WOOD 3.0

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Filip Tisler

WOOD 3.0

by
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Abstract

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The flawlessness of today's standardized construction methods has created and reinforced a weakened and artificial understanding of materiality. By furthering our comprehension of natural materials, particularly wood, designers are able to grasp the significance of the materials they employ, understand and manipulate in terms of its characteristics and boundaries. Wood as an organic living organism can be used to express a particular narrative, to tell a story of its existence and history within human use, as well as its individual identity, age, and testimony. This thesis attempts to address the potential digital fabrication methods that can be utilized to manipulate wood and its properties, which ultimately has profound implications on the tactile and sensory experiences of space. In order to create a haptic presence, the elaborate surface, textures, and details of wood are crafted for the user, and invite all the senses by creating an atmosphere in the space.

Acknowledgments

To my family

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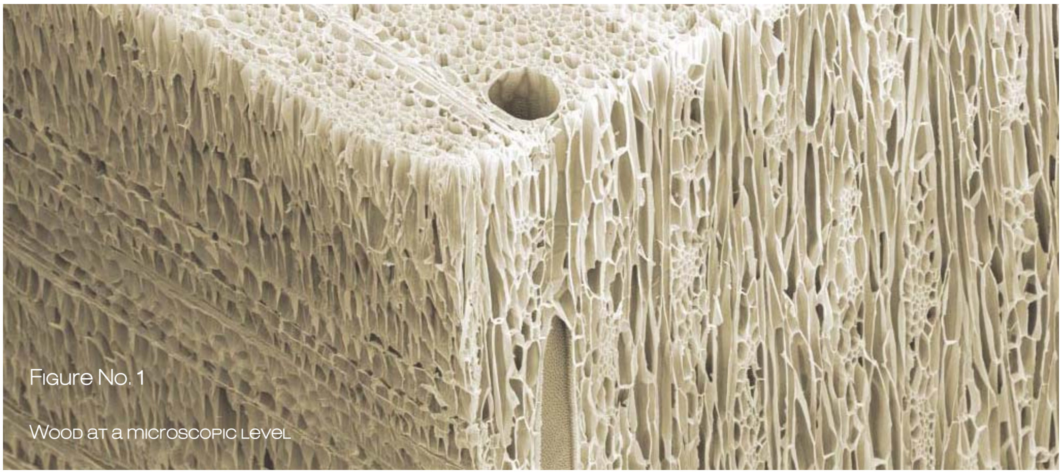

Figure No. 1

Wood at a microscopic level

Introduction 1.0

Our Current Paradigm 1.1

The work of architecture is inherently abstract - architects communicate via abstract representations that lead to abstract processes of making. This becomes a challenging context to position and express the art of craft, in any conventional definition of the term. For craft to function as a useful concept today, especially in the context of digital design and production, it must be rethought as a process of mediating not only between tools and the objects that are produced, but also between design as a process of imagination and production as a process of technique. (Marble, 2010, 39)

In fact, craft has always been mediated through a relationship between humans and technology. From primitive hand tools to industrialized machines, the quality of craft in an object has been measured by the trace of human input. Today, with the wide range of digital technology being used to increase the efficiencies of human labour (or bypass it altogether), it is useful once again to take measure: to look critically at how digital mediation is restructuring design and production, and consequently, redefining craft. (Marble, 2010, 39)

Malcolm McCullough (Abstracting Craft) argued that “digital craft: as a term is not oxymoronic, that the craft medium need not have a material substance and that the craftsperson need not touch the material directly. (Kolarevic, 2005)

The foundations of the architecture, engineering and construction industry lay firmly upon on a tacit knowledge of craft. One could argue that all parties involved throughout the building process have worked within the framework of the construction industry and its practices, each member of the team imparting professional expertise alongside an ever-evolving swath of learned experience. The architect is certainly no exception.

Craft in architecture is closely tied to detail, which is also being redefined within the frameworks of digital technology. Architectural detail, an architect's means of introducing craft into buildings, is largely a product of the relationship between design and industry. If the modernist's detail was based on negotiating tolerances between pre-manufactured components that were then assembled, today's details are based on the management and organization of information, where tolerances and even assembly procedures can be numerically controlled and parametrically integrated during design (Marble, 2010, 40).

As the central mediator in a rapidly complexifying mode of practice, the architect is tasked with untangling the interdependencies of the design team, as design and coordination require a diverse array of knowledge and expertise in both how to best communicate and construct a building. The evolution to more complex construction methods, building systems and programmatic demands has swelled the design team to a staggering assemblage of managers and consultants, further distancing the architect from the final built artifact.

While the advent and widespread adoption of advanced digital tools has certainly mutated the role of the architect in a contemporary design paradigm, these same technologies also afford a unique opportunity for the architect to regain material consciousness. Virtual simulation allows the architect to construct a virtual prototype and engage with a medium for both qualitative and quantitative simulation and analysis. These digital tools enable iteration and optimization in many respects, however, it entails detrimental aspects as very few designers consider physical material properties during the model's development.

Fabian Scheurer, founder of DesigntoProduction - an architectural consulting firm specializing in the modeling and fabrication of complex building components is a major supporter of the value of material knowledge in a digital design process. Scheurer describes, "the designer has to interpret the colourful images and either match the design to the available material or find a suitable material for the given design. Speaking from experience, the latter approach is chosen far too often, frequently resulting in awkward and inefficient solutions.” (Scheurer, 2011) Here, Scheurer advocates that to develop a design solution of superior quality yet also highly efficient, the characteristics of both form and material must be understood in full detail throughout all stages of the project. In order to appropriately convey these properties in a 3-D model, physical properties and their relationships to one another must be understood as well.

With the advanced software and technology available to architects and builders today, these computational tools have provided a platform to reunite the complexities of design, fabrication and erection, allowing the design team to better address issues of building and construction. Schuerer continues that ”if, for example, a carved surface is to be clad with thin strips of wood, it is easy to map a ‘pinstripe’ texture to the respective NURBS model and render a realistic looking, but physically incorrect image. In order to find out what really happens, one needs to base the stripe pattern on the bending characteristics of real-world wood strips. Only with this knowledge is it possible to create a valid geometry for all the slats on the surface. Also, it enables the designer to optimize both surface and pattern for fabrication as well as for visual impression.” (Oxman, 2010) As digital modelling, simulation and fabrication technology continues to evolve at such a rapid pace, the computer is no longer simply a new medium for representation. Software is now capable of computing and replicating physical behaviour - reshaping the design process and the architect’s role within it. In addition, with the resilient establishment of Building Information Modelling within professional practice, the industry is witnessing a paradigm shift that Dennis Shelden of Ghery Technology refers to with ”wherby the previous method of architectural delivery, the ‘possible to real’, is being supplanted by a new and seamless one, the ‘virtual to actual’ (Garber, 2009). Techniques of dimensional or geometric representation, formerly part of an abstract process of drawing, have evolved into an integrated system of design information embedded in production and assembly processes (Garber, 2009,39).

Figure No. 2

Center Pompidou-Metz - Shigeru Ban

The means and methods in which wood is used in current western construction practice have a tendency to neglect the inherent properties of the material. Through the exploration and understanding of the compo-

sition and resultant properties of the material along with the use of digital fabrication methods governed by these properties allow designers and architects to generate a creative platform for developing innovative architecture. By studying and computing this data, the designer is able to look to material properties to inform and dictate a variety of design decisions. Digital fabrication methods, in unison with an understanding of material properties, afford a wide degree of opportunity in creating ambient or atmospheric spatial quality through the application of wood.
The application of wood in today's western practice has a negative reputation for neglecting the inherent properties of the material, in particular exploring the ambiance that wood can create in architecture. In reducing our material development to such surface qualities, designers abandon the opportunity to utilize wood and its unique qualities to its fullest architectural potential.

The introduction of scaled lumber and engineered wood products such as plywood in contemporary practice has drastically changed the implementation of wood in architecture. The

use of wood no longer exists as an investigation of design but rather an plug and play element in a collage of standardized components. The fundamentally innate properties of wood such as grain, growth rings, and color have unfortunately been underutilized in current design culture. This sadly neglects potential design opportunities, in particular their ramifications during the digitally assisted mass customization of these building materials.

The exploration of the material composition and properties of wood, along with their use in digital fabrication methods, can result in creative and innovative modes of implementation dictated by their inherent properties. An iterative design build process built upon experimentation with wood and wood products grants the designer an ability to better understand the materials and their real world behaviour. This knowledge can ultimately be applied to achieve a more holistic use of wood in architecture.

Evolution of the Profession 1.2

Over the past two decades, technological developments have dramatically advanced, altered, and revolutionized the methods in which we create and document architectural designs. Newly developed tools, methods and associated workflows have opened new doors for designers to breach conventional barriers and further their creative potential. Historically the advancements in production and implementation of buildings directly correlates to the architectural design itself. The inherent representational nature of traditional architectural projection drawings has been maintained by digital technologies such as CAD and Revit. Digital representation further instigates and reinforces a fundamental disconnect between those who design and those who construct their designs. Digital simulation, analysis and fabrication technologies have recently afforded designers the ability to recapture and reintegrate material properties and fabrication techniques as key drivers in the form, function and assembly of their creations.

The widespread adoption of digital fabrication has also demanded that the architect diversify their skill set, requiring an integral knowledge of material properties. For the development of smart solutions, the properties of both shape and material have to be known in detail. The material being machined is just as important, the architect now must have a much deeper understanding and relationship with the material in order to properly calibrate the machine to perform the functions it needs to and in the correct manner with consideration to the materials properties.

Recently, designers have developed methods and processes for layering performance based feedback into the early stages of design development. The progressively rapid rate of technological advancements have revolutionized the methods in which we create and document architectural design. Emerging digital tools, methods and associated workflows have opened new doors for designers to breach conventional borders and expand their creative possibilities. Through history, the possibilities of architectural design have followed closely in-line with the development of the means and methods in which buildings are designed and constructed. Architecture continually informs and is informed by its modes of representation and construction, which is extremely evident in the current state of practice, when digital media and emerging technologies are rapidly expanding and changing what we conceive to be formally, specially, and materially possible. Digital fabrication, in particular, has spurred a design revolution, yielding a wealth of architectural invention and innovation.

How designs use fabrication and material techniques to calibrate between virtual model and physical artifact has become a prominent topic of recent architectural discourse. In “Translation from Drawing to Building” Robin Evans expands on the inevitable separation architects encounter between drawing, the traditional medium of design and building the final outcome. Evans explains that great invention occurs in this gap. Like traditional drawing, digital production is a generative medium that comes with its own restraints and possibilities. Digital practices have the potential to narrow the gap between representation and building, affording a hypothetically seamless connection between design and making. (Evans, 1997)

Figure No. 3

Woods transition from analog to digital

Present Ignorance 2.0

The Role of Craft 2.1

As the architect’s role expands to encompass new methods of construction, such as digital fabrication and prefabrication, they are required to understand the way these technologies fundamentally work. This premise expands to include an understanding of the machine properties, capabilities and inherent logic. For example, with a CNC router one must know the various tool paths, drill bits, and typical directions of movement. The widespread adoption of digital fabrication has also demanded that the architect diversify their skill set, requiring an integral knowledge of material properties in earlier stages of design. For the development of smart solutions, the properties of both shape and material are required in detail. The material being machined is just as important. The architect now must be capable of properly calibrating the machine to perform the functions they desire and in the applicable manner with consideration to the materials properties.

Architects are dependent on the people who build their designs, in the case of the architecture industry, this is the construction industry. In an industry that values efficiency, this results in excessive waste and an overarching commitment to environmental sustainability. However, a systematic design process or computational model, applied specifically to material constraints could frame awareness of the interconnectivity between the mediums of ecology, parametric modeling, and CNC fabrication. David Gissen describes an architectural ideology based upon the definition of Architectural Political Ecology. He defines a variety of concepts to accomplish a “production of nature”. He is attempting to look beyond the superficialities of so-called “green” design to a set of strategies that embraces substantive design rather than the relatively mundane aesthetics of environmental awareness as an applied layer to architectural design. This type of substantive design is defined by the tangible knowledge of material characteristics, such as: dimensional properties, durability, deformation, waterproofing and weathering, connection types, relative costs, colour, texture, and finish (Gissen, 2009). These characteristics define some of the performance criteria, which can and should be layered into the earlier stages of design. Further, these performance based characteristics can be identified as the primary device for delimiting from through parametric design, most often through geometric relationships.

The widespread adoption of digital fabrication has also demanded that the architect diversify their skill set, requiring an integral knowledge of material properties. For the development of smart solutions, the properties of both shape and material have to be known in detail. The material being machined is just as important, as the architect now must have a much deeper understanding and relationship with the material in order to properly calibrate the machine to perform the functions it needs to and in the correct manner with consideration to the materials properties.

Material Knowledge

Wood is regularly described as a natural-fibre composite. Lignin and hemicelluloses can be seen as a ‘matrix’ that is reinforced by the cellulosic microfibrils functioning like ‘fibres’. In addition to the properties mentioned above, wood is characterised by its relatively high strain at failure; that is relatively low stiffness combined with relatively high structural capacity. Wood products have a phenomenological character. They are intended to be inhabited in more tactile and intimate ways than almost any other material conventionally employed in building design. The wide variety of colour and texture in both manufactured wood products and natural grain woods can be used to describe their cultural significance and to outline the craft of their assembly. The structural capacity of wood products is varied and is almost typically driven by their cross

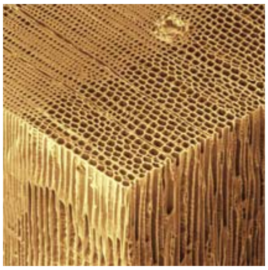

Figure No. 4

Wood grain at a microscopic level

section. Wood products are typically supported in at least two directions, creating a diaphragm, as in plywood, by altering granular layers, or by lateral bracing members on their perpendicular. These material properties lend themselves to construction techniques based on bending of wood, which is a traditional woodworking technique. The desired use for plywood is mandated by a number of factors, it is an affordable, widely available building material, utilized by the construction and furniture industries alike. This off-the shelf product provides a palette for investigation of digital fabrication techniques, specifically two-and-half-axis CNC routing.

Materials are commonly dictated by their connection types. Wood connection products are as varied as their use, and can be as simple as nails, glue, or screws or as complex as custom joinery created with a CNC machines. In digital manufacturing, wood products are an excellent material selection for testing parametric conditions. Off the shelf wood products come in manageable dimensions, capable of being easily and accurately cut. They can be repaired and worked with comparative ease. Additionally, wood products have a vast set of options meriting exploration of off the shelf connections. The thin profiles and smaller load capacities of wood products afford shorter span lengths, meaning that wood is typically used in smaller scale designs.

Tool Knowledge

Computer Numerical Control (CNC) machines are devices in which the functions and motions of the machine tool are controlled by means of a prepared program containing coded alphanumeric data. A CNC can control the motions of the work piece or tool, and the input parameters such as feed, depth of cut, and speed. The minimum knowledge for the use of CNC machines, is typically only a superficial understanding of the interface between machine and tool. However, as with any material, there are varying degrees of material intuition. While material knowledge gained through digital tools is different, one can argue that this understanding is no less informed but fundamentally different, more directly linked to the interaction between tool and material. This perceived lack of tactile reciprocity is replaced instead by more specific knowledge about the integration in all stages of the manufacturing process from concept, design, computation, and finally assembly. The goal of designers can no

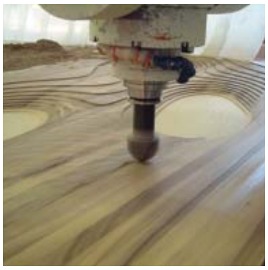

Figure No. 5

M-Shape table by Fabio Gramazio and Matthi Kohler longer be to use entirely automated processes from beginning to end, as this removes any sense of character or craft from our creation. However, we may strive to become so familiar with the software or the machine to allow assumptions that we may leave our own mark through the processes of its use. We are left to determine a set of values, in a process defined through experience, to guide our sense of craft with the machine.

To extract new performance capabilities with both materiality and modern fabrication techniques, a dialog between material, machine and designer must be the result of a refined craft defined in both modern and historic terms. The craftsman is no longer a single master but is a social structure of experience and knowledge, made available through 21st century processes of communication and interaction.

Digital Craft vs. Traditional Craft 2.2

To facilitate the illustration of the chronological evolution of wood as applied to architecture over time, specific classifications were catego

Wood 1.0

Figure No. 6

Wood 1.0 - Wigwam hut

A key feature of wood 1.0 is the vernacular means of using and utilizing materials in the most effective and efficient way possible, often resulting in minimal to no waste. These primitive structures have a tenancy to be comprised of a single species of tree due to the native understanding of that tree and its characteristics. In Wood 1.0, the master builder or craftsman achieves an understanding of the properties of the material through physical interaction and observation. With the passage of time, and the craftsmanship ability to absorb knowledge through the hand they are able to perfect a unique building technique in response to observed material behaviour.

Wood 1.5

Figure No. 7

Wood 1.5 - Timber post and beam construction

Wood 1.5 is characterized by the introduction of hand tools exclusively utilized and refined for wood working. These tools fostered new techniques of fabrication, allowing the craftsman to build more efficiently, leading to larger structures employing primitive, yet optimized joinery methods. Another feature of Wood 1.5 is the use of multiple wood species throughout a single construction. Wood 1.5 begins to consider the unique properties of different species and how they can interact with one another toward an optimal result. Not unlike Wood 1.0, the craftsman still selects particular parts of the tree for particular components, but is more selective and less improvisational.

Wood 2.0

Figure No. 8

Wood 2.0 - Stick frame construction

The widespread standardization of wood materials instigated a paradigm shift toward stick-frame construction transitioning from timber to pre-cut lumber, commonly manufactured from a limited variety of softwoods. Consequentially, wood is no longer viewed as a complex anisotropic material with unique properties, but rather as a standard prefabricated dimensional component. This standardization effectively negated the need for the designer to understand inherent properties of the material. The craftsman of Wood 2.0 is limited to a selection of linear elements at standard lengths and cross sectional dimensions. These limitations instigated major changes to methods of construction.

The manipulation and optimization of material through additives and machining is a key feature of Wood 2.5. Products and techniques have are developed through engineering strategies to achieve superior structural or visual performance. Computational techniques are often employed to optimize material performance through computer aided stress analysis. Synthetic additives, often adhesives and laminates are used to create customizable composite elements. Along with panelization of components such as plywood and oriented strand board, composite systems such as glulam or I-joists still employed dimensional lumber, but expanded the capabilities of the material.

Wood 2.5

Figure No. 9

Wood 2.5 - Glulam beam construction

As digital design technology and material computation begin to merge, architecture is beginning to shift toward non-standard modes of production. Digital fabrication has enabled designers and builders alike to embed fabrication data into a digital prototype - iterating not only to optimize material efficiency, but fabrication efficiency as well. This ability has resulting in a diminishing shape economy, where it is now possible to economically manufacture a series of customized components achieving unique, extremely complex geometries. This poses new responsibilities for the designer - the digital craftsman. The Wood 3.0 paradigm is characterized by the mergence of digital technology and physical behaviour where material comprehension is embedded throughout all phases of the design process.

Wood 3.0

Figure No. 10

Wood 3.0 - Parametric doubly curved glulam construction

Figure No. 11

Wood 3.0 - Evolution diagram

Pros:
- Minimal waste
- Working with properties

Cons:
- Primitive structures
- Small Constructions
- Improvisation

Pros:
- Material Sensitivity
- Inter-species construction

Pros:

-Efficiency of construction

Cons:

-Disregard for material characteristics

Pros:

-Computer aided optimization

Cons
- Standardized methods
- Synthetics replace material performance

Pros:

-Material Sensitivity

-Efficiency of construction

-Computer aided optimization
- Working with properties
- Inter-species construction

Western Red Cedar

Figure No. 12

Western red cedar

Distribution
Pacific Northwest United States/Canada
Tree Size
165-200 ft (50-60 m) tall, 7-13 ft (2-4 m) trunk diameter
Colour
Heartwood reddish to pinkish brown, often with random streaks and bands of darker red/brown areas. Narrow sapwood is pale yellowish white, and isn't always sharply demarcated from the heartwood.
Grain Texture
Has a straight grain and a medium to coarse texture.
Odor
Western Red cedar has a strong, aromatic scent when being worked.
Workability
Easy to work with both hand or with machine tools, though it dents and scratches very easily due to its softness, and can sand unevenly due to the difference in density between the earlywood and latewood zones. Glues and finishes well. Iron-based fasteners can stain and discolor the wood, especially in the presence of moisture.
Rot Resistance
Western Red cedar has been rated as durable to very durable in regard to decay resistance, though it has a mixed resistance to insect attack.

Figure No. 13

American white ash

American White Ash

Distribution

Eastern North America

Tree Size

65-100 ft (20-30 m) tall, 2-5 ft (.6-1.5 m) trunk diameter

Colour

The heartwood is a light to medium brown color. Sapwood can be very wide, and tends to be a beige or light brown; not always clearly or sharply demarcated from heartwood.

Grain Texture

Has a medium to coarse texture similar to oak. The grain is almost always straight and regular, though sometimes moderately curly or figured boards can be found.

Odor

Can have a distinct, moderately unpleasant smell when being worked.

Workability

Produces good results with hand or machine tools. Responds well to steam bending. Glues, stains, and finishes well.

Rot Resistance

Heartwood is rated as perishable, or only slightly durable in regard to decay. Ash is also not resistant to insect attack.

Northern White Cedar

Figure No. 14

Northern white cedar

Distribution

Northeastern North America

Tree Size

50-65 ft (15-20 m) tall, 1.3-2 ft (.4-.6 m) trunk diameter

Colour

Heartwood is pale brown or tan, while the narrow sapwood is nearly white. Numerous small knots are common in the wood.

Grain Texture

Grain is usually straight, with a fine, even texture. Moderate natural luster.

Odor

Northern White Cedar has a distinct (though moderate) cedar-like smell when being worked.

Workability

Northern White Cedar has good overall working characteristics, and works easily with both hand and machine tools. However, the wood is both soft and weak, giving it poor screw-holding capabilities. Northern White Cedar glues and finishes well.

Rot Resistance

Rated as durable to very durable regarding decay resistance; also resistant to termites and powder post beetles

Black Walnut

Figure No. 15

Black walnut

Distribution

Eastern United States

Tree Size

100-120 ft (30-37 m) tall, 2-3 ft (.6-1 m) trunk diameter

Colour

Heartwood can range from a lighter pale brown to a dark chocolate brown with darker brown streaks. Color can sometimes have a grey, purple, or reddish cast. Sapwood is pale yellow-gray to nearly white. Figured grain patterns such as curl, crotch, and burl are also seen.

Grain Texture

Grain is usually straight, but can be irregular. Has a medium texture and moderate natural luster.

Odor

Black Walnut has a faint, mild odor when being worked.

Workability

Typically easy to work provided the grain is straight and regular. Planer tearout can sometimes be a problem when surfacing pieces with irregular or figured grain. Glues, stains, and finishes well, (though walnut is rarely stained). Responds well to steam bending.

Rot Resistance

Black Walnut is rated as very durable in terms of decay resistance, though it is susceptible to insect attack.

Figure No. 16

Traditional craft, knowledge through physical interaction

Material Sensitivity 3.0

Figure No. 17

Stav church Gol, Norway - Constructed in the 1100's is the oldest wooden building existing today

Wood 1.0

Employing vernacular techniques, a key feature of wood 1.0 is the effective and efficient use of material, often incorporating all components of the tree including bark, roots and sap. The primitive structure is usually entirely composed of a single species of tree. In Wood 1.0, the master builder or craftsman achieves an understanding of the properties of the material through physical interaction and observation. From time, experience and experimentation, the craftsman nearly perfects a unique building technique in response to observed material behaviour.

Figure No. 18

Cruck Weobley - Quartered log bent to create a triangulated pitched roof

Wood 1.5

Within the same category as Wood 1.0, Wood 1.5 transcends its predecessor by employing hand tools exclusively utilized and refined for woodworking. These tools fostered new techniques of fabrication, allowing the craftsman to build more efficiently, leading to larger structures employing primitive, yet optimized joinery methods. Another feature of Wood 1.5 is the use of multiple wood species throughout a single construction. Wood 1.5 begins to consider the unique properties of different species and how they can interact with one another toward an optimal result. Not unlike Wood 1.0, the craftsman still selects particular parts of the tree for particular components, but is more selective and less improvisational.

The Primitive Hut 3.1

As Laugier explains in Essay on Architecture published in 1753 , the human necessity to create shelter for self-protection against the elements led to the creation of the primitive hut. Ultimately this simple structure paved the way for the main general principles of architecture. These principles were directly influenced and rooted to nature in both a structural and functional basis. According to Laugier, the three main elements of architecture were; the column, the entablature and the pediment. The column need to be perpendicular to the ground, free-standing, round and tapered to the ground from top to bottom resembling plants in nature. The entablature needed to rest on the columns in its full length without any corners or projection. The pediment was to be above the entablature as the gable of the roof and span the full width of the building. These finite principles are prevalent in today's modern construction methods, and it is important to keep in mind Laugier's main theory of allowing nature to indicate the rules of design (Laugier 1753).

Far too often, current designers neglect the inherent construction material and prioritize the form of the building, having a tendency to apply the material after the overall form has been established. This results in an unbalanced design process failing to preserve the natural harmony that is evoked through a holistic process that considers the material early on in the design process. Even though these may not all be seen in the final form of the building, they are essential to creating an accurate understanding of what can be physically achieved. As per Branko Kolarevic's book Manufacturing Material Effects, Rethinking Design and Making in Architecture, "the ancient Greeks turned into interrogating nature to reveal its secrets. In a sense, they endeavor to discover the codes of nature and use them with mathematics and geometry as organizing devices, which if applied judiciously, lead to 'harmony' in architecture. Today, we do not talk about 'harmony' let alone 'beauty'. Yet, like the ancient Greeks, we are operating at the level of code - whether found in nature or not - by manipulating information that remains largely invisible in the final form." (Kolarevic, 2010)

Material Tectonics 3.2

Material tectonics is "the science or art of construction, both in relation to use and artistic design" (Anderson, 2000, 83). Consequently, tectonics within architecture is not only defined by the process of construction but rather the particular detailing of each instance of the construction process. Hence it is important to represent the material accurately during the design process. The most common subject of tectonic expression is the structure and enclosure of the building. Furthermore, thorough understanding how elements come together and are joined is where the essence of material tectonics lies. For example in the Castelvecchio in Verona, the ziggurat motif was a strategic way of depicting the story of the old and the new by peeling back the layers of the facade to celebrate the connection between the existing building and the new construction. A similar strategy was used in the Brion-Vega Cemetery in San Vito d'Altivole by Carlo Scarpa, yet rather than emphasizing the old and the new, the design celebrates the memories of the family. With a chapel, meditation pavilion, and reflection pool enclosed within a sloping concrete wall it enriches the story of the cemetery as a whole. Additionally it is important to acknowledge the narrative capacity of the joint at both the human scale and the building scale.

Figure No. 19

Carlos Scarpa ziggurat

Reviewing tectonic practice in the context of wood, craftsmen regularly choose specific sections of the tree for specific components of the overall structure based on inherent properties and characteristics of that section of the tree. In traditional Japanese wood work and joinery, the craftsmen were very particular and knowledgeable about the unique qualities of various segments of the tree. For example, door screens were often made from the lower portion of the tree because they understood that this portion was less prone to fluctuations in size and shape. Similarly in the Darwin College in Cambridge, UK, the architect's knowledge of the wood and its aging characteristics inform a conscious decision of using the central core of the tree for the columns. This is because they recognize that although the wood would split along the grain, it would never cause structural failure. As previously mentioned, the main intent behind this was for the material to tell a narrative of its own existence.

Physical Prototyping 3.3

A prototype is primarily used to test a component or structure and is most commonly created at a one-to-one scale. This is done early on in the design phase to test a concept, process or to practice a tool to learn from. Before digital technologies, these prototypes were critical representations of the architect's design intent. Differentiating from abstract means of representing the building through drawing, the physical prototype allowes all senses to be engaged. These 3-D models were used to accurately depict all aspects of the physical artifact. For example the design of the Sagrada Familia by Antoni Gaudi had extremely intricate and complicated geometry for its time, and no means to represent it through a digital modelling platform. Due to this, it was important for physical prototypes to be created so that the builders would have a clear understanding of what had to be accomplished.

Dating back to ancient and medieval history, master builders were commissioned to build extravagant and noble buildings due to their extensive knowledge of working with a specific material such as wood and stone. An example of a craftsman/sculptor taking the role of an architect can be seen through Michelangelo's work on St.Peter's Basilica. During those times, building a cathedral was regarded as equivalent to creating a very large sculptural piece where the master builder had to be equally aware of the interior aesthetic and spatial qualities as well as how the building is perceived from the exterior.

Figure No. 20

Gaudi hanging chain model

Conclusion 3.4

Wood 1.0 and Wood 1.5 are both closely tied to the general principles of construction, the understanding of the material characteristics and how to successfully craft and apply them to their full potential.
Historically, through the early uses of wood, the craftsmen have been interrogating nature in order to disclose its potential and beauty with the extent of knowledge and expertise they had at that time (Kolarevic, 2010). Trees were widely respected as a living organism and it was good practice to utilize every component of the tree itself, including the wood, the bark, the roots and even the sap, as key contributors to the construction. To further illustrate, the birch bark canoe designed by early Native American tribes is an early example of the sensitivity and respect given to the use of vernacular materials. The craftsman understood the natural grain direction of the wood and therefore knew that it could be split easily along its longitudinal axis, allowing a simple and relatively controlled way of dividing the overall tree into smaller, structural segments. Other elements of the tree such as the water resistant qualities of the bark and sap were used for the hull of the canoe. Lastly, the roots were boiled to soften the matter creating a flexible yet durable weaving material to secure the birchbark hull to the frame of the canoe. This knowledge could only have been obtained through tactile interaction with the material itself. It necessitated an intimate understanding of the material in order for the craftsman to use it to its full potential and emphasize all of its

physical properties, from its structural capacities to expressive potential. At this point in time, the material craftsmen were limited to very simple geometries as they did not have the tools to both visualize, understand and create more complex projects. These forms often lead to very basic expression of the material, but nevertheless wood still evoked both a visual and haptic sensory experience.

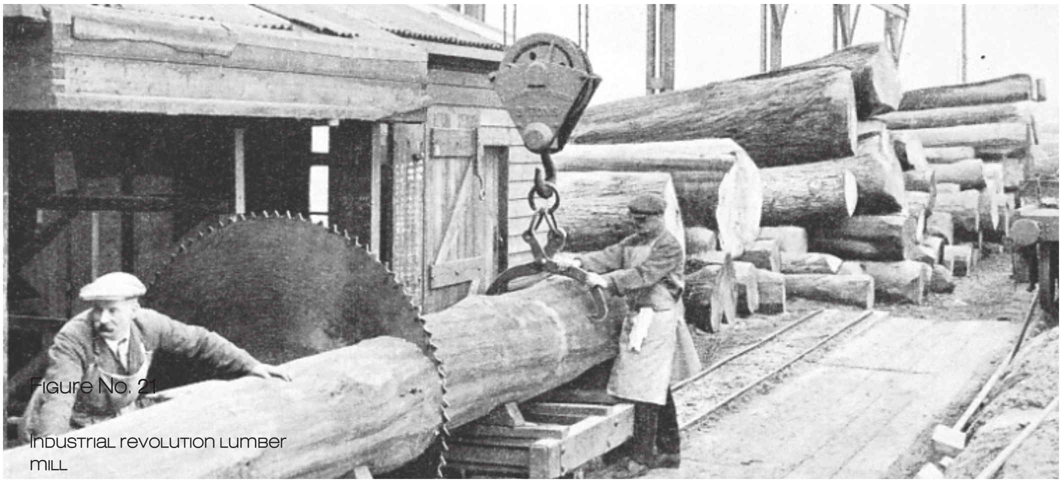

Figure No. 21

Industrial revolution lumber mill

Machine Age 4.0

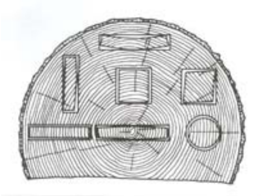

Figure No. 22

Flat sawn versus quarter sawn diagram

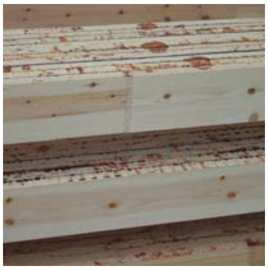

Figure No. 23

Glulam beams being laminated

Wood 2.0

The widespread standardization of wood materials instigated a paradigm shift toward stick-frame construction transitioning from timber to pre-cut lumber, commonly manufactured from a limited variety of softwoods. Consequently, wood is no longer viewed as a complex anisotropic material with unique properties, but rather as a standard prefabricated dimensional component. This standardization effectively negated the need for the designer to understand inherent properties of the natural material, but only those associated with the mass creation of a generic building element. The craftsman of Wood 2.0 is limited to a selection of linear elements at standard lengths and cross sectional dimensions. These limitations instigated major changes to methods of construction, perhaps limiting creativity, resourcefulness and innovations within building.

Wood 2.5

Simulations and engineered lumber is what differentiates Wood 2.5 from Wood 2.0 with the manipulation and optimization of material through additives and machining. Products and techniques are developed through engineering strategies to achieve superior structural or visual performance. Computational techniques are often employed to optimize material performance through computer aided stress analysis. Synthetic additives, often adhesives and laminates are used to create customizable

composite elements. Along with panelization of components such as plywood and oriented strand board, composite systems such as glulam or I-joists still employed dimensional lumber, but expanded the capabilities of the material.
The “death “ of the craftsman as well as the constant development of new building materials since the nineteenth century created a new condition for the architect, for which there is no precedent. Tectonics tries to take advantage of these developments. The question less concerned whether one uses readily available materials and building techniques, but rather how one makes a virtue of what are the typical modes of production

Mass Production and Standardization 4.1

It is said that one of the main causes of this type of production was to eliminate any non productive effort. For example, in craft production, it was considered an efficient use of time for the craftsman to locate tools around the shop and be knowledgeable about utilizing these tools. Whereas in mass production, each worker repeated a single or few simple tasks utilizing limited tool in order to optimize the efficiency of the assembly line, significantly reducing the probability of human error. Although the time required to complete a product in mass production was drastically reduced in comparison to traditional craftsmanship, it resulted in the death of the craftsman. They became less knowledgeable about composition, techniques, joinery, material properties, less of a conscious, logical mind to understand and contemplate the work, but more so a simple a hand to repeat a singular task.
The introduction of mass production in the early 1900’s had a profound impact on architecture and the process of design and construction. It brought forward the birth of the off-site architect, where their hands-on involvement became minimal. This lead to a large disconnect between the designer and builder, and architects lost a tactile sensitivity towards the influence of materials on the design. Due to mass production, architects designed their buildings utilizing standardized components which set limits on what could be constructed.
The birth of this movement occurred during an economically driven era

and thereby primarily focused on efficiency, practicality and standardization. It introduced a number of new building materials-such as cast iron, steel, and glass — which architects and engineers devised structures that were previously not possible in terms of function, size, and form. These advancements undermined the research and development of wood products. In terms of wood construction, the introduction steel allowed specialized metal fasteners such as screws, nuts and bolts allowed for increasingly efficient methods of securing timber members.

In addition, during this time, wood mills began to adopt similar strategies governed by efficiency and economical benefits. This lead to the development of standardized dimensional lumber where one log was efficiently subdivided into smaller components based on market cost and profit. Before, craftsmen were very selective as to which segment of the overall tree to use in specific conditions largely based off of the grain and the understanding that the tree continues live throughout its existence and will expand and contract accordingly. By eliminating this consideration from the use of wood in architecture, the architect loses sensitivity towards the material. This no longer results in a holistic design process but rather one that ignores the first and most critical step. Wood was no longer considered a natural living organism but rather a standard unit of construction often hidden and banished from expressing its history and natural "beauty".

Beginning of Additives and Composites 4.2

During World War II, the development of water based adhesives dramatically altered the fabrication of timber members by eliminating the use of metal fasteners. Due to the cellular structure of wood, metal fasteners were a poor method of securing different components because it removes material and could easily shear off along the linear direction of the grain. By implementing water based adhesives we are now capable of laminating multiple, thin boards together to create an infinitely large timber member. As a result, these members are proven to be stronger due to the staggered lamination of numerous boards. To elaborate, timber naturally has weaker points located at the knots in the member and this method eliminates these points of structural failure. This glulam method provided the opportunity to further explore the possibility of wood by creating structurally stable curved members and spanning large distances. As previously mentioned, the main driver of this movement was economic efficiency which carried on into the manufacturing of glulam members. Currently, it is very cost effective to use glulam in construction since the use of wood is optimized with minimal waste. Glulam can be mass customized allowing the designer to have more control over the types of species used and other appearance characteristics. This method also gave opportunity for the development of singly curved members and furthermore the introduction of accurately doubly curved components. Although doubly shaped curves were previously possible on small-scale projects such as furniture, they were not existent as large structural components in buildings. This breakthrough allowed for architects to explore new possibilities of shape and geometry for wood construction.

Conclusion 4.3

Wood 2.0 and Wood 2.5 were born out of the evolution of the machine age and were therefore shaped by principles of efficiency and economy. One can say that the essence of these periods has little relation to that of Wood 1.0 and Wood 1.5. Nonetheless, this era helped foster new modes of fabrication and was a significant milestone in advancing the fundamental use of wood in architecture. The introduction of machinery was a great contributor to expanding the ways of working with wood and, with the addition of water based adhesives, opened up opportunities of creating new engineered and optimized wood products. As Scott Marble explains in Imagining Risk, “craft has always been mediated through a relationship between humans and technology. From primitive hand tools to industrialized machines, the quality of craft in an object has been measured by the trace of human input. Today, with the wide range of digital technology being used to increase the efficiencies of human labour (or bypass it altogether), it is useful once again to take measure: to look critically at how digital mediation is restructuring design and production, and consequently, redefining craft." (Marble, 2010, 40) By further adopting many of these tools and principles early on in the process, architects can design for the wood rather than merely applying the material to the project after the design is complete.

Figure No. 24

Center Pompidou-Metz - Shigeru Ban

Evolution Through Integration 5.0

Wood 3.0

As digital design technology and material computation begin to merge, architecture is beginning to shift toward non-standard modes of production. Digital fabrication has enabled designers and builders alike to embed fabrication data into a digital prototype - iterating not only to optimize material efficiency, but fabrication efficiency as well. This ability has resulted in a diminishing shape economy, where it is now possible to economically manufacture a series of customized components, achieving unique, extremely complex geometries. This poses new responsibilities for the designer - the digital craftsman. The Wood 3.0 paradigm is characterized by the emergence of digital technology and physical behaviour where material comprehension is embedded throughout all phases of the design process.

Simulation 5.1

Wood as a building material has always been tested for its structural capabilities through physical testing. By applying enough stress to the material, craftsmen were able to understand the limitations and instances of failure. As technology evolved, the data collected from the physical testing was transferable to digital platforms providing opportunity to not only test a single member's performance, but rather apply it to the overall structural composition of the building and receive real-time feedback. We are no longer representing buildings in a virtual setting as ordinary Non Uniform Rational Basis Spline (NURBS), a mathematically model commonly used to generate and represent curves and surfaces[LS16] , but rather as digital objects with physical properties applied to them. In other words we are accurately digitally constructing our buildings. With our ability to confidently construct the virtual building in line with new digital fabrication technology and our ability to go straight from file to factory, we have eliminated the need to represent the building in a 2-D drawing. For example the Barclay's Centre in Brooklyn, NY by AECOM Architects, employs this strategy of file to factory effectively through its facade. The 675,000-square-foot building's facade is made up of 12,000 pre-weathered steel panels that wind around the building like scales on a giant reptile. The panels, each individually unique and unlike any other, swoop up and down and surround a canopy that hovers 30 feet above an entry plaza. The holistic process, fabrication and installation would have

Figure No. 25

Barclay's Centre Brooklyn, New York

been almost impossible to achieve without current, modern technology. The process of installation was streamlined with the implementation of individual, specific barcodes located on each panel that allowed the builders to digitally see where the panel should be installed on the extensive facade.

Further development of digital software simulation algorithms allows architects and engineers to accurately mimic environmental factors such as sun paths, wind vectors, seismic activity and rainfall. The need for making assumptions was significantly reduced with these tool since accurate results were obtainable based on environmental data and facts. Furthermore, this allowed for occupant comfort and experience to be optimized. In the context of wood, factors of time and aging can be simulated in order to get a relatively accurate understanding of how the material will weather throughout the years. Also the haptic atmosphere influenced by the penetration of light through the apertures of the building can be precisely represented through solar sun and shadow relationships. Furthermore with the ability to precisely apply both physical material properties as well as their aesthetic qualities to models, one can visualize and represent buildings with both real material traits and environmental factors. As per David Ross Scheer in The Death of Drawing: Architecture in the Age of Simulation, "even its esthetic and experiential qualities can be viewed as a kind of performance that can be simulated and evaluated using the model. Where an aspect of a building is difficult to quantify, the performative attitude tends either to encourage the adoption of quantifiable proxies or relegate it to secondary status". (Scheer, 2014) Therefore, due to this new body of knowledge and instant feedback from numerous factors, the architect is now responsible for setting a hierarchy on which factors should be prioritized.

Physical Computing 5.2

Physical Computing is a digital process of building interactive, physical systems through the use of a virtual platform which can sense and respond to the analog world. In general, it is a creative framework for understanding physical relationships to the digital world. Physical Computing provides the opportunity of inputting a series of different sets of simulation data allowing the architect to visualize how each simulation influences the others. This forces the architect to prioritize what is most important in the expression of the building or how to optimize it by utilizing all streams of data. By applying all sets of data the architect is able to extract patterns and relationships in physical environment and translate them into speculative algorithms. Some leading visionaries in this field are Achim Menges, and Neri Oxman. Menges uses the approach of physical computing in his Hygroscope experiment by understanding the behaviours and moisture sensitivity of wood. The experiment showcased how mere fluctuations in the humidity could trigger inherent qualities in the material to change and adapt according to its own described need. Through numerous physical experiments, he was able to collect enough data in order to be applied accurately and inform the overall model. By executing individual, physical experiments, Menges was able to use that data to simulate real-world results and understand how the artifact will perform as a whole through a virtual platform. Oxman's silkworm pavilion takes on the same approach as Menges in that she tests the ability

Figure No. 26

Neri Oxman's silk worm pavilion

of the silkworm to weave a web over a certain distance. This allows her to set parameters on the maximum distance of the woven framework on which the silkworms would deposit their silk, therefore controlling the apertures location along the pavillion.

Digital Fabrication 5.3

As technology progresses and the architect's role expands, it is their responsibility to understand the new tools that are becoming available to them. This leads to a disconnected relationship with material sensitivity, as it allows them to be more dependent on new modes of digital representation. In this digitally dominant period, it becomes very easy to disrupt the "harmony " of the holistic design process. Ever since the industrial revolution, there has been a dramatic shift from obtaining materials from nature to the current post-process component. For example, where previous master builders, such as Michelangelo, would obtain their material from the original, natural source, bring it directly to site and begin to craft the artifact, industrial processes have streamlined this process through mass production of predetermined components available from a factory.

On the other hand, with the digital fabrication tools available to the architect, a new platform opens up for exploration and experimentation with materials and new tools. Instead of utilizing standard materials, we have the tools and understanding of how to create our own custom components while maintaining those inherent principles of construction, the understanding of material characteristics and successfully crafting and applying them to their full potential. For instance the architect must have an understanding of the materials and properties and the difference between the diversity of various materials such as aluminum and wood. By utilizing CNC technology, different milling methods must be employed in order to achieve successful results. In the case of wood, large amounts of stock can be removed in a single pass of a tool path due to the physically soft nature of the material and the orientation in which the toolpath is directed is important due to its anisotropic properties. However with aluminum, being a physically hard isotropic material, methods of micromilling and the introduction of liquid coolants must be employed in order to preserve the lifetime of the tool and eliminate the risk of failure.

Conclusion 5.4

Wood 3.0 is the final evolutionary step that attempts to capture both the material sensitivity prevalent in Wood 1.0/1.5 as well as the advancements in technology and methods of fabrication in Wood 2.0/2.5. The addition of sophisticated softwares that can capture both the characteristics of the material while simultaneously maintaining the freedom of design and play, architects are able to generate honest geometries and modes of representation. Furthermore through an inherent understanding of digital fabrication methods, these designs can flow seamlessly from the virtual world to the physical. This process attempts to create a link between the intimate understanding of how wood behaves and the advanced methods of digital modelling, simulation and fabrication.

Figure No. 27

Exterior night render

Design Proposal 6.0

Introduction 6.1

The Canadian Canoe Museum (CCM) interweaves past, present and future in a unique manner through the medium of the canoe. The proposed facility is anticipated to be approximately 7500 square meters of gross floor area located on a single level. The facility will include exterior ancillary features such as a large east, north and south facing terrace, a porte-cochere, canoe basin created by modifications to the west canal wall and a seasonal boat storage house to support on-water programs. The CCM will be located on the existing Lift Lock visitor centre, extending southwards to minimize disruption to the National Historic site and will necessitate demolition of the current structure. In addition to broadening and supporting the museum experience, the ancillary features are intended to create a financially sustainable facility that is less dependent on governmental support and private donations for ongoing operations.

The CCM was developed from of a collection of canoes held by Kirk Wipper, a Professor of Physical and Health Education at the University of Toronto, and a recipient of the Order of Canada. In 1957, Wipper established a museum of his canoes at Camp Kandalore, just north of Minden, Ontario, which was originally known as the Kanawa International Collection of Canoes, Kayaks and Rowing Craft. By the early 80s it was apparent that the collection was outgrowing the capacity of the Camp to accommodate it, and that a new home and professional organization structure would be required. In 1994, Wipper transferred his ownership of the collection to the newly formed Canadian Canoe Museum, which also began investigations into a new and more accessible location than the Camp.

The museum offers a surprising and inspiring experience to a new visitor, it is not the dry object based displays that one might expect. Through the use of stories, panel boards and a wide variety of experiences – artisan workshops, actor animations, restorations and on-water programming, the museum brings the experiences and pioneering spirit of the designers, builders and users of canoes out from the past and places them into the modern Canadian context.

Through the medium of the canoe, these stories and tableaux inject life into past cultures in a way that relates them to the present. The principles of these stories are able to address concerns and issues that embroil Canadian society today and provide guidance to possible future resolutions. They yield relevant and compelling stories of physical achievement and emotional fulfillment that can provide inspiration for the couch culture youth of today. This relevance to today and the future is key to the sustainability of this museum. Its experiential programs; artisanal crafts, canoe and paddle carving, on-water programming and educational animations bring to life these stories in a tangible and enduring manner.

Site 6.2

The site at the Lift Lock in Peterborough will combine two great Canadian cultural assets in one location, leveraging the potential of both in order to entice visitors and experiences as well as create a sustainable institution of enduring significance for the early history and culture of Canada. CCM is focusing on the strengths demonstrated at its current facility: conveying early Canadian history and culture through rich stories and interactive experiences. Despite its stark industrial exterior, barren parking lot and complete lack of open water, CCM has consistently remained the most popular tourist destination in Peterborough. Once in-

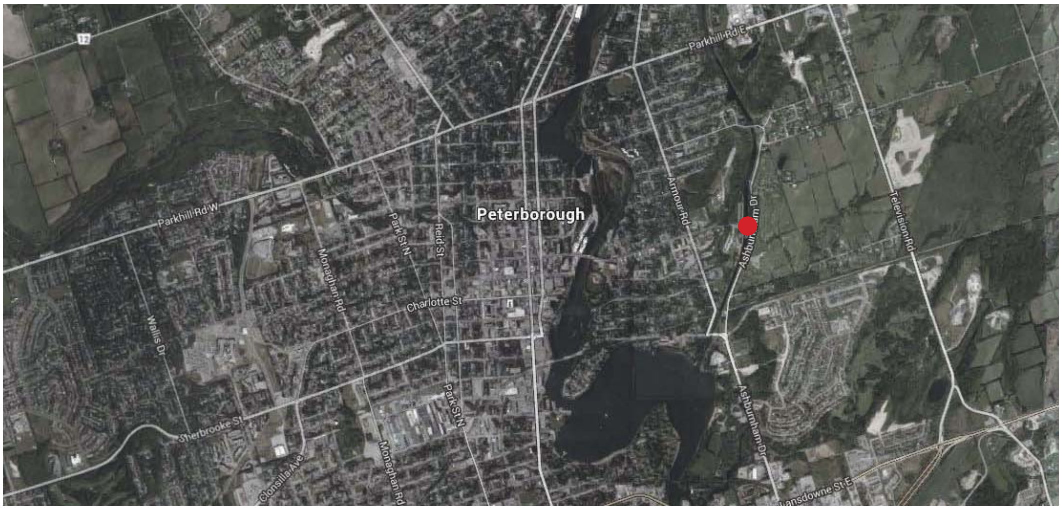

Figure No. 28

Birds eye view of Peterborough and location of site

Figure No. 29

Views into and from the proposed site

side, visitors are surprised and delighted by the experience and environment they encounter. Rather than a dry and dusty set of canoes lined up by year, CCM wraps each canoe and related artifact with a rich tapestry of experience and inspiration that leaves visitors looking for more. The Lift Lock, a hydraulic boat lift that allows vessels to ascend and descend the Trent River at a height of nearly 20 metres is a National Historic Site and is powered only by gravity. The 'elevator' has the attributes that will allow the design to provide a historical, water based setting that supports and reinforces CCM's strategy of stories and experiential learning with on-water experiences. Additionally it offers the opportunity to leverage historical attendance at CCM and Lift Lock expanding the audience and experience for both groups. Most importantly it is a unique setting that

provides sustainable and compelling advantages for the ancillary facilities that will provide a dependable revenue stream to support both museum operations in sustainable manner.

The relevance of the Lift Lock National Historic Site lies in the innovation and advancements in construction and material science focusing on concrete. At the time, it was the first lock to be built out of concrete and the largest structure in the world to effectively utilize unreinforced concrete. Constructed in the early 1900's, it was the result of the advancements and innovations that occurred during the industrial era that lead to the rapid evolution of technology and how it is being used in our current paradigm. Similarly as the lock used innovation in concrete, the design and construction of the CCM will focus on the evolution of wood and the human aided, technological advancements of wood.

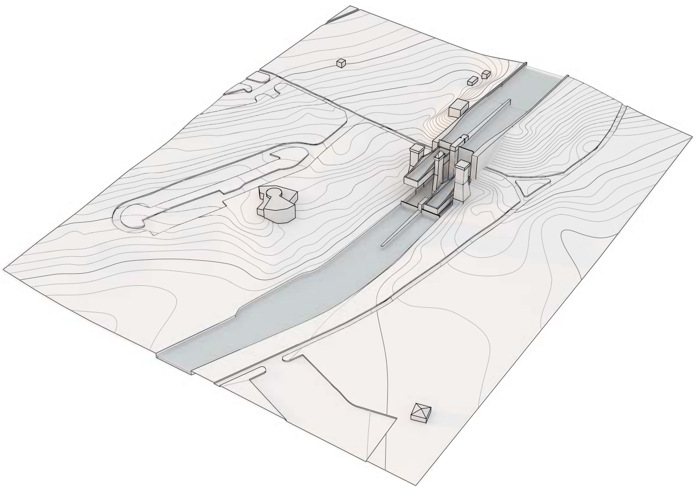

Figure No. 30

Existing site with existing buildings

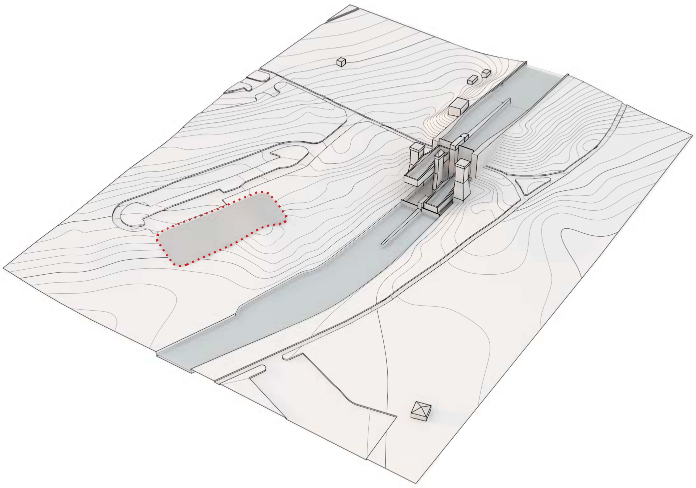

Figure No. 31

Proposed and allocated site

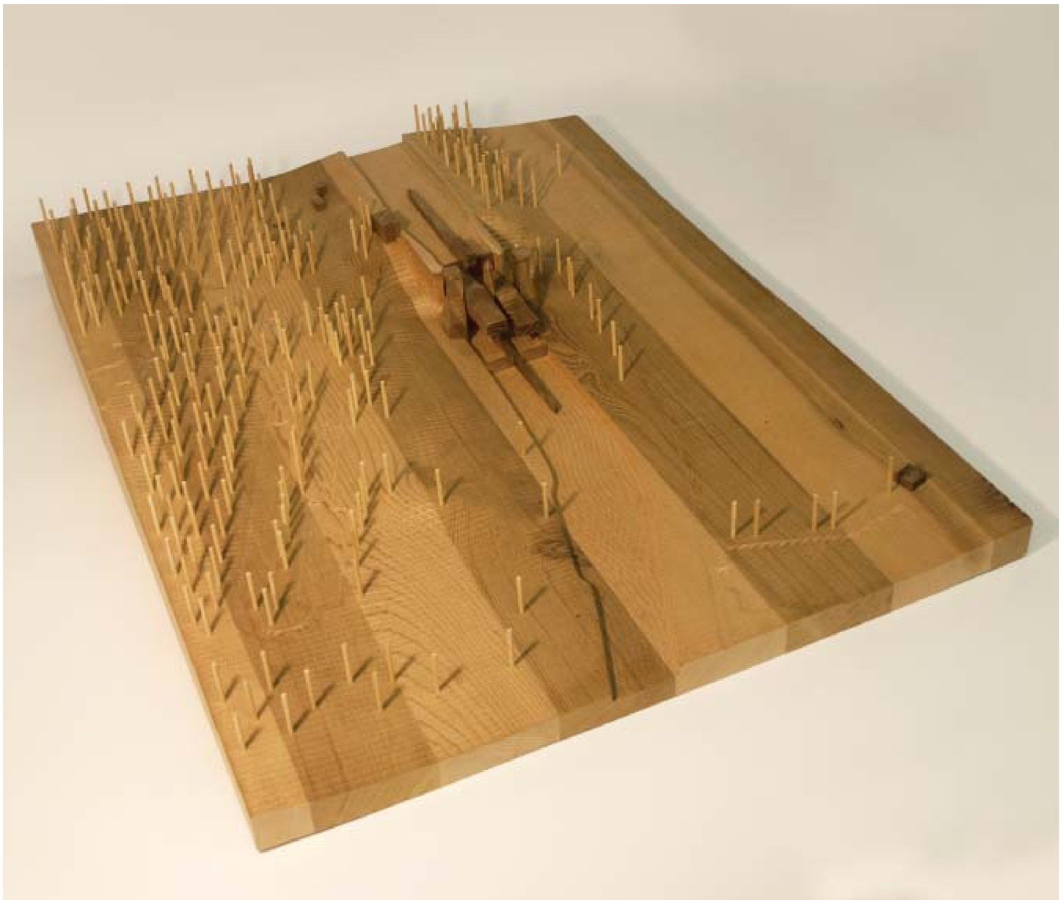

Figure No. 32

Wester red cedar and black walnut site model

Program 6.3

The CCM is intended to operate year round and attract approximately 60,000 visitors in its first year of operation. The ancillary facilities are designed to support both museum visitors and boaters. These facilities will include[LS21] : Multifunction room and Pre-function rooms seating 250 to 300 people in banquet format divisible into as many as three rooms of 150, 75 and 75. Therefore the facility is designed to support weddings, corporate and charitable events and conferences. The room may also serve for educational programs with First Nation Groups such as the Friendship Center. Furthermore it will include commercial spaces such as a full service restaurant seating approximately 50 to 75, full service bar seating approximately 20 to 30 and a Café seating for 30. Additionally, the terrace will provide exterior seasonal seating expansion for the above program. As well as the exterior events area for interactive programs with First Nations groups and other events, artisan activities and workshops. The modification to the Canoe Basin created by reconfiguration of the west canal wall, south of the historic elements of the Lift Lock, provide a place for canoes to dock.

As previously mentioned, the Canadian Canoe Museum (CCM) interweaves past, present and future in a unique manner through the medium of the canoe as well as the evolution of the canoe. The design aims to capture the narrative of the canoe exhibitions by expressing the progression of wood both as an organic, living organism as well as a building material. As Charles Darwin stated in The Origin of the Species "One general law, leading to the advancement of all organic beings, namely, multiply, vary, let the strongest live and the weakest die". In terms of design, this can be interpreted as the process of applying the material characteristics early on in the design in order to produce an honest product that utilizes wood to its fullest potential and the knowledge accumulated over time.

Figure No. 33

Program diagram

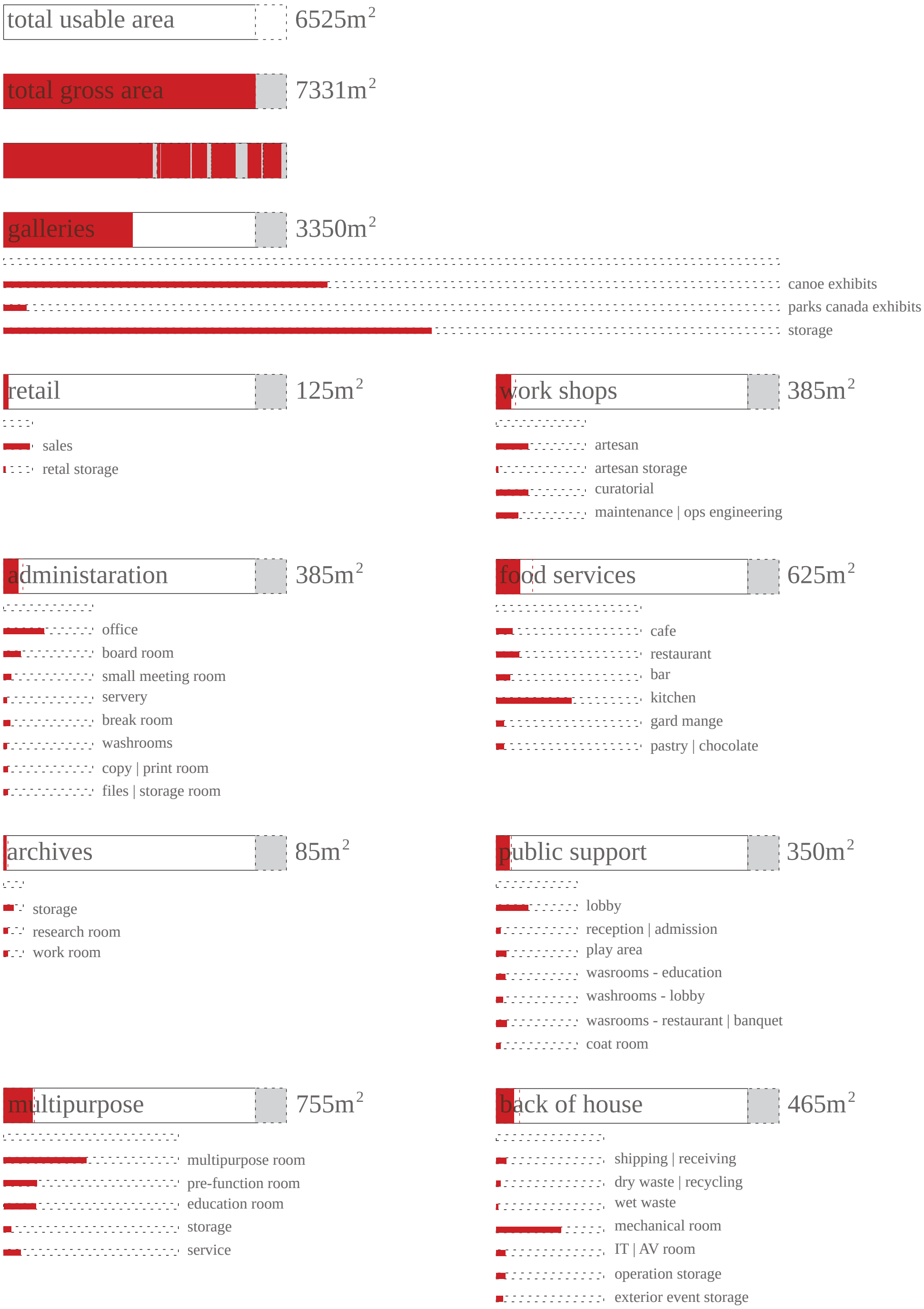
total usable area
6525m2
total gross area
7331m2
galleries
3350m2
canoe exhibits
parks canada exhibits
storage
retail
125m2
sales
retal storage
work shops
385m2
artesan
artesan storage
curatorial
maintenance | ops engineering
administaration
385m2
office
board room
small meeting room
servery
break room
washrooms
copy | print room
files | storage room
food services
625m2
cafe
restaurant
bar
kitchen
gard mange
pastry | chocolate
archives
85m2
storage
research room
work room
public support
350m2
lobby
reception | admission
play area
wasrooms - education
washrooms - lobby
wasrooms - restaurant | banquet
coat room
multipurpose
755m2
multipurpose room
pre-function room
education room
storage
service
back of house
465m2
shipping | receiving
dry waste | recycling
wet waste
mechanical room
IT | AV room
operation storage
exterior event storage

Figure No. 34

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Design Intent 6.4

Problem Statement

This thesis attempts to address the potential digital fabrication methods that can be utilized to manipulate wooden properties which ultimately has critical implications on the tactile and sensory experiences of space

Design Strategies

The design strategies mimic the three categories of wood illustrated earlier, concerning methodologies to transform wood and the appropriate techniques of applying wood as a material to the design process. The strategies touch upon the suitable instances in the process at which the material should be considered taking into account a number of properties and characteristics such as tree size, colour, grain texture, odor, workability and rot resistance, to name a few. Additionally, just like in any other woodworking era, it is fundamental to understand the tools with which the wood will be manipulated. In the current paradigm, computer numerically controlled milling tools are the pinnacle method of working with wood. These tools, like all others, become an extension of the designer's craft. Therefore now through mass customization, one can create infinitely unique components of the building only limited by the materials capabilities and the parameters set by the tool.

Strategy 1

The first design strategy focuses on how the presence of wood and the use of specifically selected species can inform the mood or atmosphere in a space, based on the wood's physical properties and characteristics.

The application of this strategy can be seen through three crucial components of the design; the facade, the atrium screen and the columns. More specifically, the facade exemplifies the natural aging characteristics of western red cedar from a saturated maroon colour to a pale silver. Like all wood species, the exposure to UV light causes the desaturation of the original wood colour. This wood species was specifically selected for both its ability to survive the harsh Canadian climate as well as the

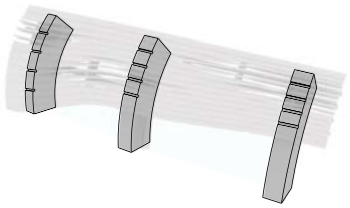


Figure No. 35

Facade assembly
exterior columns

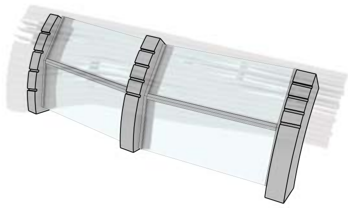


Figure No. 36

Facade assembly
mullions and glazing

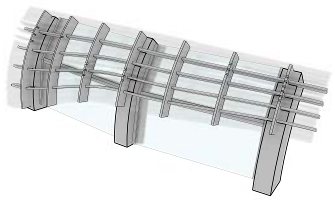


Figure No. 37

Facade assembly
substructure

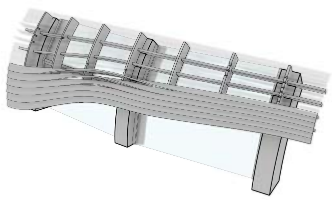


Figure No. 38

Facade assembly
Western red cedar louvers

drastic fluctuation of original colour versus the colour after prolonged sun exposure. This quality will capture the passage of time and express the narrative of the buildings life. Initially the rich, saturated colour will stand out and emphasize the building's existence in situ, but with time, the building will begin to blend into the site and mimic the monolithic presence of the Lift Locks. This expression touches upon the natural cycle of life of all living entities. It absorbs the influences of its environment as all things are a product of nature and nurture. Throughout the years the building will express its beauty, initially by its untouched innocence and over time through its wisdom and narrative.

Due to its geodesic geometry, the individual slats or louvers had to overlap, similar to how shingles are laid onto a roof. This condition creates

Figure No. 39

Facade assembly
location of apertures

a naturally formed composition of highlights based on the overall geometry, and allows the sun to unveil the embedded colour palette within the wood. Due to the direction of louvers, this composition can be best viewed and understood from the human scale. Conversely, the interior will maintain the original colour throughout time. This can ensure a consistent influence on the atmosphere of the interior spaces. In contrast to the subtle colour of the interior finishes, the saturated red cedar will identify the boundaries between interior and exterior.

Another element that embraces this strategy is the use of ash for the interior atrium screen. Opposite to the red cedar, American white ash has a pale beige colour which was specifically selected in order to create a lighter environment. Due to the minimal allowance of natural light, this species provides a brighter and warmer feel to the interior exhibition space. Additionally the selection of this species was influenced by its ability to be easily bent by manipulating its cellular structure through the use of steam. This allows the interior atrium screen to both act as a visual barrier for private spaces, but also be able to open up and create apertures in order to generate a visual connection between disconnected spaces. In addition, the elasticity of this wood allows the program to optimize the functional use of individual interior spaces, such as the relationship between the exhibition space and the multi-purpose space. The screen acts as a secondary barrier from the natural light that is desired in the multi-purpose space but is harmful to the exhibition space due to the light sensitive artifacts. Similar to the expression illustrated

Figure No. 40

Facade aging diagram - year one

Figure No. 41

Facade aging diagram - year two

Figure No. 42

Facade aging diagram - year five

Figure No. 43

Facade aging diagram - year ten

in the western red cedar facade, the desire to preserve the narrative of the buildings life is expressed through the aging and splitting of the columns caused by the dehydration of the wood. Standard practice tends to use dry timber because the wood will no longer drastically fluctuate in size. For the desired expression of the columns, using green wood was intentionally done in order to allow the material to age over time and develop splits down the length of the member. Atlantic white cedar has one of the more significant shrinkage ratio in comparison to other softwoods thus resulting in prevalent splits along the length of the wood. By using appropriate sections of the tree, one can ensure that split will not impact the structural integrity of the system. Due to the manner at which the wood will be dried, from the periphery to the core, these splits are

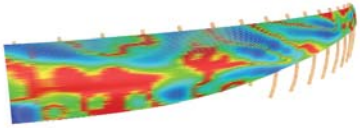


Figure No. 44

Facade aging diagram - year twenty

Figure No. 45

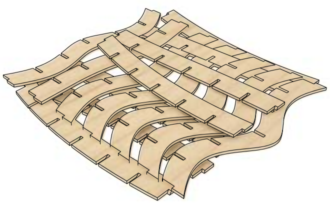
Facade curvature analysis diagram

outcomes of how the exterior dries faster than the interior, and showcase how the separation of the splits become narrower as they move deeper toward the center.

Strategy 2

The second strategy focuses on how initial physical wood testing and collection of data driven by a general design concept can be implemented earlier on in the design process through physical computation in order to produce an accurate and honest design.

The application of this strategy is demonstrated through the concrete panels in the exhibition space as well as the facade. Firstly, the concrete panels were used in the exhibition space as a method of curating the ca-



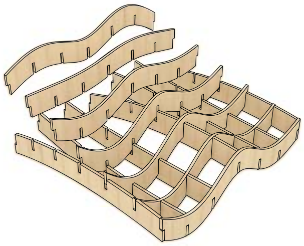


Figure No. 46

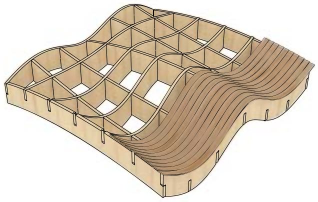
Concrete panel assembly waffle components

Figure No. 47

Concrete panel assembly creating the form work structure

Figure No. 48

Concrete panel assembly applying American white ash strips



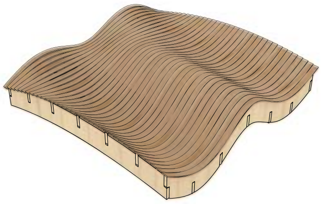


Figure No. 49

Concrete panel assembly completed surface

Figure No. 50

Concrete panel assembly applying the border

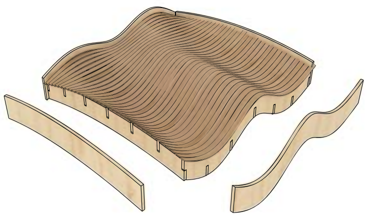


Figure No. 51

Concrete panel assembly pouring concrete and sealing the face

noe display in a very natural way to mimic the inconsistency of a forest and its landscape. The intention behind this was to create an atmosphere that exemplifies the process of portaging. By understanding the design intent, one is able to identify the appropriate wood and the respective method of achieving that objective. In this case, the desired species was American White Ash due to its grain composition composed of largely spaced growth rings allowing it to have one of the more significant modulus of elasticity. By inherently using quarter sawn sections of the tree, we can ensure the best performance and consistency while attempting to bend the strip.

The quarter sawn orientation of the grain in the member is important because it allows one to work with the natural characteristics of the tree,

Figure No. 52

Concrete panel assembly
wood textured
doubly-curved concrete
panel

therefore optimizing the process. Through this understanding, one can execute a variety of experiments to define how the material behaves as well as determining parameters and limitations.

This physical interaction with the material gives the designer both an innate, human understanding of the woods characteristics through touch and feel as well as a set of usable data. By collecting this data and feeding back into the computational model, one is able to produce an honest geometry that is dictated by the limitations that were derived out of the experiments. Throughout history, wood has been used as a method of forming concrete because formwork can be easily assembled and that the wood is non porous. With the use of dimensional lumber, these forms often took on rectilinear shapes or very basic geometries. With the tools available today, one can accurately fabricate complex formwork com-

Figure No. 53

Structure assembly
steel columns

Figure No. 54

Structure assembly
northern white cedar
column cladding

Figure No. 55

Structure assembly steel rings and cross-bracing connections

Figure No. 56

Structure assembly installation of cross-bracing

posed of doubly curved geometries. Secondly, the facade demonstrates this strategy through a similar process of initial material testing which is later on programmed back into the computational model.

For the ease of assembly and installation of the facade strips on site, the process of dry bending was the appropriate approach in order to streamline the construction of the facade. Similar to the previous experiment, strips of Western Red Cedar were dry bent in order to derive data to support the maximum bending radius before failure. Furthermore, due to the limited lengths of standard dimensional lumber available, it is necessary to develop a strategy of creating connection details in order to help express the continuity of the overall surface. To elaborate, Western Red Cedar is available between 6-12 feet in length when purchased from conventional saw mills. Due to this limitation, it is necessary to provide an exterior substructure to the facade knowing that the strips were unable to span the full length between structural columns. By understanding these limitations and utilizing the data collected from these experiments, it is possible to generate an honest surface and a rational grid structure in order to accommodate the use of standard sized lumber. As previously mentioned, it is vital to derive a surface from geodesic curves since the material being used was standard sized lumber. As a result, the strategy of overlapping louvers was implemented in order to accommodate for the significant differentiation in the surface height between the middle portion and where the surface terminates. This in combination with the application of an image sampler that manipulated the apertures of the louvers creates an abstracted expression of water moving through a river.

Figure No. 57

Structure assembly installation of transverse beams

Figure No. 58

Structure assembly installation of longitudinal beams

Due to our ability to accurately model every component of the building, we are able to seamlessly transition from file to factory through digital fabrication methods.

Strategy 3

The third strategy focuses on how digital design tools and digital fabrication methods can effectively embrace and emphasize the natural wood properties through manipulation and exploitation of the material.

This strategy is demonstrated through nearly every component of the building. However, the following three examples illustrate it most effectively; the ceiling and floor finishes, the facade structure and the concrete panels. Due to the nature and form of the building, a standard wood floor composed of rectilinear wooden strips would result in awkward termination points when meeting with the curved slab edge. This condition applies to the ceiling as well. In order to avoid the awkward moment at the slab edge, a method of tweening the perimeter curves was exercised. This resulted in the strips varying in width with the largest width being at the midpoint and progressively tapering down towards the terminating point. Due to this, each individual strip has a shape customized to the curvature of the outer slab. Without digital fabrication technologies, it would be difficult and extremely labour intensive to achieve this type of floor and ceiling condition. Through mass customization, which has recently made significant advancements, it has become both physically and economically possible to fabricate countless custom components. As a result of this, the building is able to holistically express the form of the structure throughout its entirety.

Similarly in the facade substructure, digital fabrication is employed in order to provide specific locations at which the wooden strips would be notched into and at what angles they are to be positioned in order to provide the desired amount of natural light. Due to the large quantity of strips covering the facade, each vertical member of the substructure would have a completely custom set of notches that would in turn formulate the composition of the wooden strip louvers. The vertical members of the substructure would be made up of bent glulam beams which would be laminated to the desired curvature and accurately milled using a CNC machine, positioning the desired notches in their appropriate locations.

Figure No. 59

Column to cross-bracing detail new

Figure No. 60

Column to cross-bracing detail aged

Finally the concrete panels demonstrate this strategy through the development of formwork for molding the concrete into curvilinear panels. As opposed to the previous two examples which utilize digital fabrication methods to create the final elements that will be installed to compose the final building, this examples employs digital fabrication to create a tool for the development of the final product. The fabrication of a plywood waffle structure creates a rough framework for the American White Ash wooden strips to be attached to. When the waffle structure is fully clad with the wooden strips, a border can be attached to the perimeter and properly sealed off to avoid any leaks. Finally, glass fiber reinforced concrete is progressively poured in to create the end product which would be later on installed in the building.

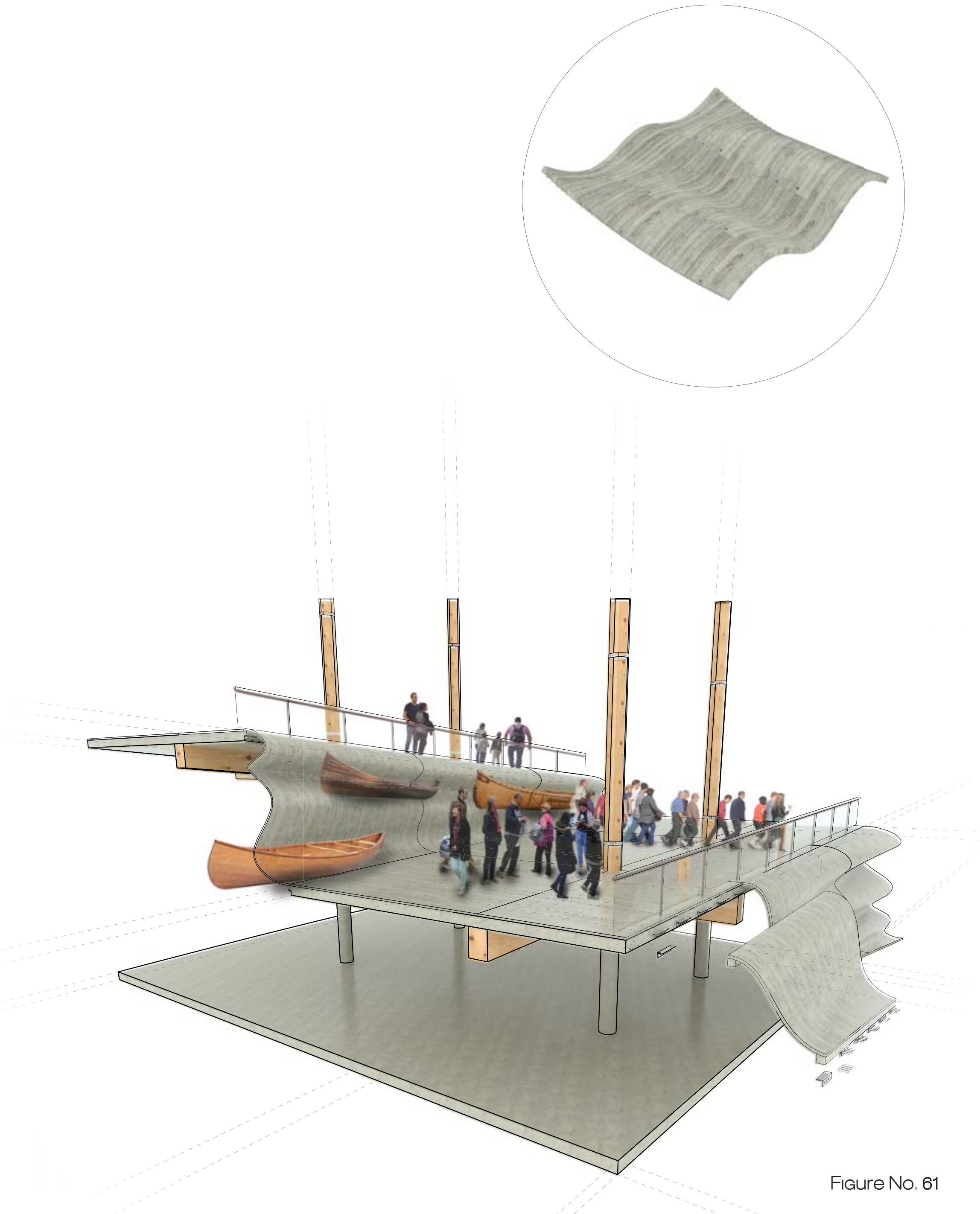
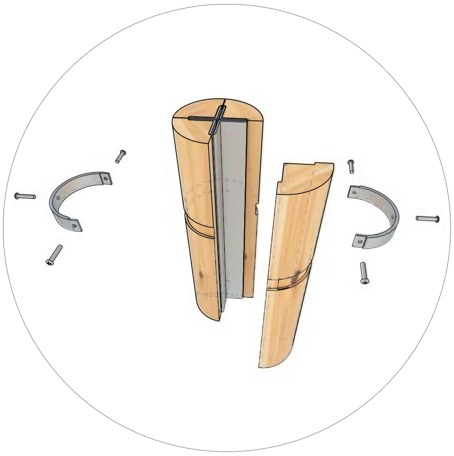


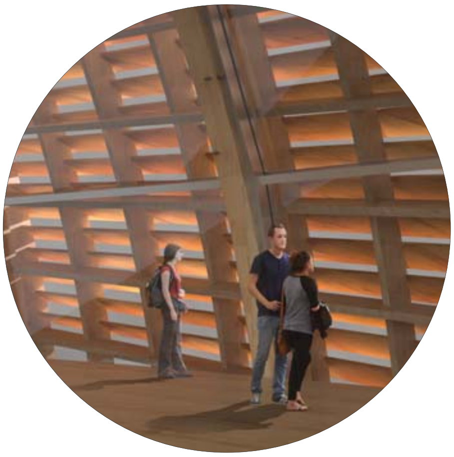
Figure No. 61

Interior column and concrete panel diagram



By using the tree trunk as a whole the columns are milled in order to meet up and fit into the steel structure while maintaining the grain direction as well as the orientation of the tree as it would grow in nature. The purpose for this is to allow the wood to age and shrink as it would naturally over time, gradually developing slits along the grain that would climb up the columns. This form of material expression is able to archives the museums age and history through the natural properties of the wood. By utilizing the entire diameter of the tree trunk the tree retains both it heartwood and sapwood which is critical in preventing the wood from splitting completely through due to the fact that heartwood particularly the innermost core shrinks significantly less than the sapwood maintaining its structural rigidity while both expressing the beauty of the wood and the passage of time.

The concrete panels formed with steamed American ash strips create a neutral backdrop for the exhibition space while still alluding to a tradition means of crafting a canoe seen in cedar strip canoes, together this architectural feature allows the vibrant collection of wooden canoes to stand out and be curated to their fullest potential. In the spirit of portaging canoes are seen in one of two states, drifting through the water or perched up on a the face of a rock. The concrete panels attempt to combine express these two conditions referential to the erosion of rock formations made by water in motion thus creating an atmosphere in the space mimicking the motion in nature as one embarks on the journey of portaging through the building and exhibition space.



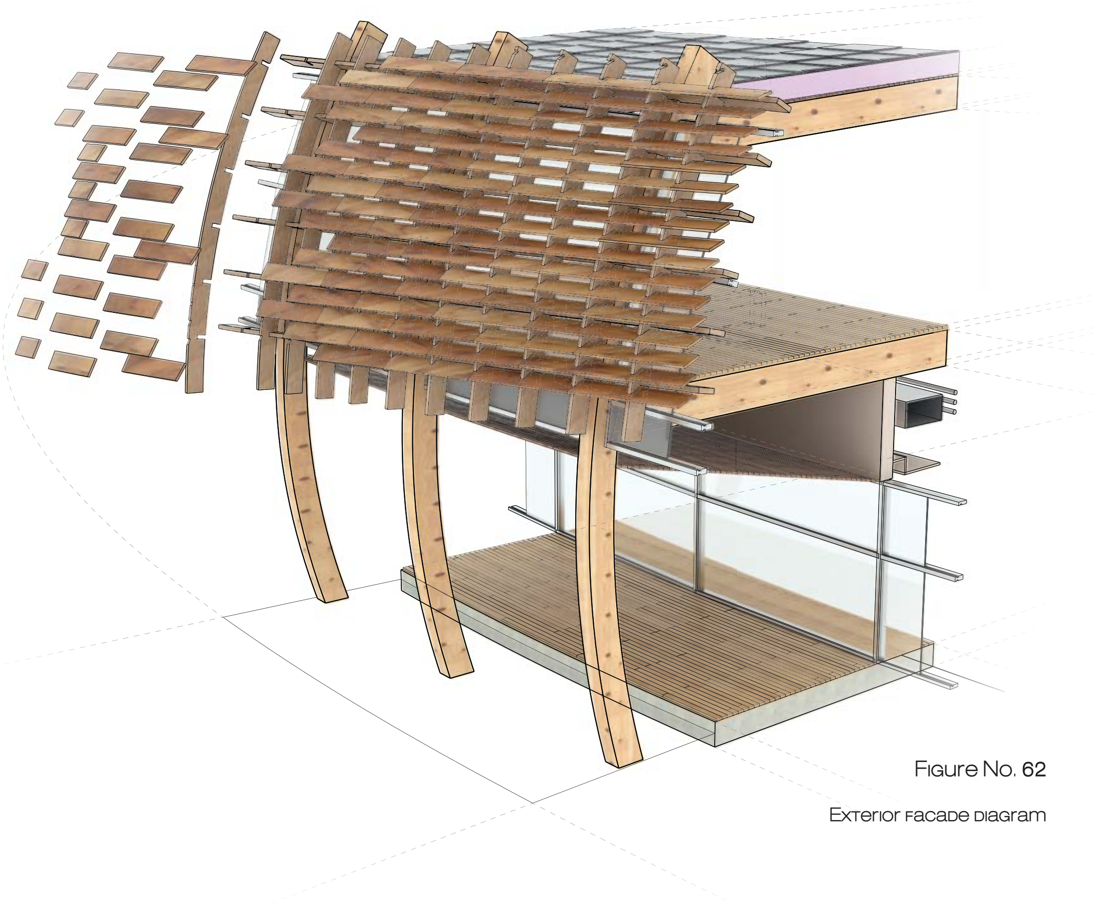
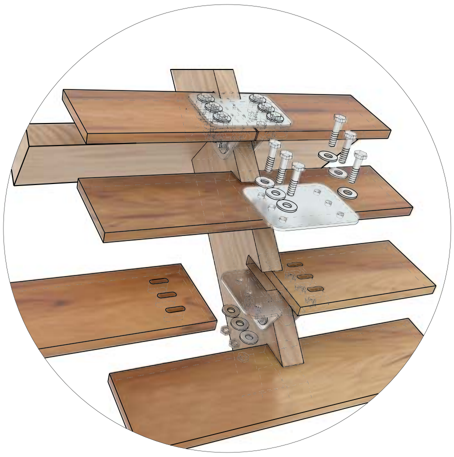
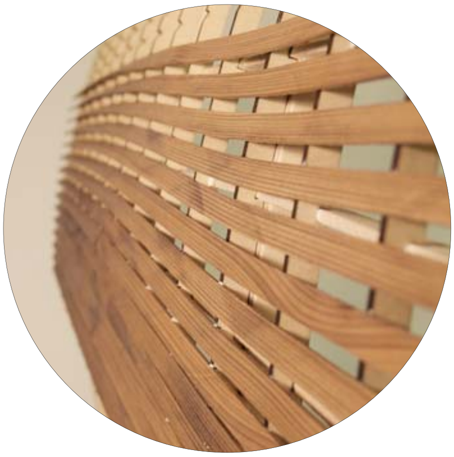


Figure No. 62

Exterior facade diagram





Due to the limitation and parameters set by the natural length of the tree only certain dimensions of rectilinear members can be extracted from the overall log. As a result of this the facade strips required points of transition where one louver transition to the next. This was accomplished by locating multiple points of connection with the vertical facade substructure. By maintaining a minimum of three points of connection the curvilinear geometry of the facade is able to be achieved. The western red cedar louvers create apertures by twisting open based on programmatic requirements for example the multipurpose room and offices, located on the upper floor are desired to have significant amounts of natural light thus the louvers rotate fully in order to achieve this while also providing sightlines to the beautiful surroundings. The louvers rotate between a range of ten to ninety degrees from the normal of the surface. This provides a varying degrees of natural light throughout the day as well as creating sightlines to the canal, lift locks and adjacent park.

By retaining the antiquity of traditional woodworking which was based on material sensitivity perfected during the age of craft in conjunction with mechanized tooling developed during the industrial revolution has resulted in the evolution of woods application in architecture. Woodworking and fabrication process have evolved in parallel with architectural ideologies established by technical innovation. Instigated by the computer wood 3.0 followers the third wave by challenging the mind instead of the hand thus instead of trial and error we can anticipate through simulation.

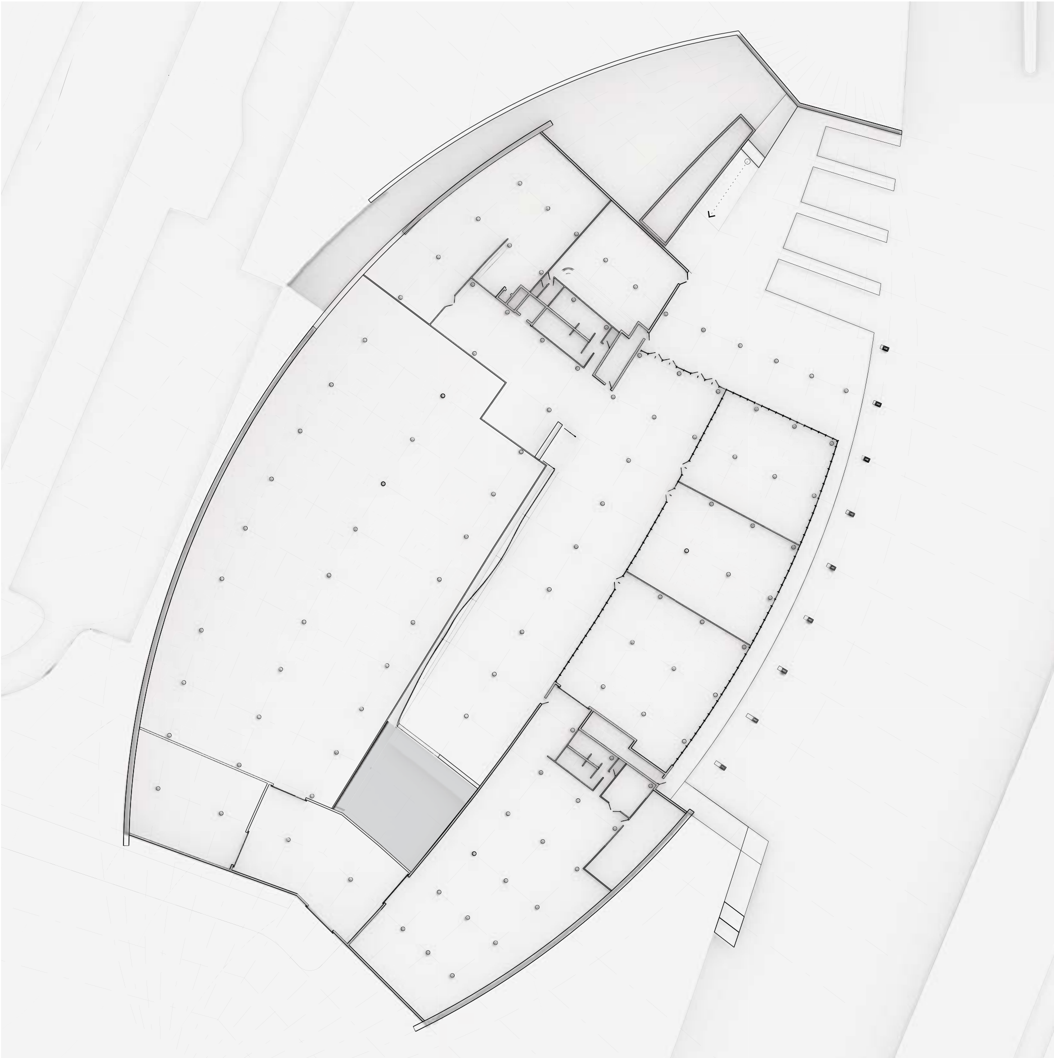


Figure No. 63

Basement floor plan

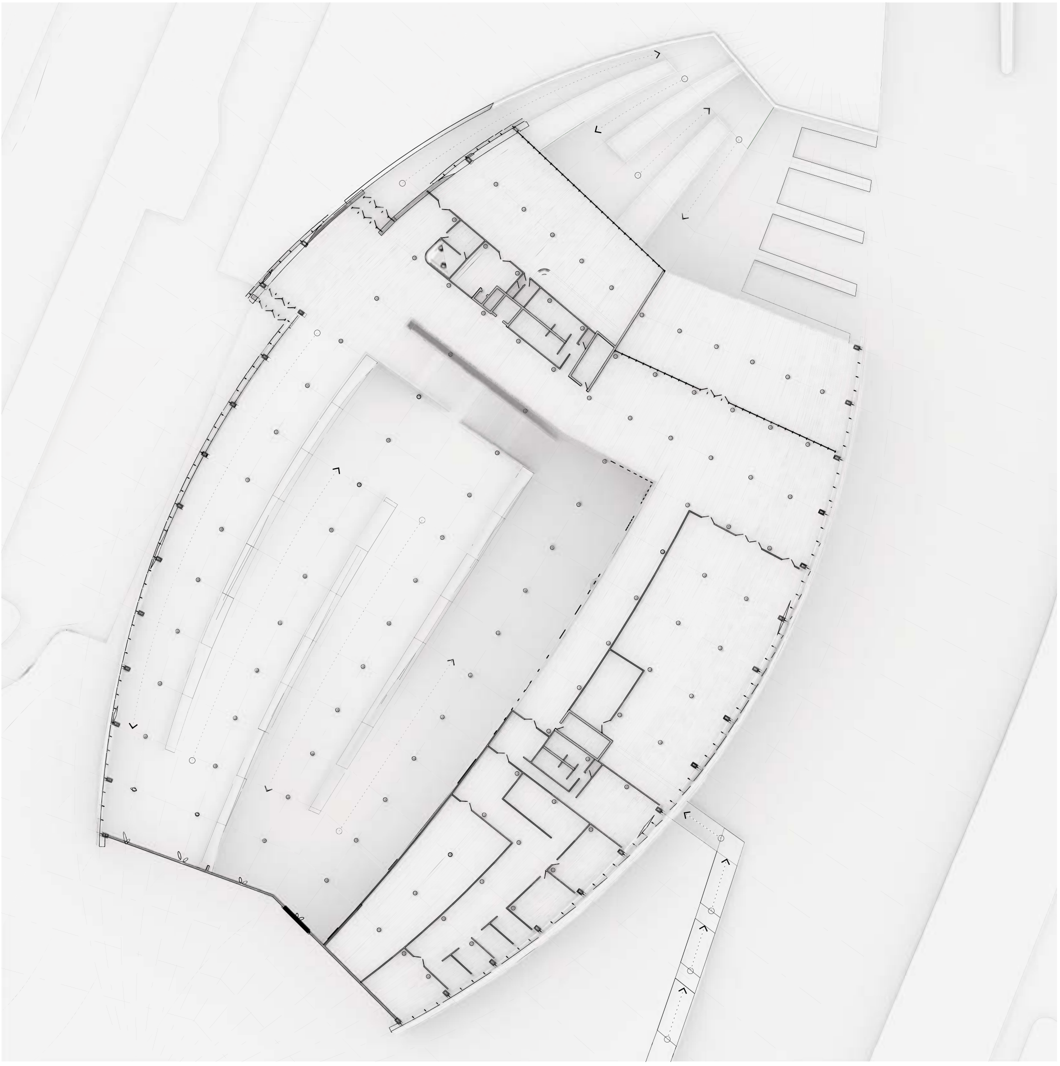


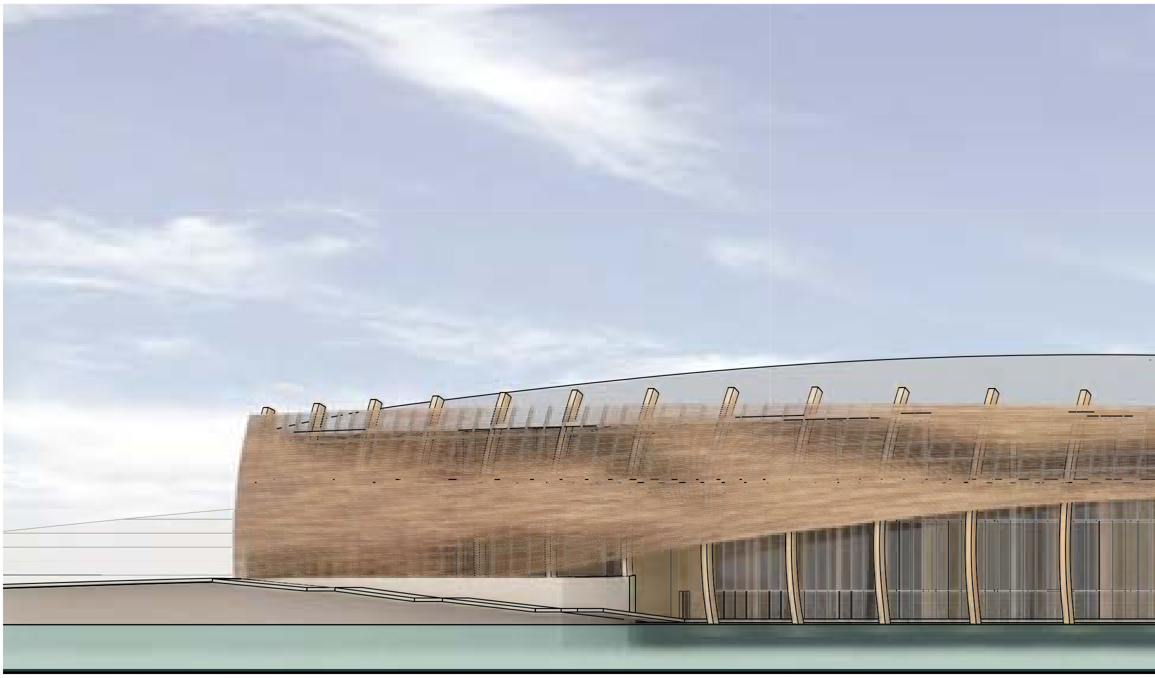
Figure No. 64

Ground floor plan


NOVA CRAFT CANOE

Figure No. 65

Exterior day render approaching the museum by canoe



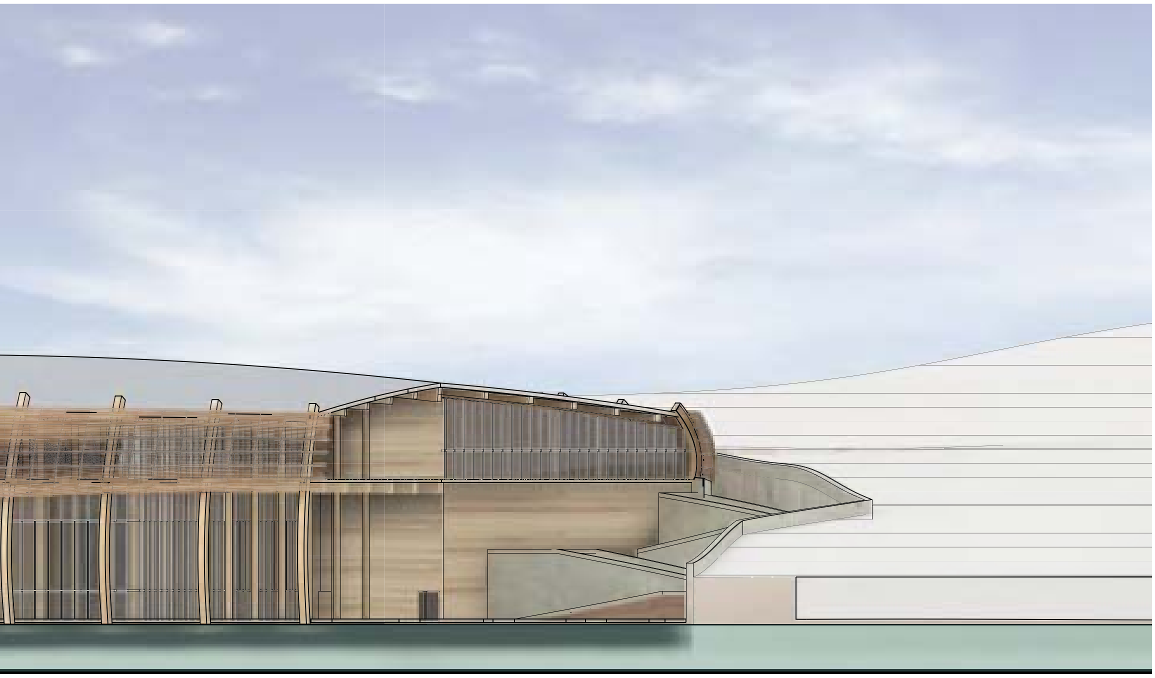
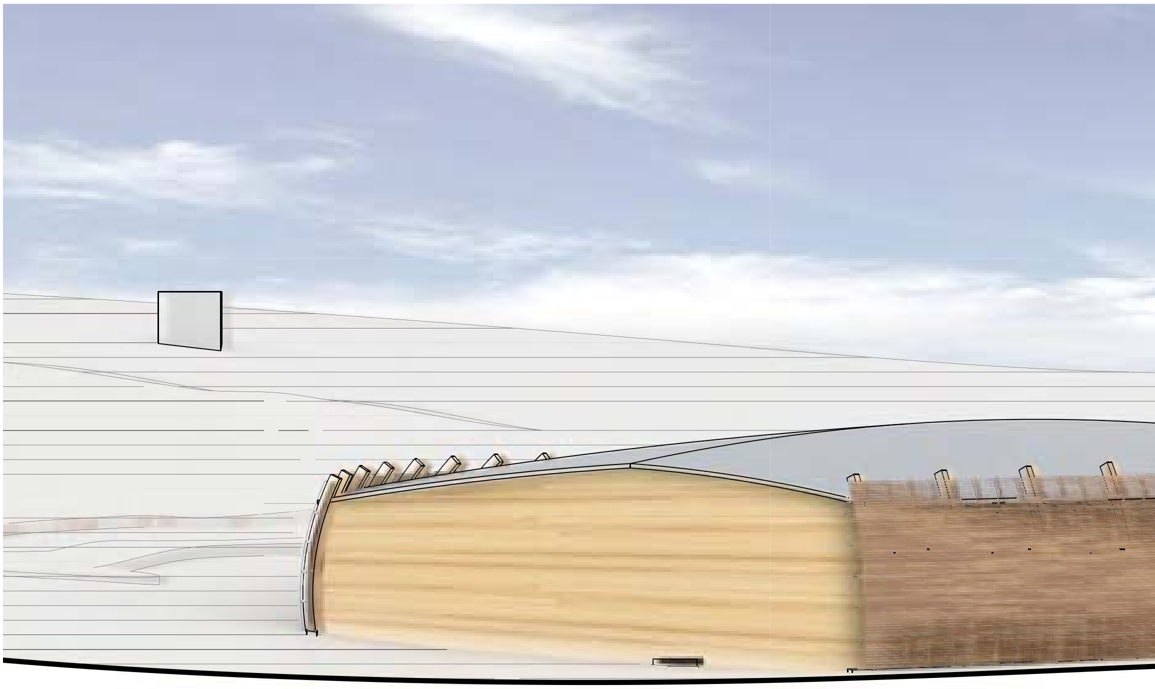


Figure No. 66

East elevation



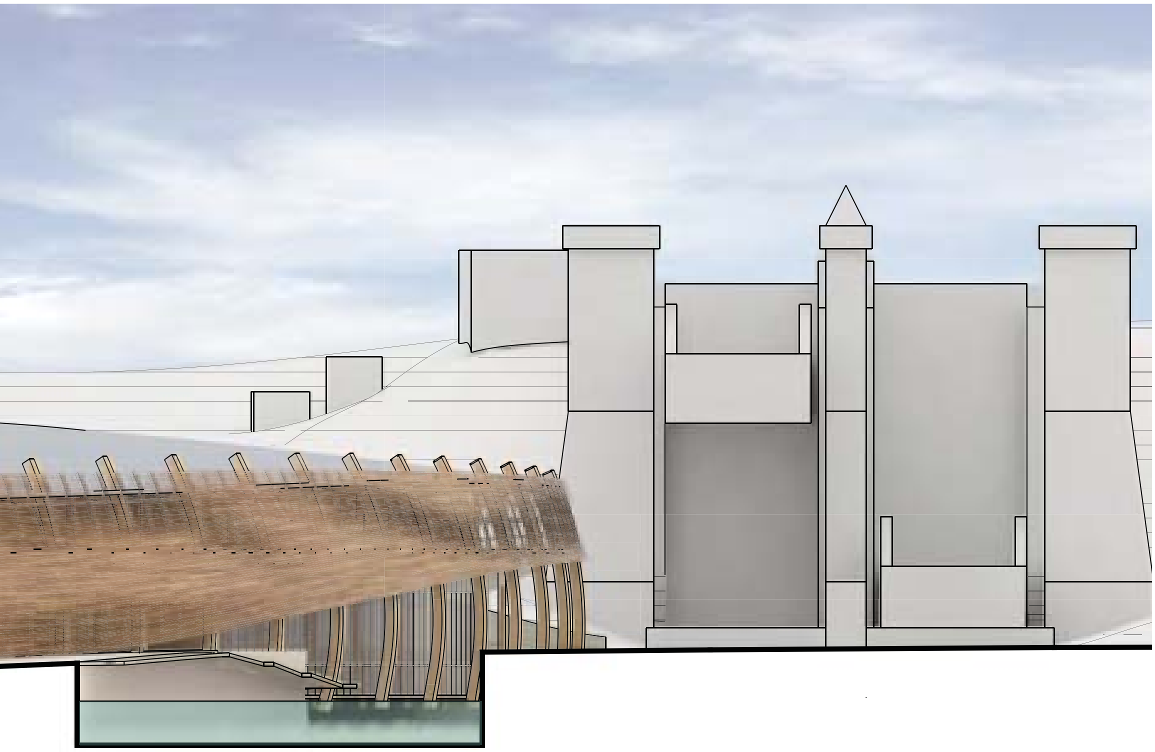
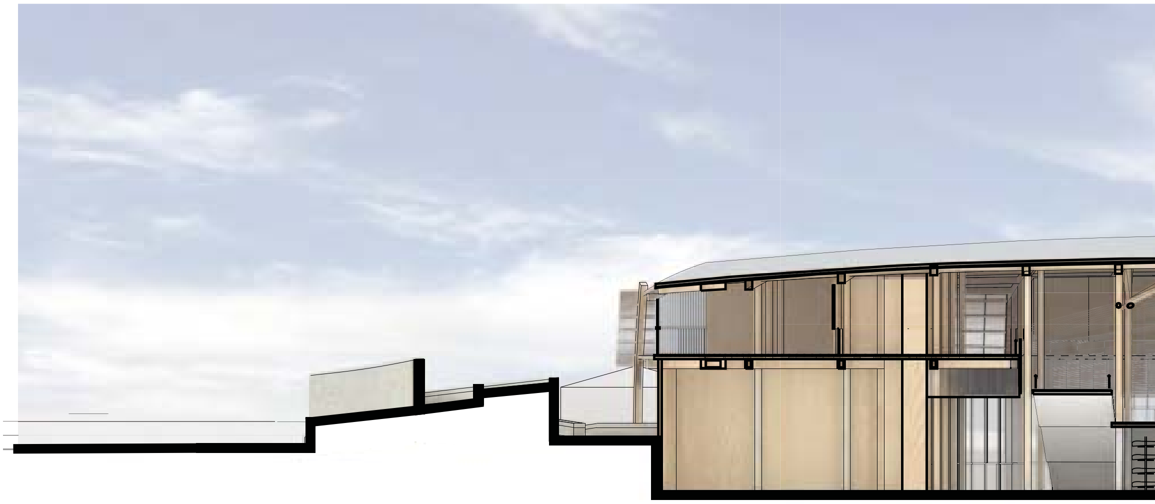


Figure No. 67

South elevation

Figure No. 68

Interior exhibition space render



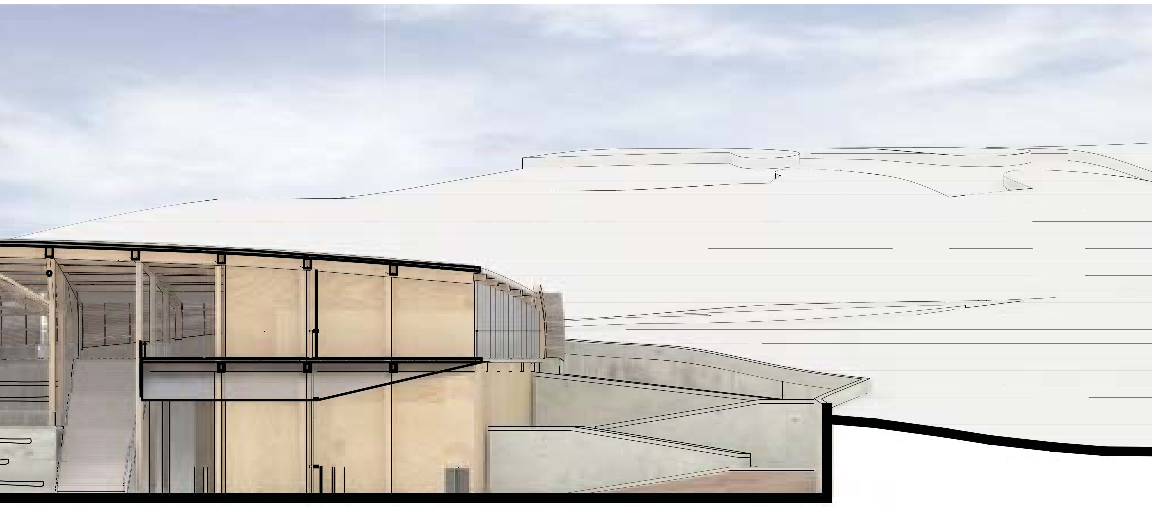


Figure No. 69

Longitudinal Section facing west

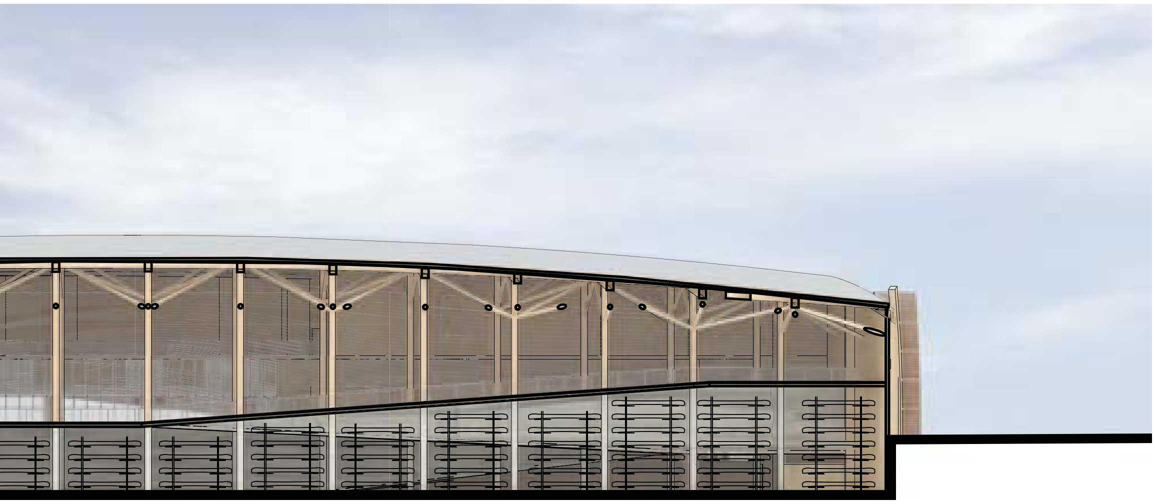
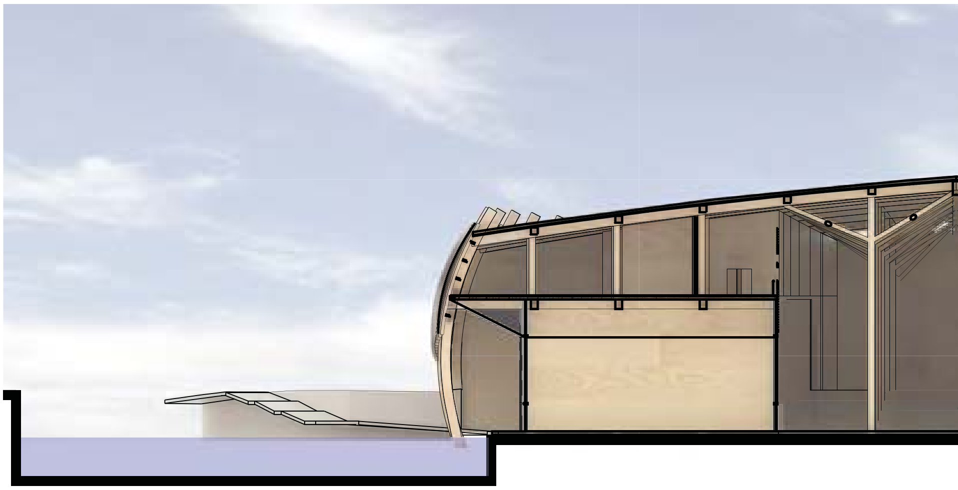


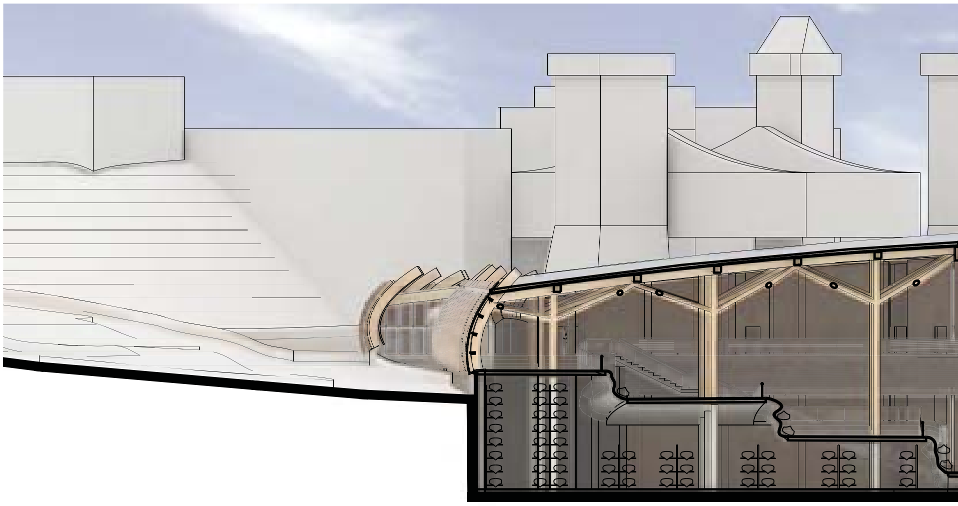
Figure No. 70

Longitudinal Section facing east

Figure No. 71

Interior exhibition space render





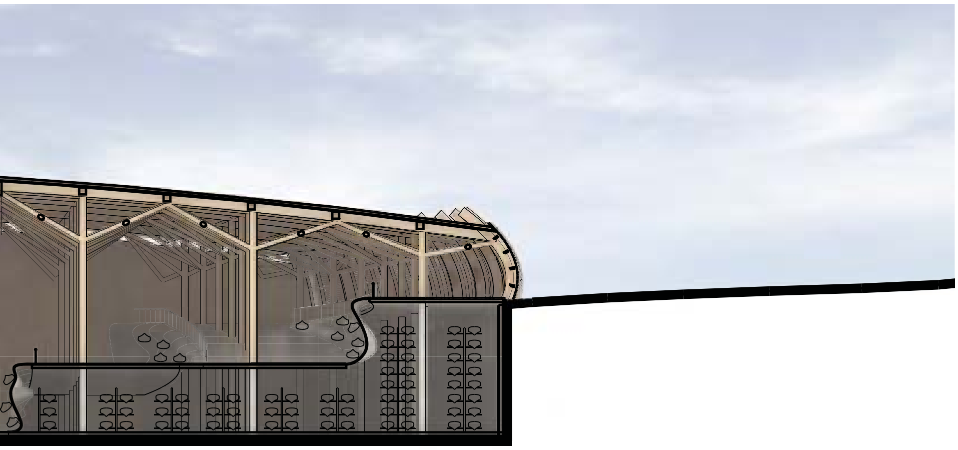


Figure No. 72

Transverse section facing south

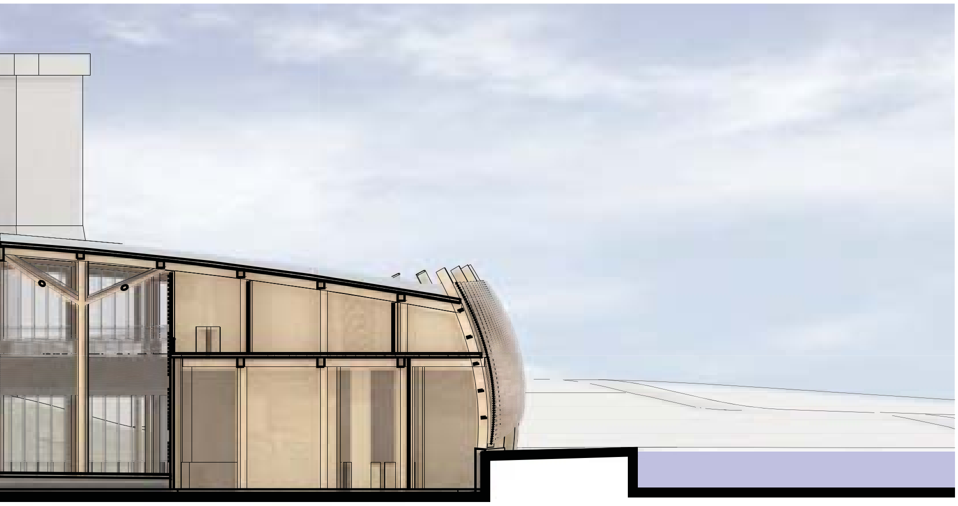


Figure No. 73

Transverse section facing north

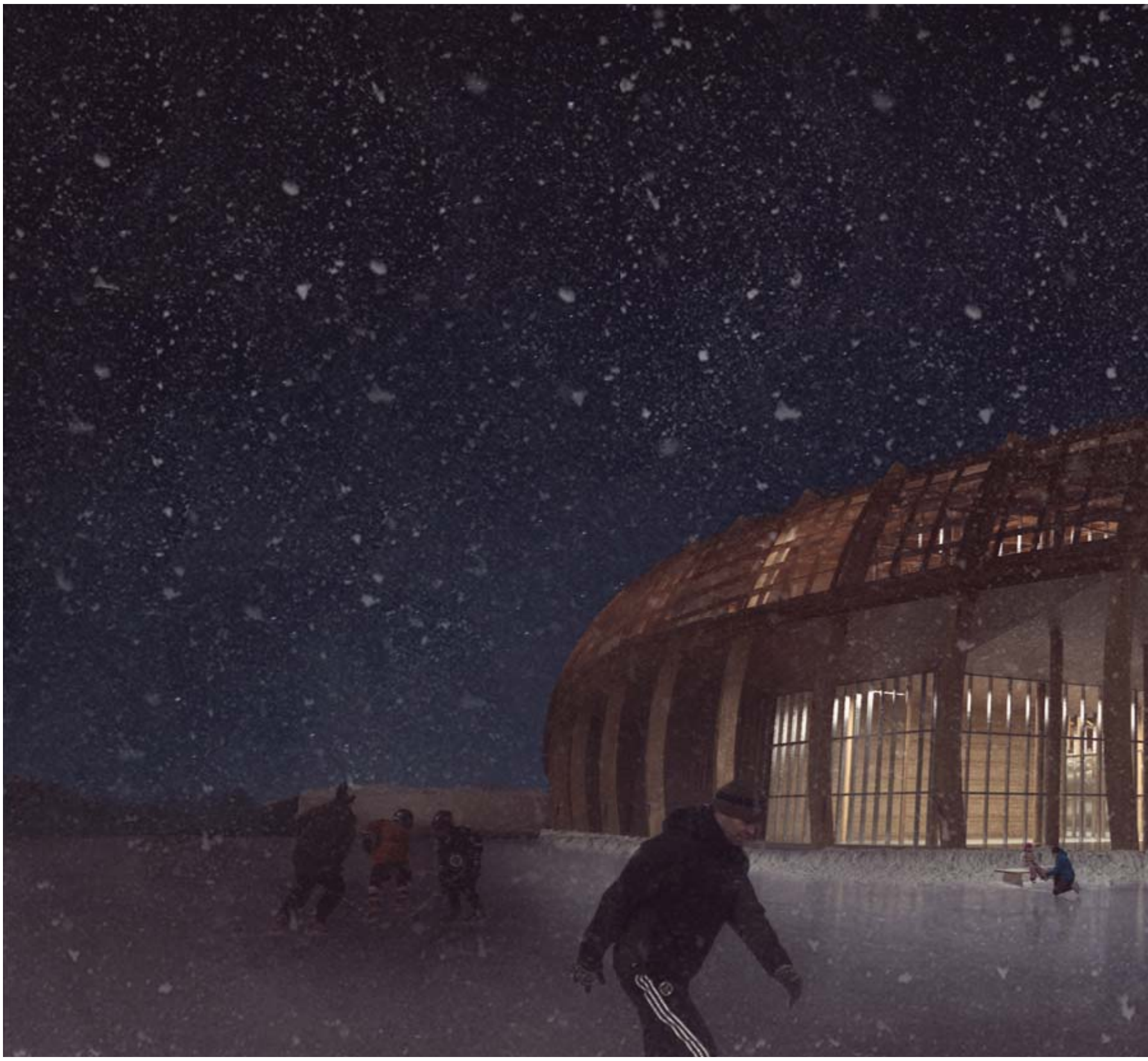


Figure No. 74

Exterior night render

Conclusion 7.0

In his book, "The Death of Drawing", David Ross Scheer applies two meanings to the title. The first premises that drawing is the basis of the craft which has defined the architectural profession for years. The loss of this craft, or at least its passing from daily practice, will bring about profound changes in what it means to be an architect: what skills they possess, what role they play in the creation of buildings, and what defines their profession. Secondly, representational design thinking is based on a system of signs and their referents, with the critical space for imagination. Simulation-based design asserts an identity between the design and the building that forces the imagination to find other spaces to work. This thesis attempts to address the potential digital fabrication methods that can be utilized to manipulate wooden properties, which ultimately have profound implications on the tactile and sensory experiences of space. This can only be achieved through a new understanding of craft and our current potential for mass customization and differentiation which inevitably leads to a new typology. With the combination of traditional woodworking knowledge, in tandem with parametric design softwares, we are able to create a haptic presence, through elaborate surfaces, textures, and details, crafted for the user, inviting all the sense by creating an atmosphere in the space.

New Craft 7.1

Throughout history, the evolution of craftsmanship has been significantly influenced by the tools available at the time. From traditional woodworking with the use of hand tools to the introduction of motorized tools specific to woodworking, there has always been a need for physical and intimate interaction with both the material and the tools. Through this physical hands-on approach, a significant amount of sensitivity towards the material and the tools was gained not by viewing the interaction of the tool and material, but rather through the hand itself. These tools inevitably become an extension of the craftsman's hand where every element of the artifact and process had to pass through their hands.

In our current time, the development and evolution of computer numerically controlled machinery has made evident advancements providing the craftsman with a new extension of the hand. With the use of this new machinery coupled with computational design softwares, architects are able to introduce the knowledge of the craftsman early on in the design process allowing this information to mandate design decisions. This approach leads to the development of honest geometries and eliminates any inconsistencies throughout the lifetime of the design process resulting in streamlined and uninterrupted progression from file to factory. The proposed Canadian Canoe Museum applies this methodology throughout the entire design process initially by working with the desired materials in order to obtain an innate understanding of how the material behaves, and furthermore conducting a series of experiments that were used early on to inform design decisions. Every individual element of the building was designed with a conscious understanding of fabrication techniques and has the potential to be exported for fabrication.

Mass Differentiation 7.2

In today's diminishing shaped economy, producing one-off, custom components is less of an issue in cost than identical mass produced components. This is a result of new tools and advancements in machinery. More importantly, this creates opportunities for architects to distance themselves from using standardized building materials and methods giving them the possibility of having full control over every aspect of the design. In other words, these advancements create a platform for architects to maintain a high level of creativity while still benefiting from the advantages of mass production and ease of assembly. Historically, through the evolution of craftsmanship and building materials, there was a sudden transition from holistically crafted designs to economically driven production during the industrial era. However in our current paradigm, the strengths of both extremes can coexist. The proposed Canadian Canoe Museum utilizes this concept through practically every expressional design strategy from the structure to the facade to the interior finishes.

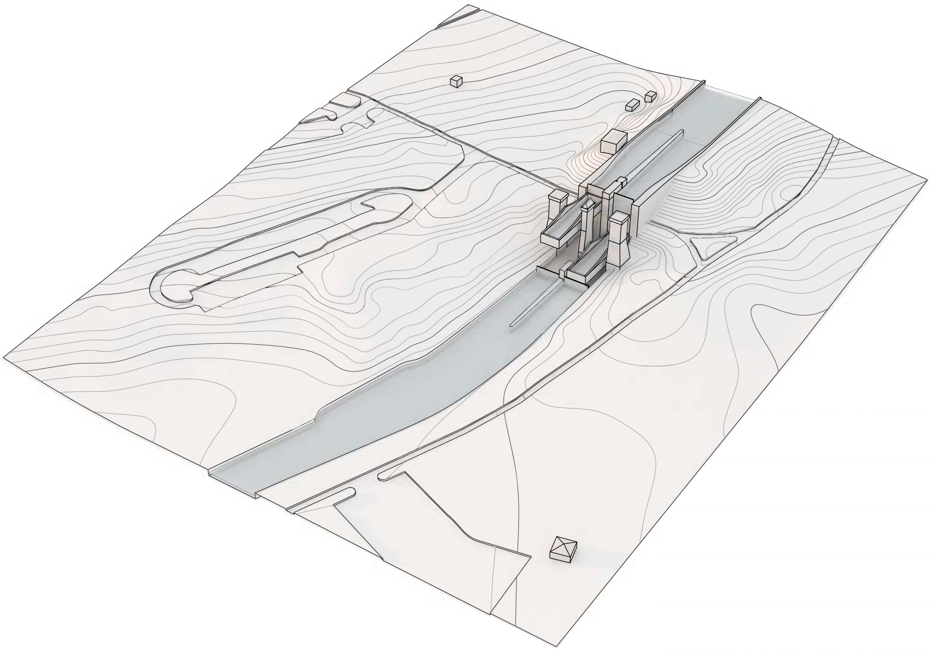
Typology 7.3

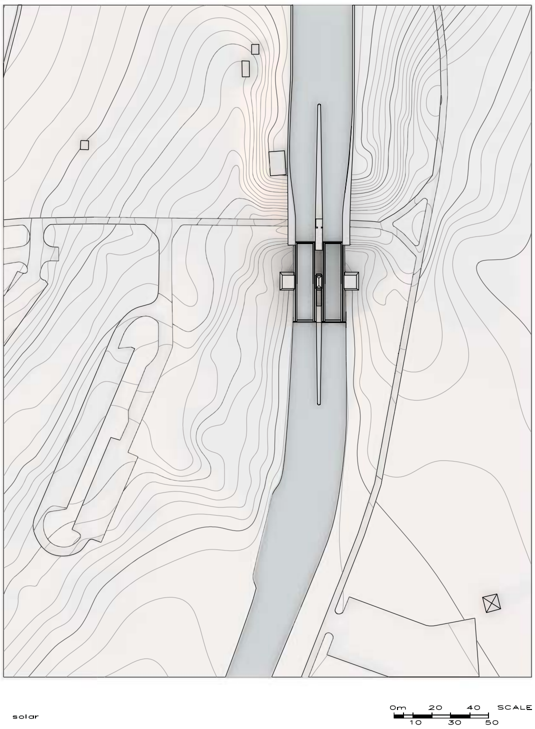
Typology can be defined as a classification according to general type. By effectively utilizing the previously mentioned methods of new craft and the evolution of mass differentiation, this new methodology opens doors for architects to explore and optimize their designs through a material driven design approach that can be made tactile through the understanding of digital fabrication methods. By distancing ourselves from standardized building materials, architects are able to influence their designs by the inherent material properties rather than the dimensional sizes of mass produced elements. Furthermore by specifically experimenting with the material for a desired effect, architects can be confident that they are producing honest designs that stay true to the materials properties and characteristics.

The materials which we us to build with, fabricate with, and enclose us tell a story and have profound implications on our tactile experience within architecture and place. In order to create these spaces and atmospheres which engage our senses, allow a haptic understanding, and ultimately give meaning to place, the choice of materials and tectonic techniques must be of a primary significance. The design of the new Canadian Canoe Museum synthesizes the skillful artisanal craft of woodworking with wood 1.0 and the accuracy and efficiency of Wood 2.0. By using modern digital fabrications and a deep knowledge of the material, we are able to create, with deliberate decision and expertise, a narrative truly unique to the project, both enhancing the identity of chosen species and that of the Canadian Canoe Museum. Only with an in depth knowledge of the different grains, cuts, ageing processes, colours and odors of different species can we permit several new possibilities to manipulate the characteristics and boundaries that wood can achieve. And, by designing the processes of making and fabrication to parallel material decision whilst in the design phase, are we able to create a palpable presence through details and elaborate surfaces and textures, allowing a haptic relationship with, and sensory experience within architecture.

Appendix A

Early Experiments





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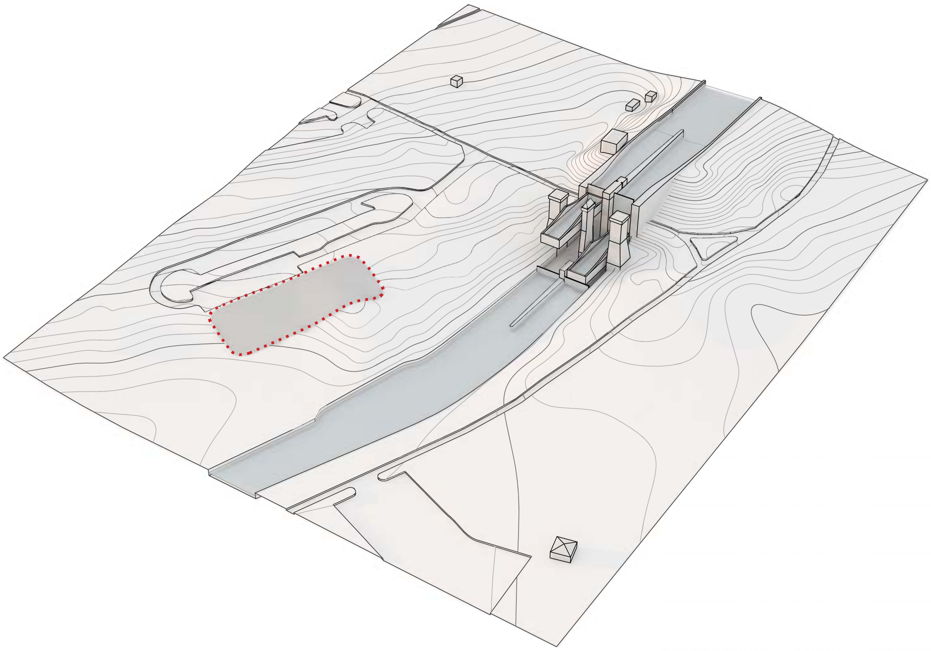

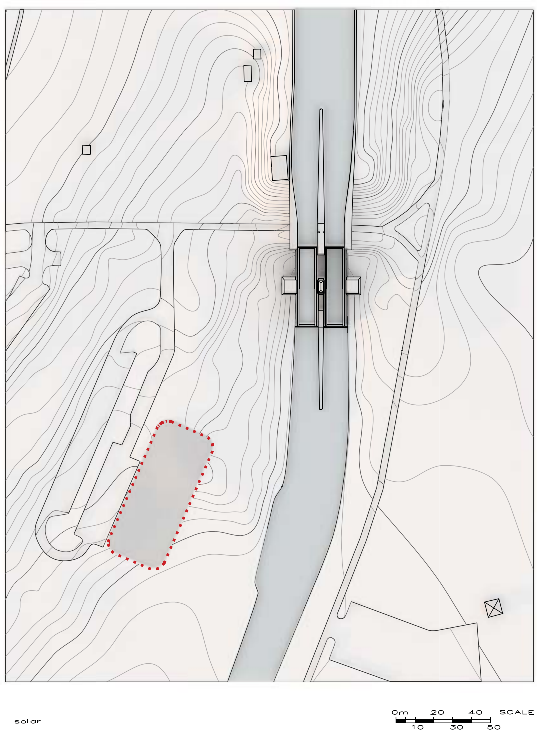

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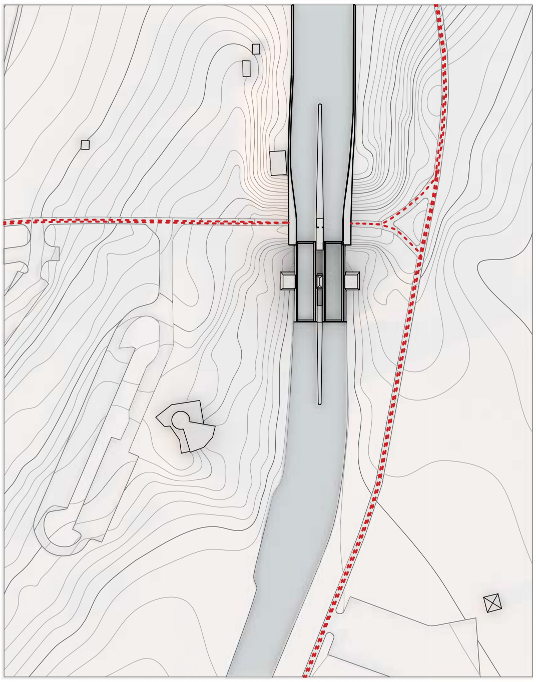

vehicular cirulation

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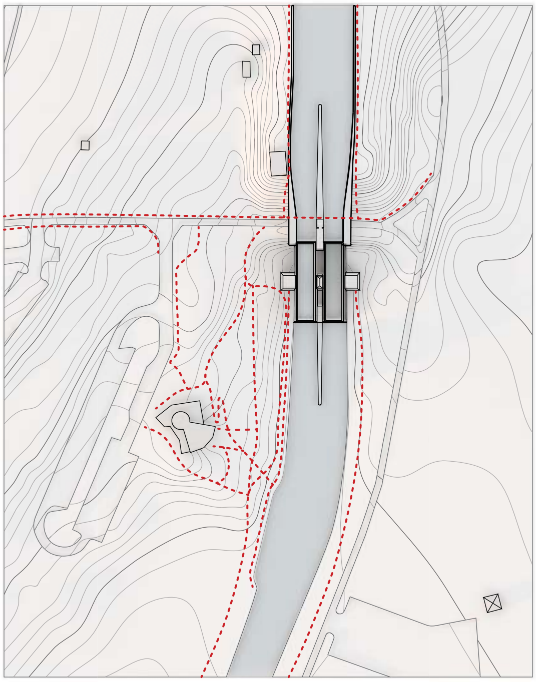

pedestrian circulation

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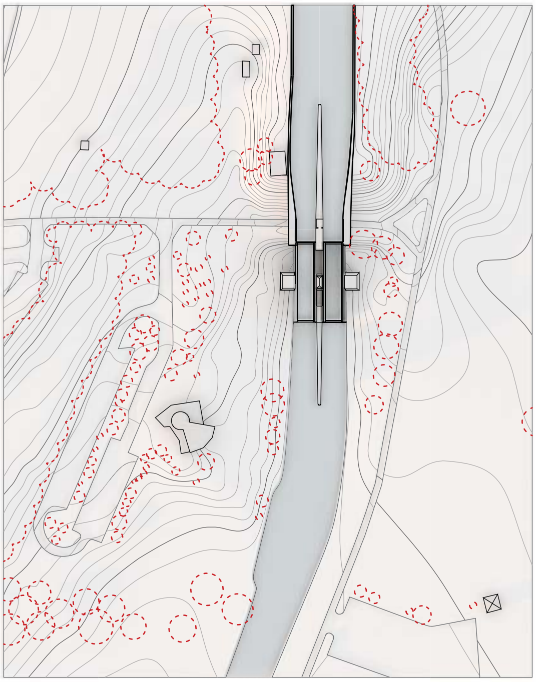

vegitation

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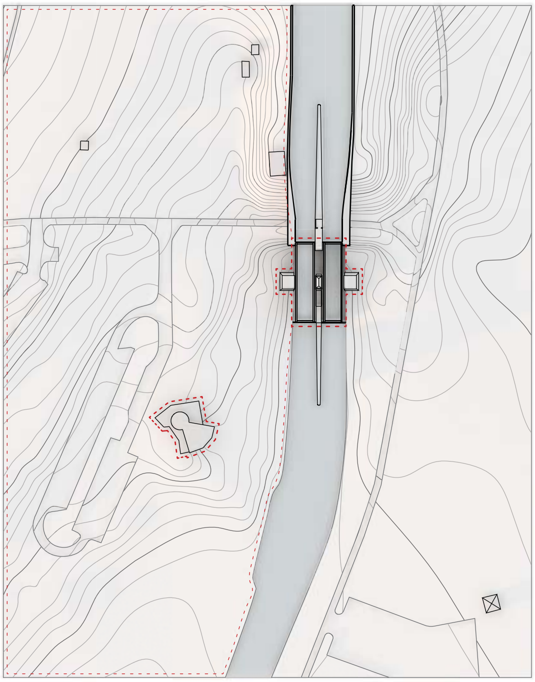

major landmarks

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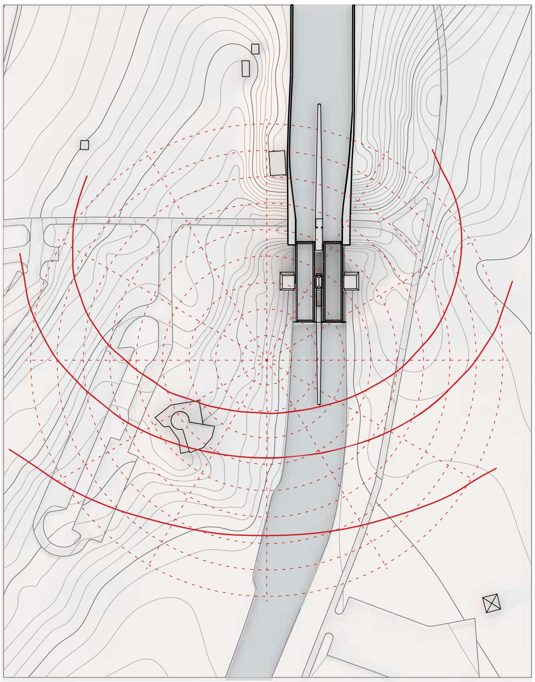
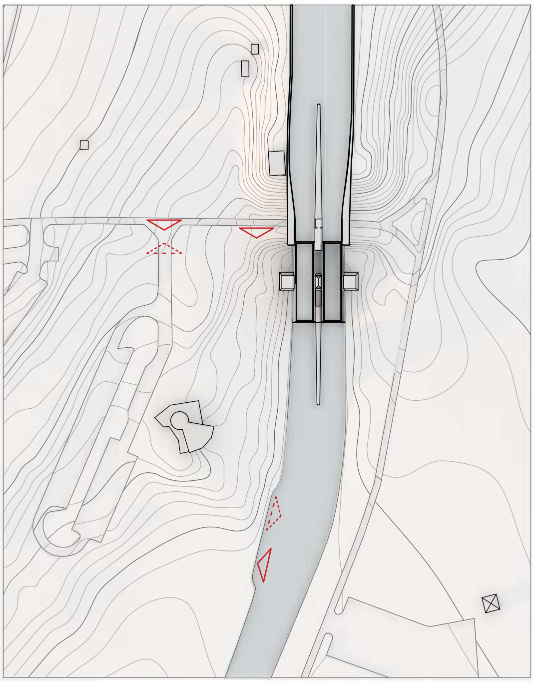


solar



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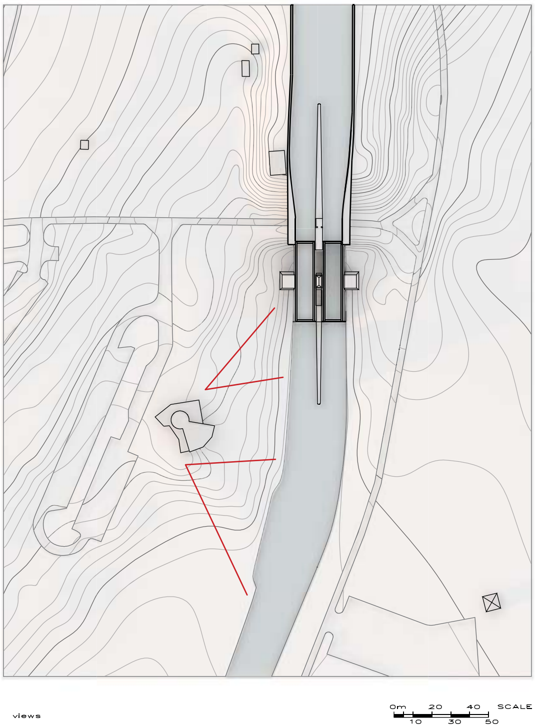

views
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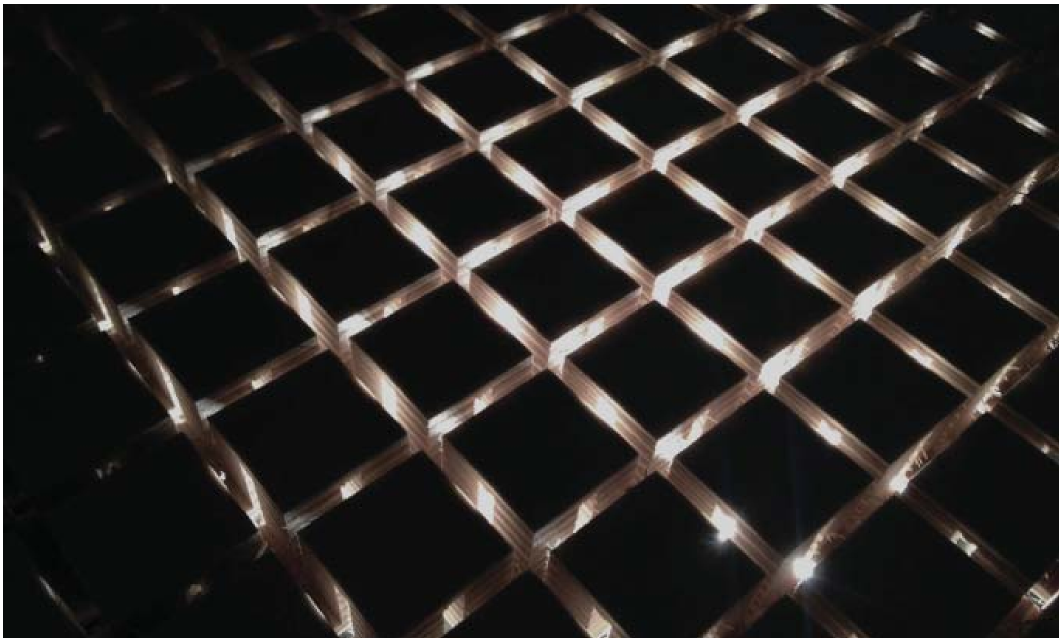
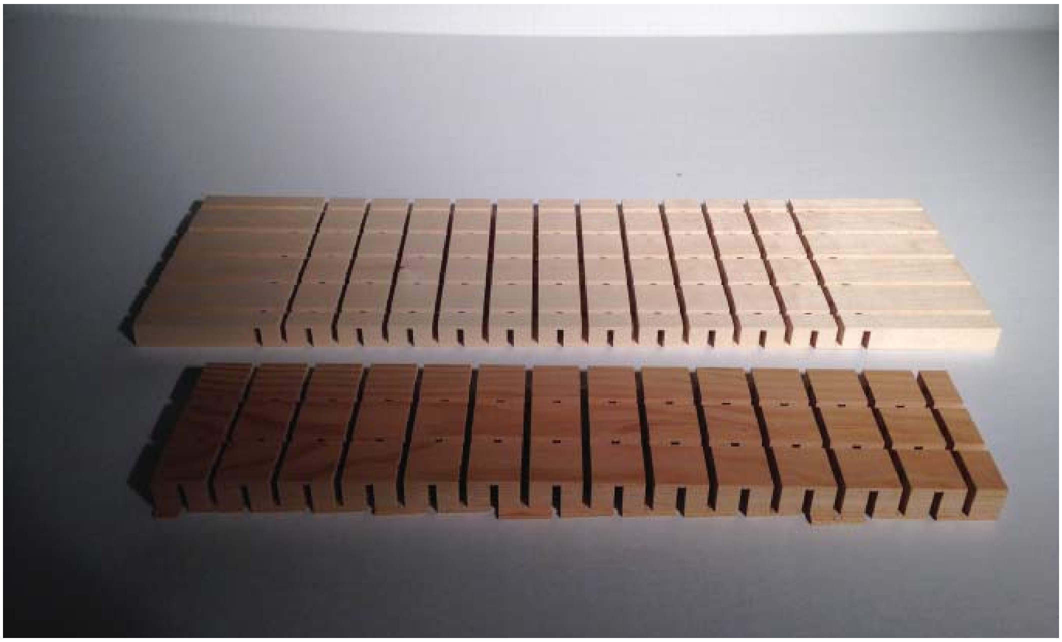
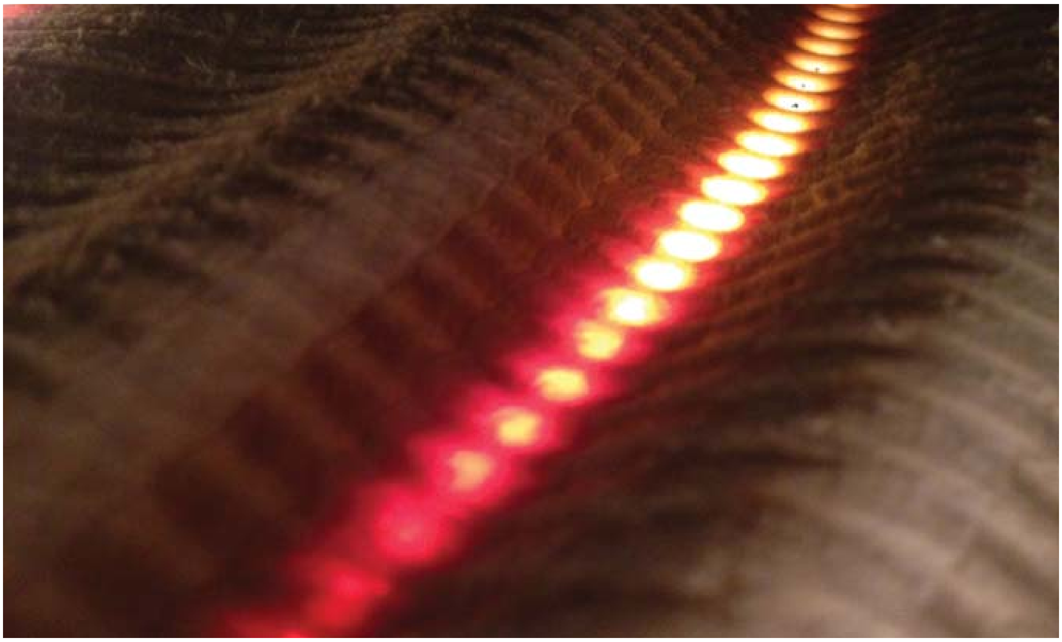
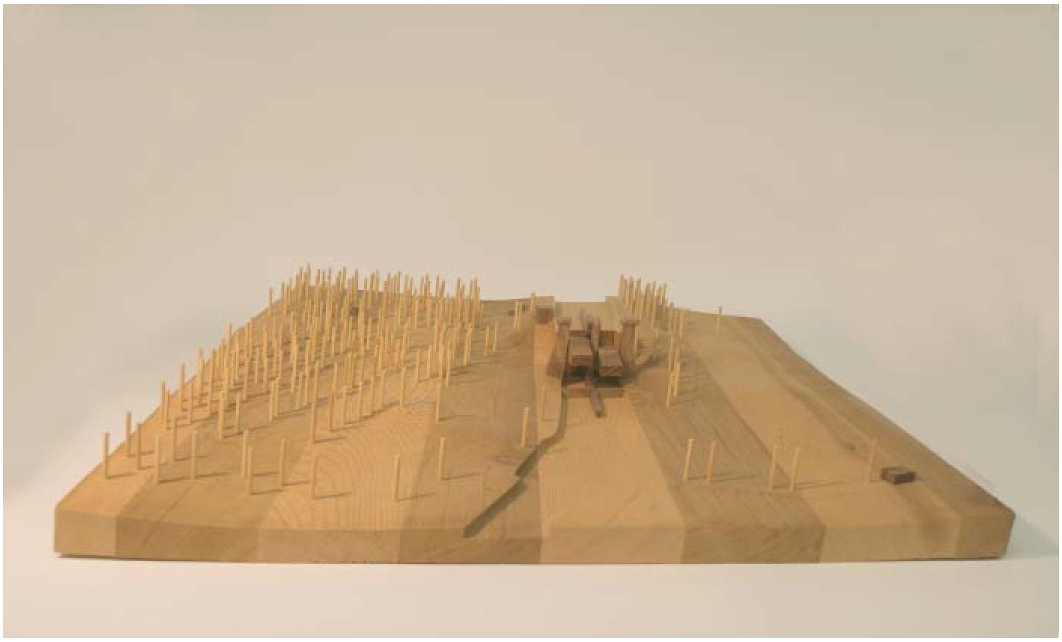


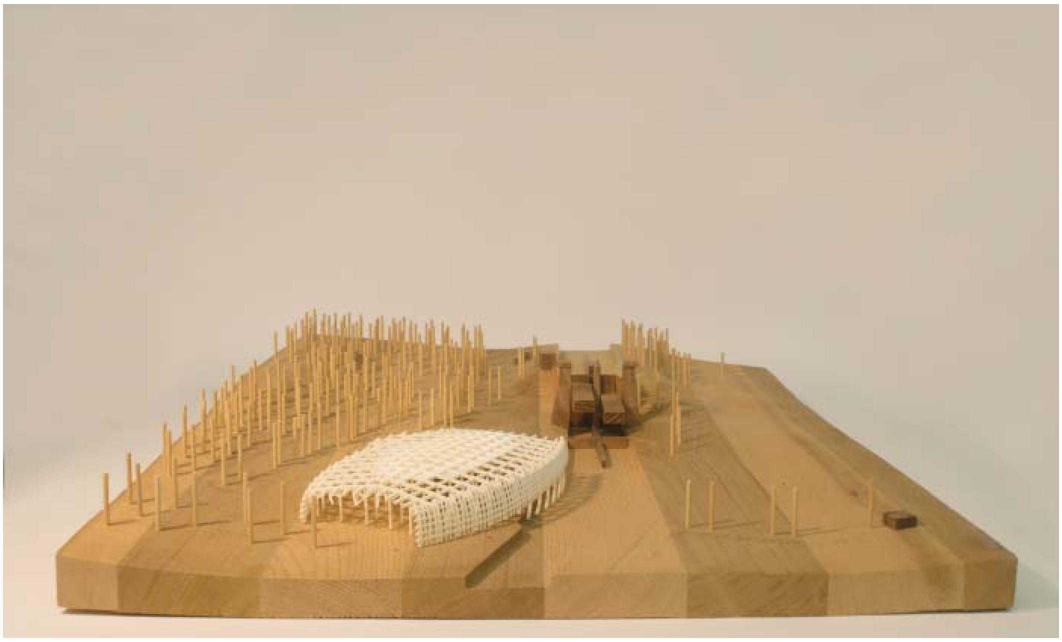


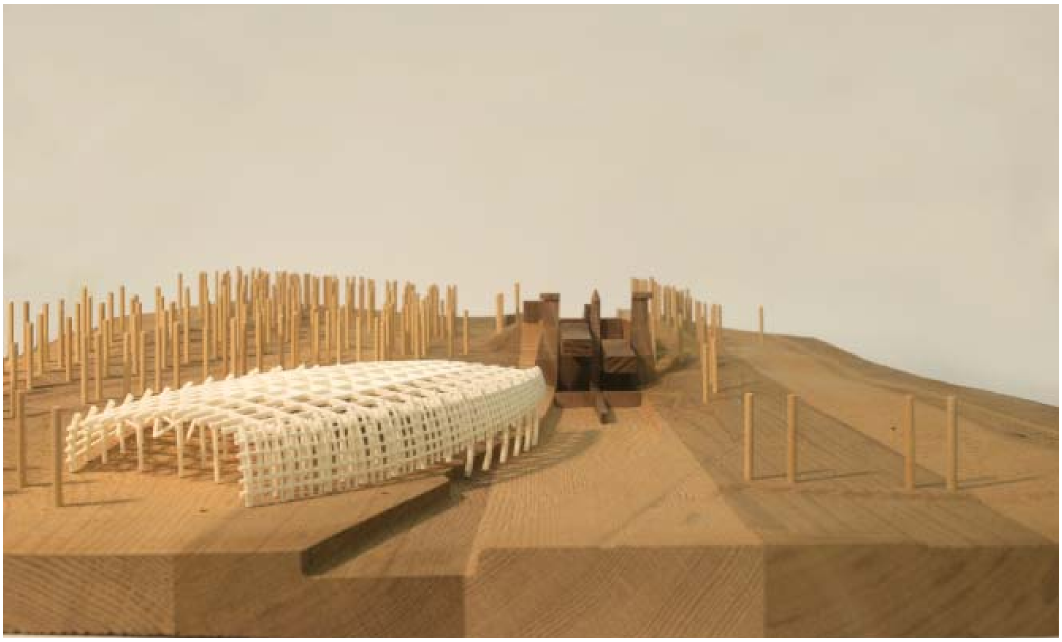


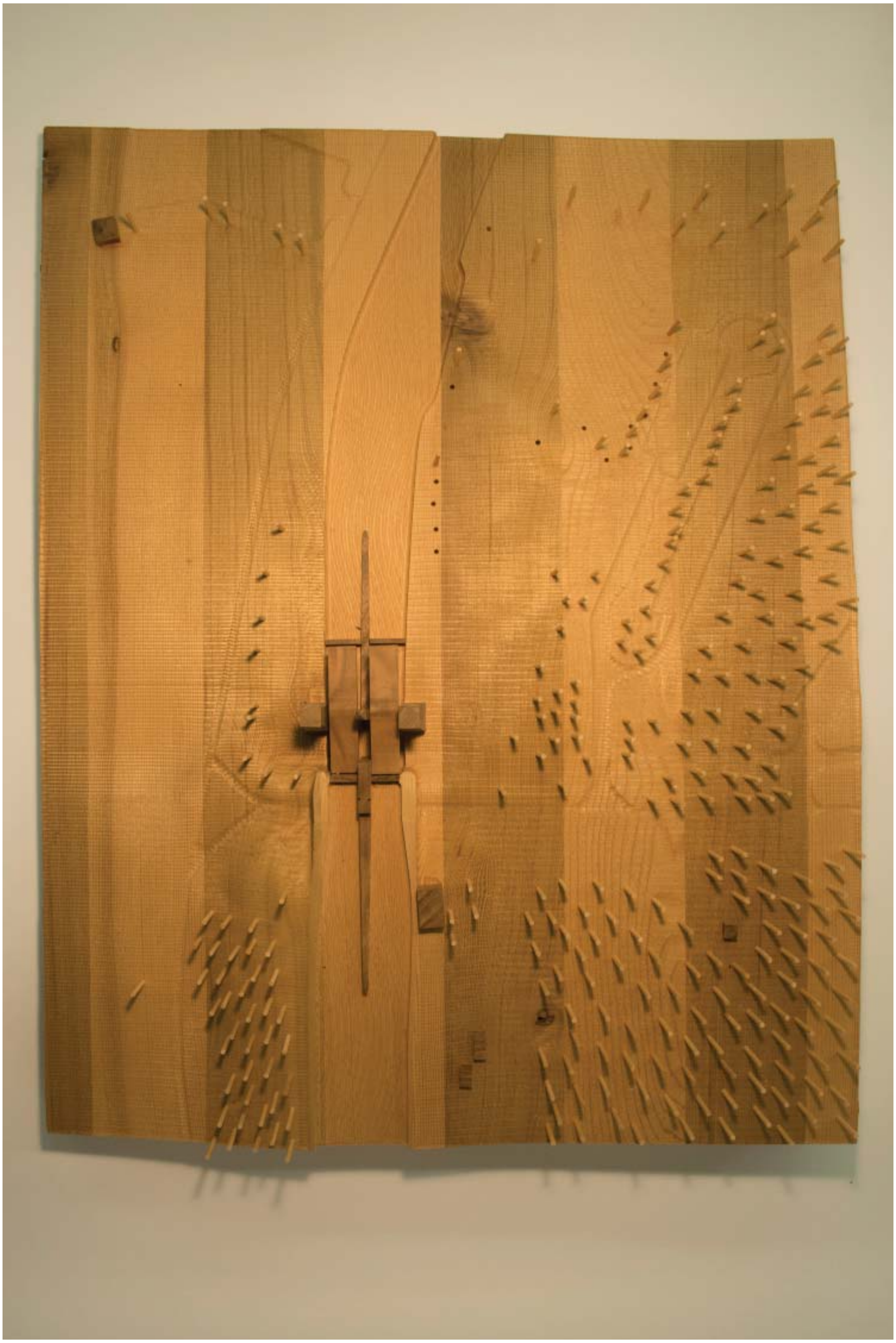
Appendix B

Model Photos









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