF, Tekes, Formas, VINNOVA, Stockholm, 2007.

[29] Gordon J.E.: The New Science of Strong Materials. 2nd ed., repr. Penguin Books, London, 1991.

[30] Baillie, C. (Ed.): Green composites. Polymer composites and the environment, Woodhead Publishing Limited Cambridge, 2004.

[31] Anon.: Vision 2030 – Innovative and sustainable use of forest resources. A technology platform initiative by the European forest-based sector. CEI Bois, CEPF, CEPI, editors. Brussels, 2005.

[32] FAO – Food and Agricultural Organization of the United Nations (ed.): FAOSTAT database: Forestry Production and Trade, 2015.

[33] Carus et al.: Environmental Innovation Policy: more efficient resource use and climate protection through sustainable material use of biomass. pp 32ff, Hürth; 2013.

[34] Armstrong, T.: An overview of global cement sector trends. Insights from the Global Cement Report, 10th Edition. Technical Congress FICEM-APCAC. Lima, Peru, 2013.

[35] CEMBUREAU - The European Cement Association (ed.): Activity report 2013, 2014.

[36] World Steel Committee on Economic Studies Association (ed.): Steel Statistical Yearbook 2014. Brussels, 2014.

[37] Plastics Europe (ed.): Plastics – the Facts 2014/2015. An analysis of European plastics production, demand and waste data, 2015

[38] International Aluminium Institute (ed.): Primary aluminium production. Database, 2016.

[39] Mantau U., Döring P., Hiller D.: Holzeinsatz im Bauwesen – Verwendungsstrukturen nach Gebäuden und Gewerken. In: Weimar H., Jochem D., editors: Holzverwendung im Bauwesen - Eine Marktstudie im Rahmen der "Charta für Holz", pages 1-69. Thünen-Institut, Bundesforschungs-institut für Ländliche Räume, Wald und Fischerei, Braunschweig, Germany, 2013.

[40] Sathre R., Gustavsson L.: Process-based analysis of added value in forest product industries. Forest policy and economics 11: 65-75, 2009.

[41] Mantau, U.: Is there enough wood for Europe? In: Mantau et al.: Real potential for changes in growth and use of EU forests (EUwood) - Final report, pages 19-34. Hamburg, Germany, 2010.

Alfred Teischinger, Dipl.-Ing. is professor and department head of Materials Sciences and Process Engineering (MAP) at the Universtät für Bodenkultur Wein in Vienna, Austria. alfred.teischinger@boku.ac.at.

Building Systems—Constraint or Chances for Architects?

Hermann Kaufmann

ABSTRACT

Wood construction will only be able to take hold on the market for large-volume construction if standardization and development of prefabricated systems permit competitive construction of residential and commercial buildings. Will this render architects as guarantors of good design obsolete, or are they particularly necessary in this segment?

INTRODUCTION

The transfer from the fossil to the biogenic era is underway. In any case, efforts and developments towards sustainable strategies can be found in many areas of daily life. After 20 years of research and development on the subject of saving energy in the operation of buildings and the introduction of renewable energies, it is evident in construction as well that the next question will be focusing on the origin of those resources that are already growing rarer. The call for sustainable raw materials is impossible to miss wood with its extraordinary properties has become a promising path for the future of building. Just a few years ago, multi -story construction was deemed unthinkable. Today, we have reached buildings with 18 floors and implemented wood buildings of continually enlarging dimensions. For wood construction to really take hold on the market, standardization and development of prefabricated systems are needed to permit competitive construction of residential and commercial buildings. Will this render architects as guarantors of good design obsolete, or will they be needed all the more in this segment? There is a great danger that what has happened before in prefabricated building construction will repeat: That standard house types will be offered and architects will become unnecessary. However, there are already some construction systems, most of them developed with architects, that are open and adaptable enough to offer sufficient design tolerances for flexible reaction to the respective location and its functional and design requirements.

Keywords: Architecture, building systems, architectural design, WCTE 2016

LCT SYSTEM

The LifeCycle Tower construction system was created in a three-year long interdisciplinary research and development phase preceding the construction of the pilot project in Dornbirn. The system was to be suitable for buildings .with up to 20 floors. Under consideration of the current construction standards, an implementation-capable, idealized high-rise type has already been developed in this phase for the site of Central Europe. It was to be usable as an office building, hotel or residential building alike. The project was to be developed to meet the following objectives:

- Maximum future-proofness
- Shortening of the construction phase by factor 3 assume compared to conventional buildings
- High quality of architecture

Figure 1. Rendering—Building System LCT

Figure 2. Rendering—Main Constructive Elements Building System LCT (Columns, Glulamn 2x24,24, Wood-Concrete Ceiling Element. Beams Glulam 24x28, concrete 8 cm)

Figure 3. Rendering—Exemplary Office

- Wood must remain perceptible.
- The construction must pass cost comparison with conventional buildings.

LCT ONE

The LCT ONE (LifeCycle Tower ONE) is a pioneer construction in many respects. The project is the first eight-floor wooden building in Austria. Itis for the first time that an almost high-rise building will be made in wood construction. Furthermore, it is the prototype for the prefabricated wooden system developed for the research project "LifeCycle Tower". The aim of the project is to verify the feasibility of the construction system and to declare its functional efficiency under real terms of use. Because this construction system should achieve international marketability, this pilot project is a central building block for testing and marketing.

The building consists of a reinforced staircase core bordering one-way to the office space. Contrary to the proposal in the previous LCT research project to build the staircase core in wood as well, here it is built in site-mixed concrete. This was the result of an intensive examination of the statutory provisions of fire prevention,

Figure 4. Rendering—Research Project—LCT Tower

Figure 5. Rendering—Research Project—LCT Tower

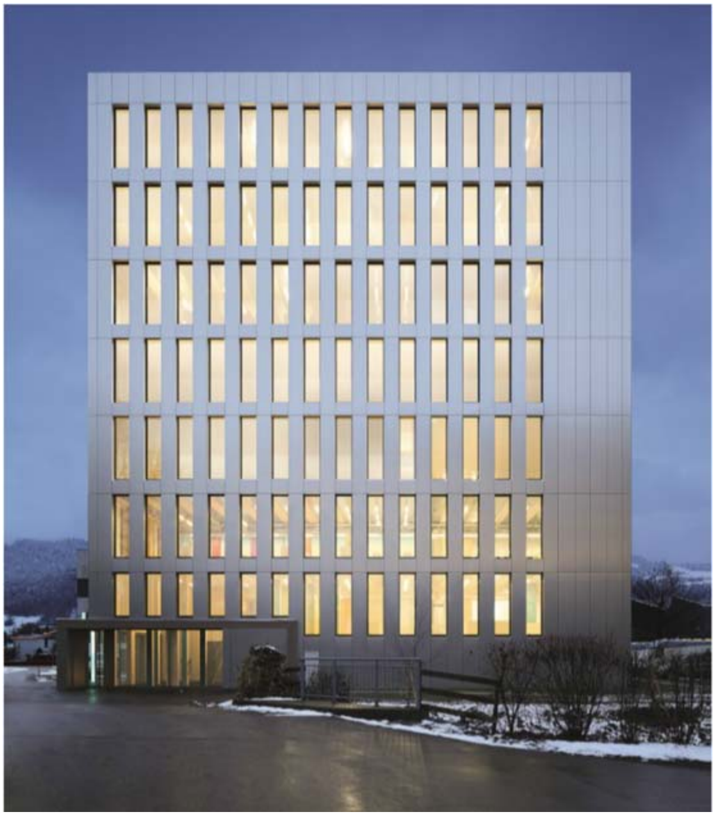

Figure 6. View East (Credit: Radon Photography)

which shows that it is currently not possible to make the core out of combustible material. With the certification (according to DIN EN 13501) of the fire resistance REI 90 of the timber joint hybrid ceiling, an important condition of the fire prevention authorities was fulfilled and an important step towards realization was taken.

For this purpose, several timber joint elements of 2.7 meters -corresponding to a facade grill - multiplied by 8.1 meters -corresponding to the potential depth of space - were subject to a fire test at the company Pavus in Czech Republic.

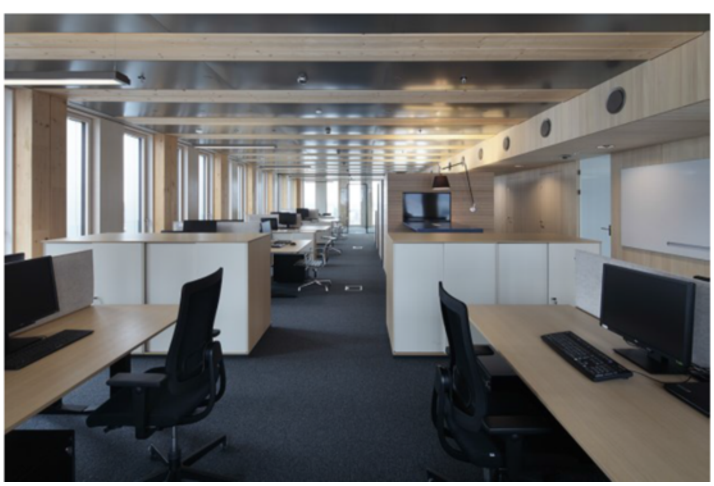

Figure 7. Office Landscape
(Credit: Radon Photography)

Figure 8. View North (Credit: Radon Photography)

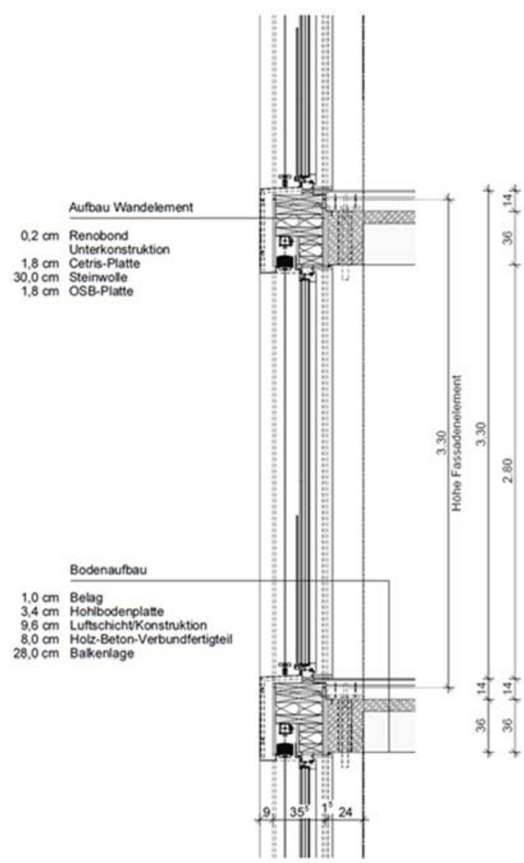

Figure 9. Façade Cut

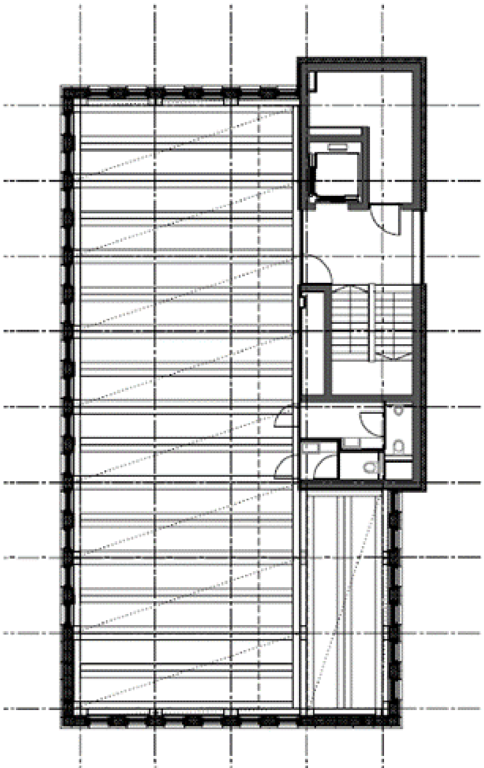

Figure 10. Floor Plan

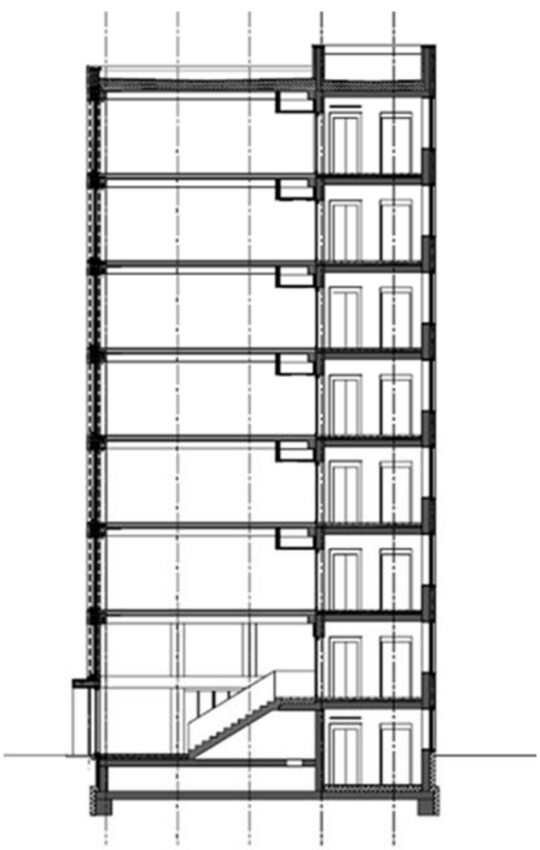

Figure 11. Cross-Section

Figure 12. Montage Façade Element
(Darko Todorovic Photography)

Figure 13. Façade Element
(Darko Todorovic Photography)

Figure 17. Ceiling Element, Consisting of BS Wooden Beams With 8 cm Thick Reinforced Concrete Plates (Illwerke - Thomas Girardelli)

The timber-concrete joint ribbed ceiling is the real key for building upwards, because it makes it possible to separate the corresponding floors consequently by a non - combustible cover. The wooden beams are inlaid into a steel formwork of 8.1 x 2.7 meter s; the distances in between are formed and concreted using a grouting technique. Thanks to the high grade of pre-fabrication, the building cycle becomes much simpler. The ceiling elements can be made industrially in a more precise manner, there are no curing times on the building lot and for the laying of a ceiling element the workmen indicate just 5 minutes.

The connection between concrete and laminated timber construction is not made via complicated binders, but rather with screws and shear grooves. A lintel beam of concrete considerably contributes statically to the distribution of the enormous forces from the facade bearings. The cross-grained wood of the double bearings stands directly on the concrete; the connecting arbor is grouted to the pre-fabricated segment on the

Figure 18. The Double Supports are Fastened to the HBV Ceiling Elements and Secured Against Pulling Out Using Only Simple Pipe-Mandrel Plug-In Connections. This Principle of Building Shell Construction Ensure the Vertical Size Compliance of the Building and Guarantees for Height Development According to Plan and in a Timely Manner. (Illwerke - Thomas Girardelli)

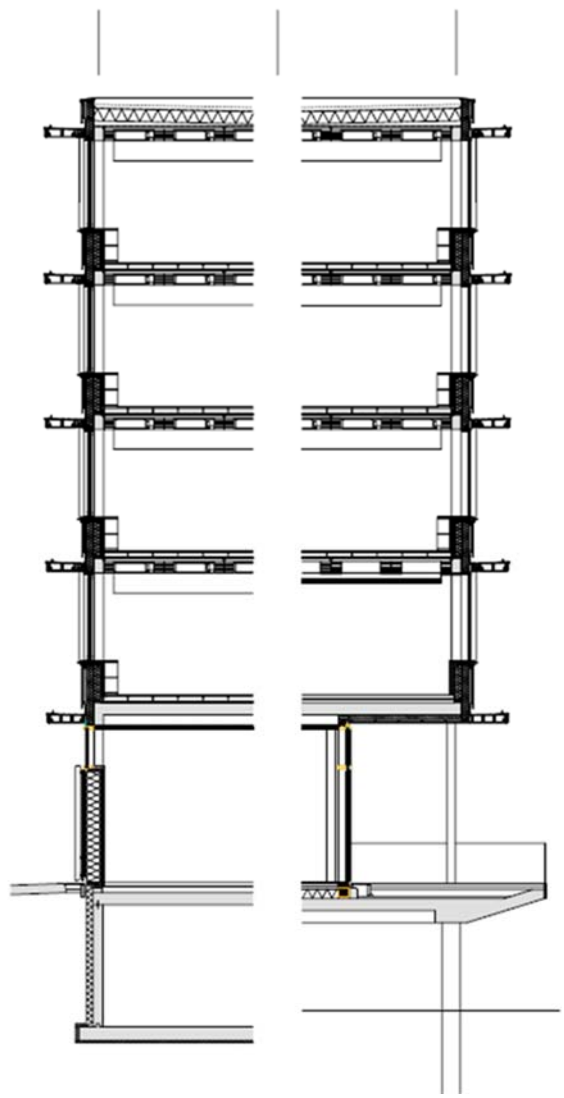

Figure 19. Façade Longitudinal Section

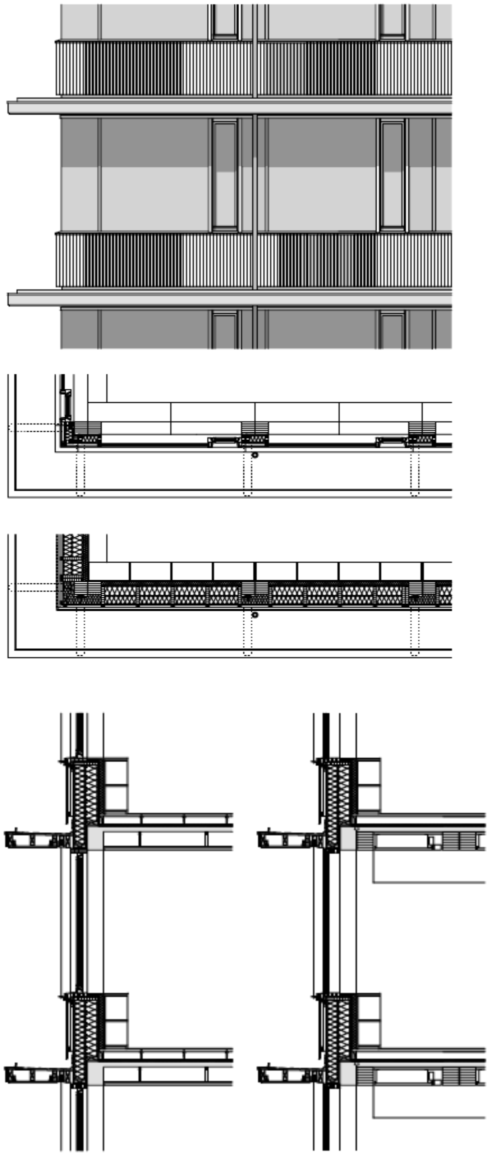

Figure 20. Façade Detail

construction site. This lintel beam facilitates the necessary separation of the construction in terms of fire protection for every floor, also on the bearing level, and also makes discharge from the ceiling into the bearing without charging a timber work element across the fibre. Following the spread of the forces, the bearings are tailored according to the effective statical requirements.

ILLWERKE CENTER MONTAFON

The scenic and structural environment of the new location for the Illwerke Center Montafon, referred to as IZM, which will offer space for 265 staff members starting in the summer of 2013, and where approx. 15,000 visitors a year are awaited, is characterized by the interplay of a future landscape with formative artistic interventions in landscape and large plane buildings. The result could easily be the decision to formulate a strong and robust construction which defines the place anew in a self-confident way. Such an attitude is not unusual in terms of constructions in the alpine region and truly shows the tradition of constructional modelling in the power plant sector in Vorarlberg.

As a result, the long structure, due to its position, forms a clear front and back, thus offering an unhindered “performance“ with a generously projecting roof, as well as a compact zone for delivery and parking, protected by the existing buildings.

The decision to also build into the lake has, first of all, a pragmatic reason, because otherwise, the longitudinal structure would not have been possible; on the other hand it created a moment of “unusualness“ with a higher potential for space. This is shown in the inside development, as the common areas, such as the dining hall and conference hall, occupy the space on the lake and, herewith, become an especially memorable place.

Of course the decision for a simple form requires that the surface of the ground floor be subject to limitations; therefore, the new visitors centre is situated on the first floor in the case of a conversion or modification, with direct connection to the foyer, but with a higher reference to the landscape through its higher position.

In the concept, special attention is paid to an all-embracing “sustainability“. Herewith, the clear structure offers optimised preconditions for the establishment and the operation of the construction without extraordinary measures. The good volume-to-outer surface relation and the sensibly developed enveloping structure guarantee optimum values of energy consumption in summer and in winter. The passive house standard guarantees low energy consumption and operation costs. The end of the life cycle is calculable with comparatively low deconstruction costs due to the building technique using elements.

The constructional measurements also facilitate easy maintenance of the building through optimum access to the facades. The consequent skeleton structure with few reinforcement cores offers high flexibility. It could be extendable for adding another floor.

Wooden construction has the advantage of good parameters concerning CO2-equivalent for the primary energy consumption for the construction, as well as for maintenance and deconstruction.

The construction is conceived with the simplest serial elements. Wood-concrete connecting elements are laid on glued laminated bearings which are integrated into the façade, and those elements are held within the centre axis of a steel beam borne on stanchions.

The serial classification guarantees precise constructional qualities, a dry construction method with a high degree of prefabrication and, herewith, a quick construction progress characterized by a high organisational degree in addition to high efficiency. The aim of such a construction is to guarantee fire protection for higher buildings despite visible, thus unprotected, wooden construction. Therefore, the hybrid ceiling element on one hand, which consequently separates the floors due to its concrete element of bearing overlays, as well as the curtain-type fire screen in the facade, are an important argument for the attainment of the security requirements. On the other hand, a sprinkler compensates the combustibility of the material. In the context of massive emergency exit stairs, more than the presently regulated 4 floors could be built and the building attains a higher fire security level than the valid safety requirements currently demand.

Figure 21. Wagner, View North (Credit: Radon Photography)

Figure 22. Wagner, Foyer (Credit: Radon Photography)

WAGNER

This extension of an existing building, constructed with the LCT shows the flexibility of the system. Also the wish of the client for a brick façade could be fulfilled.

Design: Architekten Hermann Kaufmann ZT GmbH

Figure 21. Wagner, Inside Office, Clad With Beech (Credit: Radon Photography)

BTV MEMMINGEN

This new built bank building for the bank of Tyrol and Vorarlberg has a wooden façade and shows also the design possibilities of LCT.

Design: CREE by Rhomberg

Figure 24. Rendering BTV Memmingen

CONCLUSIONS

Using the example of the LCT building system, it is shown that it is possible to react to various situations by adjusting design in serial construction as well, provided that the system concept is sufficiently flexible. This requires an architect's work again, making him indispensable for ensuring the construction-cultural aspects. When we speak of sustainable construction today, and thus longevity of buildings, we usually forget that this greatly depends on architectural quality. The history of construction shows that beautiful and architecturally high-quality buildings valued by people will be preserved for us in the long run. The architect will find his tasks in system construction as well, and will remain a vital partner in the process.

Hermann Kaufmann, Architeckten, is Professor at Technische Universität (TU) München in the Department of Architecture. [*kaufmann@tum.de*](mailto:kaufmann@tum.de)

Figure 25. Rendering BTV Memmingen