

Loon Lake Theater Roof Structure - Multi-Disciplinary Design Research in CNC Timber Framing

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Abstract

Following the example of the design research project for an outdoor theater roof wood structure at the UBC Malcolm Knapp Research Forest at Maple Ridge, B.C., - a multi-disciplinary case study of contemporary applications of CNC timber framing technology - this paper reviews the collaboration between the disciplines of architecture, wood science and structural engineering throughout the design process. The research illustrates the particular characteristics of the roof design fabricated on a CNC beam processor and highlights the potential CNC timber framing technology to promote collaborations on innovative contemporary wood design solutions in the particular context of British Columbia.

The design research project for an outdoor theater roof wood structure at the UBC Malcolm Knapp Research Forest at Maple Ridge, B.C., is a multi-disciplinary case study of contemporary applications of CNC timber framing technology. The project is a collaboration of faculty researchers and graduate research assistants from the UBC School of Architecture and Landscape Architecture and the UBC Centre of Advanced Wood Processing, the UBC Malcolm Knapp Research Forest and practicing engineers.

With a focus on collaboratively developed innovative design, the research explores the potential of CNC timber framing technology for the design of a light-weight roof structure that promotes the economical and ecological use of existing natural resources through material-efficient designs and fabrication methods. Innovative design in this research is defined as collaborative work that resonates at the intersection of technology, material science, manufacturing processes, techniques of assembly and a changing context. It is these fields that constitute the expanded context or complex ecology that projects need to engage. The expanded context in perpetual flux

requires design ideas and methods to be continually reviewed and updated.

For the research, 3-D CAD/Cam software and a CNC beam processor are used to develop wood-to-wood joints for a material-efficient design that addresses the given conditions at the outdoor theater: existing columns, the character of the site in a forested area at the edge of Loon Lake at Maple Ridge and structural issues related to the roof configuration and wood joinery. Developed as a space truss system, the design seeks to utilize CNC timber framing to produce small-scale wood members for a spatially complex roof design. Beyond its engagement with concerns and requirements of its immediate context and program requirements, the research is also placed in the particular regional condition with its focus on forestry, wood industry and a concern for natural resources.

This paper reviews the collaboration between the disciplines of architecture, wood science and structural engineering throughout the design process of the outdoor theater roof structure. The paper illustrates the particular characteristics of the roof design fabricated on a CNC beam processor and highlights the potential CNC timber framing technology to promote

innovative contemporary wood design solutions in the particular context of British Columbia.

1. Design Innovation

To generate innovative design interventions that make a constructive long-term contribution to the preservation, maintenance and evolution of the environment, design activity must be based on a comprehensive understanding of its context. Innovative design needs to engage in the fields of technology, material science, manufacturing processes, techniques of assembly and context that constitute the expanded context or complex ecology.

Innovative design research that engages in the expanded context promotes ecological design through articulating a vision for the future that is pursued with ingenuity responding to current conditions rather than by limiting life styles and building methods to isolated conditions and methods. Rather than to retreat from an open-minded and broad culture, innovative design engages in the complexity of its surroundings. This approach to innovative design embraces technology as “a font of endless creative solutions” based on the belief that “scientific research, innovative design, and cultural evolution are the most powerful tools we have”[1] towards a sustainable future.

Design innovation as defined here is based on an extended definition of ecology, expanding the context of design interventions beyond the environmental performance of materials and types of construction to broader considerations and long-term implications of building. The need for a changing attitude towards the natural environment in order to achieve innovative design solutions is underscored by the fact that while “our ability to act is greater at the landscape and site scale, the probability of long-term success in pursuing a goal of sustainability is greater at the regional level.”[2] The need for environmental preservation and energy efficiency have led to the promotion of living conditions that equally correspond to natural settings and existing climate conditions; related design and building methods reflect the potential and limitations of the economic, cultural and social context while acknowledging “that human activity and technological systems can contribute to the health of environments and natural systems from which they draw benefit.”[3]

The related development of the concept of nature over time towards the inclusiveness of *ecology* corresponds to notions of place and place-specific architecture and an all-inclusive definition of context beyond the limits of human perception. While modern science was still

based on an anthropocentric understanding of the environment, the related changing terminology from environment to ecology is characterized by the reassessment of the surroundings where aspects of place now include interrelated natural and man-made conditions including social, cultural, economic and technological factors.

Consistent with this definition of innovative design is also a temporally specific response to the conditions of the cultural, geographic and economic context in regards to the environment. Consequently, design methods and solutions have to be critically reviewed to ensure their continuous relevance.

Solid panel construction that uses large amounts of wood, for example, might be meaningful only under specific temporary economic and environmental conditions. Solid wood panel construction responds both to environmental and economic necessity to utilize large quantities of beetle-infested wood in British Columbia within a short time period to avoid economic and environmental damage from dying forests in the region at a large scale. Given that some areas of British Columbia will see up to 80 percent of its mature pine trees killed by the beetle infestation in the near future, solid wood panels offer an opportunity to utilize the affected wood for building components with high environmental performance. For the duration of the pine beetle infestation in the province, solid wood panels with their inherent sustainable and structural qualities of wood as a building material can not just simply introduce a new construction product or method but more importantly can contribute to solving a current environmental and economic problem in the region.

Solid wood panels are environmentally friendly and result in buildings with favorable environmental performance: no chemical treatment or glue is necessary to produce and install the wood panels as low grade lumber and leftover materials from timber production can be used without diminishing the quality of the panels. The solid wood wall panels consist of layers of slab board placed in alternating direction to prevent shrinking and settling while the surface of each the wood layers has small grooves to improve insulation properties of the wall panels. The solid wood wall panels structurally are dimensionally stable and have a high load bearing capacity. Given their thickness, the wall system can achieve up to 90-minute fire ratings. Manufactured using CNC controlled machines the panels are not limited to modular dimensions; panels can be manufactured in any shapes, thicknesses and sizes. The CNC

production process allows for mass-customization of wall panels to meet the requirements of specific designs while the high degree of prefabrication and easy assembly of panels allows for short assembly times.

2. Design Research Collaboration

Collaborative design projects are predestined to engage in an expanded context or complex ecology within which innovative research projects need to be situated. Collaborative design projects offer the opportunity to address a broad range of considerations including the potential and interests but also the rules, limits and preconceptions of the disciplines and professions involved.

While innovative design through collaboration corresponds to a conceptual approach that acknowledges the complex interrelationships that constitute the surroundings, many benefits of multi-disciplinary design research can only be explored and brought to bear through literal engagement with technology, craft and materials. The development of innovative design solution using CNC fabrication technology hinges on actual machining time and work hours spent together on shared design ideas while directly working with available equipment.

Direct exposure to the multiple influences and factors are central to an innovative design process. In this important aspect of collaborative research, work is often hindered by institutional funding and research structures that focuses on infrastructure, exchange and representation of research ideas rather than to provide opportunities for extended exchange and explorations of design ideas that address the very practical issues of innovative multi-disciplinary design research work.

Currently, while there is a lot of interest in wood fabrication and wood building research at the university level, in the industry and in the design professions, research funding does not favor the direct collaborative operation of available technologies because the focus on collaboration does not extend to the direct access to existing technology and the availability of staff to operate available wood fabrication equipment. This inhibits practical collaborative design research.

Equally, since the development of innovative design solutions evolves from a creative struggle that involves the exchange between often contradicting design cultures and approaches of the different professions and researchers participating in collaborative research, the exchange between

architects, engineers, material scientists, and clients benefits from a not strictly goal oriented research environment.. In order for design projects to evolve beyond preconceived solutions that are based on the accepted design conventions of the participating research fields, research collaborations need to provide room for invention through imagination and experimentation, including creative failure and finding of solutions by chance and accident.

3. CNC Wood Processing

If, as described earlier, the intricate conditions that characterize human interaction with the natural world can be understood in terms of cultural, spatial, ecological and economic systems integrated into complex interrelationships with their surroundings, then building - from conception and design to construction - needs to be seen as one of the activities integral to this system of dependencies. As part of their expanded context, buildings need to be designed to be site specific and to address the social and economic conditions of a particular project.

Digital fabrication technologies in design and construction play a significant role not only in the transformation of design and building methods but figure into an extended discourse on cultural developments. Globally available technologies connect the design and building process to a broad range of long-term ecological factors by creating a correlation between “the emergent political, economical and social processes and ... architectural techniques, geometries and organization.”[4] Through the interrelationship to economy and culture, technology and its applications are also directly related to territory and time as well as to ideas of ecology. Fabrication technologies, consequently, need to be understood in conjunction with the influences by and contributions to a whole host of social, cultural and economic factors thereby acknowledging that “deep and enduring changes ... are not technological but social and cultural” and that, similarly, long-term economic growth “requires a series of gradually accumulating changes in the organizational and institutional fabric of society”[5] that take place over longer periods of time.

In British Columbia, digital wood fabrication can build on an existing wood building tradition, forestry and lumber industry. In order to remain competitive locally, in Canada and on the global market in the face of limited wood supply and growing pressure from foreign producers, the British Columbia lumber industry depends on technology to enhance the value

of wood products. Global competitiveness requires the ability to export ideas, technological know-how as well as sophisticated building techniques. The focus on innovation in building methods and design through digital fabrication technologies is critical considering global competition where finite resources, growing environmental awareness and a focus on the preservation of natural resources are a central aspect of a regional building culture that is environmentally sensitive and economically viable in the long term.

4. CNC Timber Framing

CNC beam processors have the potential to efficiently produce a large number of beams with individual joints and connection details for timber frame construction helping to realize building designs that incorporate sustainable building features and related spatial conditions without adding to the immediate cost and effort involved in the production of individual building components. Consequently, CNC beam processors can be used to produce new spatial and material expressions consistent with the notion of complex environments. Given the capacity to efficiently create ever-smaller building modules and spatially complex building components, CNC-fabricated wood building elements can be designed to meet the specific and changing requirements of individual building projects while promoting efficiency of material use and assembly. Flexibility and adjustability of CNC fabrication processes allow for an efficient application of mass-customization technologies to explore formal and spatial conditions corresponding to ideas of complexity and the openness, individuality and self-expression of contemporary living conditions. With their inherent sustainable and economical characteristics, contemporary wood products, fabrication and production methods can be used to generate site specific designs as part of an ecologically sensitive building culture.

However, unless used in a research environment independent of current market conditions, mass-customization technologies like CNC beam processors are utilized by companies involved in the mass-fabrication of houses commonly geared towards overall cost-effective repetitive design solutions with standardized building components. Benefiting from repetitive tasks, the economy of production promotes modular building systems with a limited number of interchangeable building components discouraging building designs that include formally diverse building components to accommodate the specific conditions of the context buildings are intended for.

The collaborative use of a CNC beam processors can be equally efficient, however, if the technology is used to produce building components for a large number of distinct building designs; independent designers and contactors can prepare the data files necessary to process individual building designs. The collective use of the technology to develop designs sensitive to particular project conditions is aided by the general availability of software used to generate data files for the processing of timber beams and joinery details. The software allows for a decentralized preparation of data files that can be used to efficiently operate mass-customization technologies like CNC beam processors that require significant investments. Hence, when used as part of a decentralized design process that brings together a number of contributors and design intentions, current fabrication technologies can advance design and construction methods beyond the standardization of building components towards mass-customization as a cost-effective reality in a production process that supports a sustainable building practice.

5. Fabrication in a Changing Context

While technological developments of wood products and their application address a number of issues that influence sustainable characteristics of wood structures, they do not offset the need to design and realize buildings for changing uses and conditions over time. Mass-customization and technological advances that “combine the economic benefits of mass production with custom fabrication’s opportunities to ‘Have it your way’”[6] do not automatically accommodate changing conditions. These limitations to accommodate change over time are unrelated to wood products and wood fabrication and processing technologies specifically but are a mere consequence of the application of ideas of complexity to the realm of architecture in general where increasingly fine modularity of complex formal and spatial designs “cannot prevent the results from merely introducing (newly) prescriptive pattern of occupation.”[7]

The technical ability to efficiently create ever smaller building modules and spatially complex building components does not alleviate the fact that, by the nature of its materiality, all architecture “constitutes limiting factors and – even in its most open ended configuration – conditions the use of space”. Even architectural interventions that intend to promote diversity and differentiation “cannot escape the finite limits of practice (where) mere complexity does not equal true indeterminacy.”[8] Consequently, notions of complexity translated into the realm of architectural

production are in conflict with the need of sustainable design to avoid inflexibility that prevents development and changes in a society and culture. To create long-term sustainable designs expected to accommodate a changing society, innovative design has to synthesize ideas of complexity suited to understand and operate within a complex environment by allowing for spatial openness and indeterminacy. CNC fabrication technology with its capacity to generate exchangeable customized building components can accommodate changing needs and conditions and ensure the suitability of building configurations to an ever-changing complex ecology.

6. Outdoor Theater Roof Structure



Figure 1. Concept Rendering

The project for an outdoor theater roof structure at the University of British Columbia Malcolm Knapp Research Forest at Maple Ridge, British Columbia serves as an example both rooted in its local conditions as well as reflective of larger processes addressing technology's potential to generate designs consistent with the conditions of their extended context. 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. In addition to referencing the regional wood building tradition illustrated by a range of existing buildings and structures at the Loon Lake camp ground at Maple Ridge, the research introduces wood design methods mediated by CNC wood fabrication technology.

The roof design takes large scale CNC fabrication technologies as a starting point for innovative wood construction methods that build 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. Given this focus, the design research is intended to contribute to the transformation of the B.C. wood industry from a resource-based to a technologically sophisticated and knowledge-based economy.



Figure 2. Project Site

The design research uses the smallest possible wood member the utilized CNC beam processor can generate. With this focus, the project explores the potential of the CNC beam processor to use small spare lumber from larger scale beam production to generate a complex, roof structure foregrounding the potential of CNC wood processing as a resource efficient building technology.

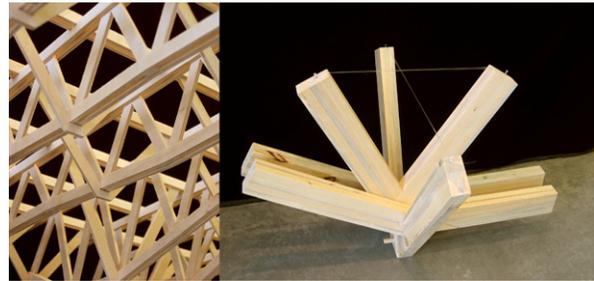


Figure 3. Joint Study

For the design, a CNC beam processor is used to fabricate a material-efficient light-weight wood structure with wood-to-wood connections using short 2"x4" wood sections to assemble the theater roof. Existing columns at the outdoor theater are utilized for the 8 x 11 meter wood roof structure that will be covered in light-weight corrugated translucent panels to protect the stage area of the theater from rain and snow while allowing sunlight and shadows of the surrounding tree to animate space truss design. Integrated stage lighting will allow for evening performances, illuminating the wood structure and the immediate context.

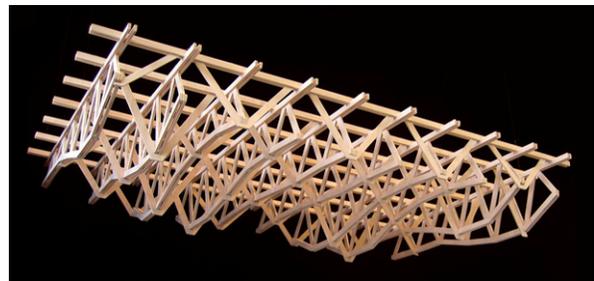


Figure 4. Design Study

The roof structure that is hung from the existing columns is designed as a space truss with a perforated plywood diaphragm to provide rotational stability. The bottom plane of the structure is articulated to illustrate the moment forces within the structure. The asymmetrical forces within the roof are reflected in the shape and configuration of the wood structure. A steel tensile system as a secondary structural system shortens the overall structural span between the existing columns to respond to the extreme snow loads at the site.

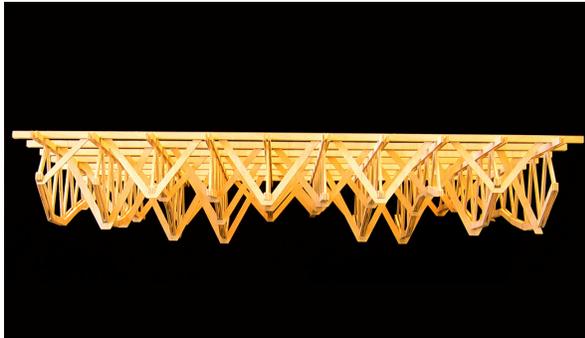


Figure 5. Asymmetrical Structure

Likewise, the roof design references conditions beyond the immediate site and context 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 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 alluding to an abstract dimension beyond the immediate surroundings.

7. Conclusion

The Loon lake Outdoor Theater Roof is a product of a multi-disciplinary collaborative process. The interdisciplinary research team[9] 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. In addition to student research assistants from the University of British Columbia School of Architecture and Landscape Architecture, the project was developed collaboratively with structural engineers, researchers from the University of British Columbia Centre for Advanced Wood Processing and developers of CNC



Figure 6. Perforated Diaphragm with Leaf Pattern

timber framing software. 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.

8. References

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- [9] Research Team: Assistant Professor Oliver Neumann with Ana Sandrin, Mike Lemon, School of Architecture and Landscape Architecture, UBC Department of Applied Science; Assistant Professor Robert Fuerst, Daniel Schmitt, Thomas Tannert, Centre for Advanced Wood Processing, UBC Department of Wood Science; Structural Engineering: Dan Sundvick P.Eng., AnnaLisa Meyboom P.Eng.; The project is funded and supported by the Forintek Canada Corporation and the University of British Columbia Malcolm Knapp Research Forest. Software support for the project is provided by Dietrich's North America