CNC Timber Framing - Innovative Applications of Digital Wood Fabrication Technology.

Oliver Neumann,
Assistant Professor
School of Architecture and Landscape Architecture
University of British Columbia
Vancouver, B.C., Canada
neumann@oliverneumann.com

Daniel Schmidt
Arquitecto, MASc
Profesor del área tecnológica,
Escuela de Arquitectura
Universidad Mayor
Temuco, Chile
schmidt.email@gmail.com

Figure 01: Concept Rendering

I. Introduction

The discourse on depleting natural resources and compromised environments has led to extended research on sustainable design methods, building practices and materials. Beyond the actual performance of building products and components, research on sustainable building increasingly focuses on the long-term effects of the production, application and life cycle of building materials on the natural environment, human inhabitation and quality of life.

While material efficiency and origin are part of this research, the perception of utilizing as little material as possible to achieve "Eco-efficiency" can be misleading. With not only the amount and origin of a material as significant factors, the ecology of the fabrication process and final product needs to be equally considered. Consequently, efficiency needs to be understood in an expanded ecological context.

Technological developments and especially computer aided manufacturing technologies play a significant role not only in the transformation of design and building methods towards efficiency and sustainability but also in the visualization and perception of cultural conditions and developments. Globally available technologies connect the design and building process to a broad range of long-term ecological factors creating a correlation between "the emergent political, economical and social processes and … architectural techniques, geometries and organization." Through this interrelationship to economy and culture, technology and its applications are directly related to notions of place and territory as well as to fundamental ideas of ecology.

In the 19th century, technological developments led to the decline of timber frame construction by making the production of small and uniform dimension lumber very efficient. The then newly developed construction systems allowed for and extended the use of wood in construction by relying heavily on standardization to improve efficiency of production process. At the same time, the effects of industrialization altered the notion of economy in not accounting for waste and the parallel development of the engineered products industry. However, more recent developments in timber framing technology promote for the efficient application of wood joinery traditionally used in large section timber to small scale wood members.

These new developments in computer controlled timber framing make structures with wood-to-wood connections economically and environmentally viable.

In addition, introducing wood-to-wood connections as an alternative becomes attractive because of the benefits of building only with wood. Most structural failures in wood buildings due to fire are caused by weakening of connectors. Eliminating metal connectors could result in a more reliable structure while significantly reducing the cost of construction.

2. Project objectives

The collaborative research and design study for an outdoor theater roof structure at the University of British Columbia Research Forest at Maple Ridge, B.C., Canada, focuses on the use of digital media in prefabrication and material optimization while exploring contemporary timber framing applications for a spatially complex design. By utilizing small square section timber and minimizing the use of alienating connectors, the research on the wood roof structure illustrates the potential of a design culture that seeks innovation in a broader understanding of ecology rooted in regional culture, environmental conditions, economy and tradition. Labor intensive manufacturing techniques are redefined aided by computer controlled machines and virtual modeling of complex geometries is translated into simple operations. The result is a more sensible and accurate response to the context of the design intervention.

In order to generate innovative design interventions that make a constructive long-term contribution to the preservation, maintenance and evolution of the environment, design needs to be based on a comprehensive understanding of its context and the distinctive qualities of the materials used. The outdoor theater roof design builds on the B.C. wood building tradition and the existing forestry industry to promote sustainable wood building designs through material efficiency and efficiency of assembly. With this focus, the design research contributes to the transformation of the B.C. wood industry from a resource-based to a technologically sophisticated and knowledge-based economy. (Figure 02)

Figure 02: CNC Beam Processor

Particular to the application of CNC wood fabrication are the potential and limitations of the production technology and related timber framing software used for the design, development and fabrication of the project. Equally relevant to the design process using CNC technology is the collaborative exchange between designers, wood scientist, engineers and fabricators involved in the project to accommodate the diversity of interests, expertise and concerns of all participating researchers. This approach is consistent with the notion that it is also no longer possible to understand construction simply in terms of proper use of material. Recognizing that "the age of mechanical production, of linear processes… is rapidly collapsing around us" we need to equally consider material resources, production, design and assembly processes in order to achieve effective design solutions. Dissociation of the influencing factors leads to ecological deficiencies of the design.

Main focus of the project is the performance of timber framing methods and traditional wood-to-wood joints that were allowed to thrive due to the abundance of large timber in smaller square sections. The challenge of the theater roof project lies in the application of traditional timber framing methods mediated through CNC technology to the proposed roof geometry. While traditional wood-to-wood connections were developed over time using trial and error - precarious connectors were introduced later - the range of developed traditional joinery is applicable today using empirical methods for the dimensioning of the elements.

3. Project description

The design research explores design methods mediated by CNC wood fabrication technology. With this focus, the project explores the potential of the CNC beam processor to use small spare lumber from standard larger scale production to generate a complex roof structure, thereby foregrounding the potential of CNC wood processing as a resource efficient building technology. (Figure 03)

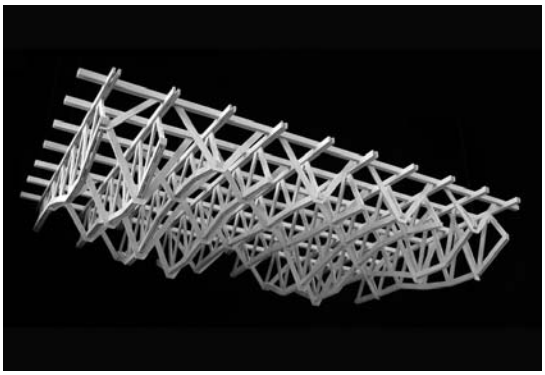

Figure 03 - Model Study of Roof Structure

For the design, a CAD/CAM software is used to generate a 3D model of a material-efficient light-weight wood structure linked by wood-to-wood connections. A CNC beam processor will be used to fabricate the short 2"x4" wood sections for the 8 x 11 meter space truss theater roof structure that will be hung from the existing columns at the site. A perforated plywood diaphragm provides rotational stability at the top. The bottom plane of the structure is articulated to illustrate the moment forces within the structure and to provide the spatiality required above the stage. For rain and snow protection, the wood roof structure is covered in light-weight corrugated translucent panels that allow sunlight and shadows of the surrounding trees to animate the space truss design.

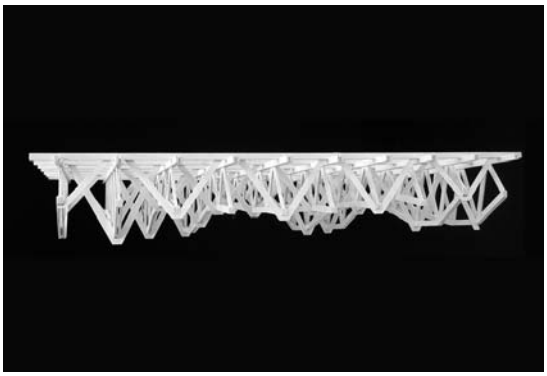

Figure-04: Asymmetrical Configuration

While the design aims to satisfy the specific needs related to program, climate and locale, the project equally references concepts beyond the site and immediate context of its intervention by introducing a scale independent of the size and resolution of the wood structure. The roof, with its systems of spatially interlocking trusses, is asymmetrical in order to read like a fragment of a larger continuous surface. While the logic of the wood structure responds equally to the forces in the roof and the orientation of the stage towards the audience, an oversized leaf pattern that perforates the horizontal plywood diaphragm introduces imagery that points beyond the particular scale of the building intervention and camp ground context.

With a focus on resource and material efficiency, process effectiveness towards ecology in the use of the smallest members possible and wood to wood joinery, the design research equally explores the limits of the CNC fabrication technology. It relies on the creative use of timber framing software used to prepare the data for the CNC beam processor. The complex geometry of each piece is then translated to machine language resulting in the operations required for the fabrication of the components.

In parallel explorations, the design is developed with the aid of digital model studies, physical study models that test spatial and structural characteristics, digital models with focus on joinery details, structural models for the calculation of complex load conditions and necessary load transfer in the joints, and 1:1 joints studies that explore the spatial and structural characteristics of wood-to-wood connections. Most effort in the design process has been put in the reduction of forces that meet at each joint, thereby permitting the use of small section timber for the project.

It is not conceivable to think of a solution like the design of the Loon Lake roof without technology, given the formal and structural complexity of the project. All building components and cuts are customized to create a spatially and structurally coherent model. The data necessary to formally describe and cut each component of the roof structure, even in a small project, would constitute an unattainable challenge without the software.
The timber framing software allows for the modeling and programming of all building components simultaneously. By enabling the review joints and the overall design prior to fabrication the CAD/CAM software is essential for the reconsideration of wood-to-wood connections as an economical and efficient way of building.

While computer generated models, drawings and associated data of timber framing software help to visualize the spatial characteristics of the design and allow for a seamless flow between the design and fabrication phases of the project, structural calculations throughout the design process are particularly important since timber frame structures depend on their connections for structural integrity. Consequently, the design

and detailing of joinery is the most difficult aspect of the design and engineering process. With timber framing joints "rely(ing) innately on removing material from one member, in order to support another" careful development of the joint configurations is of particular importance. This is especially important when several wood members have to be jointed as part of a complex space truss design.

Figure 05 - 1:1 Joint Study

To configure each component consistent with the structural model of the space truss design traditional joinery has to be reinterpreted and modified. Many different configuration where tested to achieve as small loads as possible. The fact that wood performs differently depending on the direction of the force makes the design of each joint even more complex. Given that components and joints are weakened by the removal of material to allow for the interlocking, the arrangement of the trusses had to be frequently reconsidered throughout the design process, to achieve a feasible solution for each joint and to preserve the original idea of structural continuity.

4. Conclusion

The Loon Lake Outdoor Theater Roof is a product of a multi-disciplinary collaborative research process. The interdisciplinary team of architects, engineers, material scientists, digital fabricators and software developers reflects the diversity of aspects implicated by the research into the potential of digital wood fabrication technologies. While exploring limits CNC timber framing technology and material-efficient wood construction, the project is driven by the desire to explore CNC timber framing technology for a contemporary architectural solution for the outdoor theater roof. With a focus on wood-to-wood connections, the research project negotiates assumed building conventions and limiting traditional aesthetics while it benefits from the expertise of the collaborating engineers and wood scientists as well as the guiding input of developers of utilized CNC fabrication technology and software.

Innovative design in this project is defined as work that resonates at the intersection of the fields of technology, material science, manufacturing processes, techniques of assembly and the context that constitute the expanded context or complex ecology that projects need to engage. It is through the collaborative design research on CNC wood fabrication technologies that common design and building practice is put to question and boundaries are explored and expanded.

With the final model not jet finished, many aspects of the design still need to be revised. As a pioneer project without precedent most of the decisions are based in experts' opinions and the collaborative input of the participating disciplines. The fundamental contribution of this work lies in its experimental character. All results and experiences that derive from this work will contribute to the understanding of the potential of CNC fabrication technologies to contribute to wood-to-wood connection performance and reliability for small square section timber.

References

1-William McDonough, "economy, ecology, equity" in Massive Change by Bruce Mau and The Institute Without Boundaries, Phaidon 2004: 194)
2-Foreign Office Architects, "FOA Code Remix 2000", in 2G, Issue 16 (2000):122.
3-Toshiko Mori, "Immaterial / ultramaterial: architecture, design and materials", Presidents and Fellows of Harvard College, 2002: xv.
4-Ben Brungraber and Jim DeStefano, "Timber Frame Construction. Architecturally Exposed Timber", in STRUCTURE magazine, (March 2006):28.
5-Research Team: Assistant Professor Oliver Neumann - UBC, Daniel Schmitt, Profesor del área tecnológica, Universidad Mayor, Temuco
Ana Sandrin and Mike Lemon, UBC School of Architecture and Landscape Architecture; Assistant Professor Robert Fuerst, Thomas Tannert, Centre for Advanced Wood Processing; Structural Engineering: Dan Sundvick P.Eng., AnnaLisa Meyboom P.Eng.;

Keywords:
Digital Fabrication, Ecology, Collaboration.