# Local Timber to Support Community Growth

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**Keywords:** robotic fabrication, mass timber, prefabrication, onsite construction, sustainable design, rural development

**The research presented in this paper focuses on utilizing local resources and innovative construction methodologies to create novel, high-performance buildings through deployable digital design and fabrication techniques. Customized design and fabrication workflows are developed as a robust strategy to support prosperity and community re-settlement on a remote island. The research prototypes a health and education facility as proof of concept of the proposed digital design and localised fabrication workflow. Located off the coast of British Columbia, Canada, Hope Island is explored as a site to prototype the design and fabrication workflow proposal. The Tlatlasikwala people – original inhabitants of the island – have expressed an interest in re-occupying it after being wrongfully driven off the land[1]. The strategy proposed through this research aims to augment and support them by enabling an economic model that promotes community localism. It integrates cutting-edge technology with local skills and knowledge to ensure efficient materials use through customized robotic fabrication systems. The strategy reduces carbon emissions by engaging with local material properties, minimizing the need to transport a wealth of equipment and materials offshore, and promoting circularity. The design of a health and education facility is used to apply material and fabrication research in a prototypical way. Additionally, it addresses the island requirement for a local clinic and classrooms for children, both essential for the residents to establish a life on the island. The design is developed with programmatic flexibility allowing for expansion and change. However, the focus is on an efficient design to fabrication workflow based on local resources and form-found geometries. This research project directly responds to the principles of the AIA framework for design excellence by engaging with design for equitable communities and design for local resources. The building application fosters human interaction and sociability, while the custom-designed fabrication process ensures that the community is engaged in the construction and takes ownership of the project. Bringing digital fabrication to the remote island up-skills the community in an engaging way that showcases technical innovation augmented with local skills. By deploying a strategy that uses architectural geometry and digital fabrication to capitalize on local natural resources while minimizing materials waste, the island is provided with a process that can efficiently support the growing community socially and materially for years to come.**

## INTRODUCTION

### 1.1 URBAN DEVELOPMENT AND INDUSTRIALIZATION

The ways in which cities are designed and built have not largely changed in centuries. In most cases, a settlement is established due to proximity to a certain local resource or trade route. Industrialization proceeds afterwards, with the mass production of buildings to support the settlement. Industrialization of the 1800s saw the rise of automation and mechanical thinking to make lives better by providing goods and services quicker through mass production that then led to increased consumption[2]. This period was associated with high levels of pollution and unclean cities as a result of the high rate of manufacturing and production from factories. However, these factories were not the sole reason why industrialization proved to be so unsustainable. The processes involved in the manufacturing of building products is optimized for linear, mass production. It results in standardized components which on one hand limit the geometric vocabulary of the industry, require long transportation routes, and need to be designed to stand transportation loads resulting in over-engineered and inefficient components (in their material use and geometry). Additionally, manufacturing occurring outside of the construction site limits the benefits that onsite construction can bring to the local economies (i.e. activating nearby spaces and local shops). Novel digital design and fabrication tools and techniques enable us to create geometries that will perform sustainably, and to move from fabrication techniques focused on mass production to ones focused on mass-customization. Digital fabrication techniques also respond to the material properties, taking advantage of its strengths over its standardization.

### 1.2 TIMBER IN BUILDING CONSTRUCTION

Timber is one of the most traditional building materials and has been used by societies for thousands of years. Contemporary construction practices suggest a growing interest in building with timber, due to its sustainable credentials and novel technologies, at a scale not previously attainable[3]. The solid timber industry continues to grow in across North America, Europe and globally. New production plants are opening for business all over the world, while existing plants are increasing their capacity by extending and opening new sites.

The use of industrial robots to manufacture wooden structures, as a field, has seen a significant amount of research contributions during the last five years from roboticists with creative and architectural backgrounds. Research has been focused on 1) the fabrication of wood panels, wood frames and spatial structures[4] 2) traditional timber joints and differentiated timber joints using both robots and computer numeric controlled (CNC) joinery machines[5].

The compact size of robots and their flexibility allows for onsite manufacturing, which is impossible for joinery computer numerical controlled (CNC) machines. Their potential to feed stacks of the wood material to cutting and milling machines has also been a field explored by architects as means to increase speed, accuracy and streamline digital flows of information over manual CNC production workflows[6]. Additionally, the development of scanning technologies maximizes its potential by having a greater understanding of its intrinsic characteristics as opposed to standardizing it. This reduces wastage to a minimum and strategizes the nesting and positioning of the timber components on the raw material[7]. By observing the cross-sectional qualities of each log of timber, designers are able to determine the age of the wood, as well as understand how many knots and deformities exist in the log which would cause processing issues further down the line. If a log has too many deformities that were only discovered after the tree has already been harvested, then the likelihood of materials wastage becomes significant. The ability for thin laminates to be assembled into a beam that is flexed under pressure is only possible if the wood is of highest grade with minimal to no imperfections.

Glue-laminated timber is a high performance, strong structural building material that can be bent under high pressures to adapt to the needs of the project. Glue-laminated timber consists of numerous layers of wood laminates, with the outermost layers consisting of the strongest wood species whereas the laminates in the core of the beam consist of weaker species (though still of relatively high strength compared to other species)[8]. An understanding of the different timber species and their characteristics allows mixing the laminations to optimize performance, reduce waste, and create customized, high-performance components (Figure 1). These efforts together provide great potential for the robot – scanning technologies and process customization as tools to create novel timber structures that adapt and respond to local and material conditions. The low price, flexibility and transportability of industrial robotic arms allows for ease of transportation and use for on-site / near-site locations as opposed to keeping them confined to a manufacturing facility

## 1.3 REMOTE LOCATIONS: A CASE FOR HOPE ISLAND

Remote locations–such as Hope Island–present a unique set of challenges for prefabricated construction. When the local economy cannot support the production of building materials on-site, then the reliance on transportation from larger centers is necessary. The process to construct a building in a remote area relies on several transportation routes, skilled workers, and industrial factories. Disrupting this system through innovation will bring the construction process to the communities. This engages and upskills the community in novel digital fabrication processes that will allow them to attain the economic benefits of onsite construction whilst allowing them to participate in the digital economy, in-turn bringing prosperity to the region. On-site digital fabrication allows for multiple layers that consider all forms of sustainability (economic, social, and environmental).

The strategy behind the Hope Island Health and Education Facility is to provide an architectural methodology that enables the sustainable construction of local buildings to allow residents to re-settle on their island. Due to the abundance of local timber resources in the area, the local people would traditionally use wood for not only building construction, but also the fabrication of canoes, pieces of art, and totem poles to be displayed in front of residential properties. These structures would be built using species such as western hemlock and lodgepole pine[9]. In some cases, such as in canoe fabrication, the wood would be steam bent into shape to accommodate the hull of the boat using local skilled labourers. Therefore, wood craft became a significant element of the local art and culture on Hope Island. The traditional construction methodology provided inspiration for the fabrication strategy for the construction of the Hope Island Health and Education Facility. By utilizing a well-known local resource while processing it in a modern way, the local culture is able to persist while celebrating the sustainability of the structures built for the residents.

## 1.4 ROBOTIC FABRICATION PROPOSAL

Advances in robot arm technology have expanded the possibilities of different use cases, from precise microchip assembly to the fabrication of entire buildings. Robot arms, such as those manufactured by ABB and KUKA have been utilized to assist humans with the manufacturing process of materials or elements of a building. The benefits of such a system include accuracy, efficiency, safety, and costs of construction, among even others[10]. In the use case of processing and fabrication for timber components, robot arms can switch their end-effector to carry out multiple tasks along the fabrication process without the need for multiple robot arms or the linear workflow of the industrialised factory. On this scenario the robot arm can process lumber, cut it down to dimensional laminations and even glue, clamp, and flex into beams. Because all processes are able to occur on-site, robot arms can also use scanning technologies

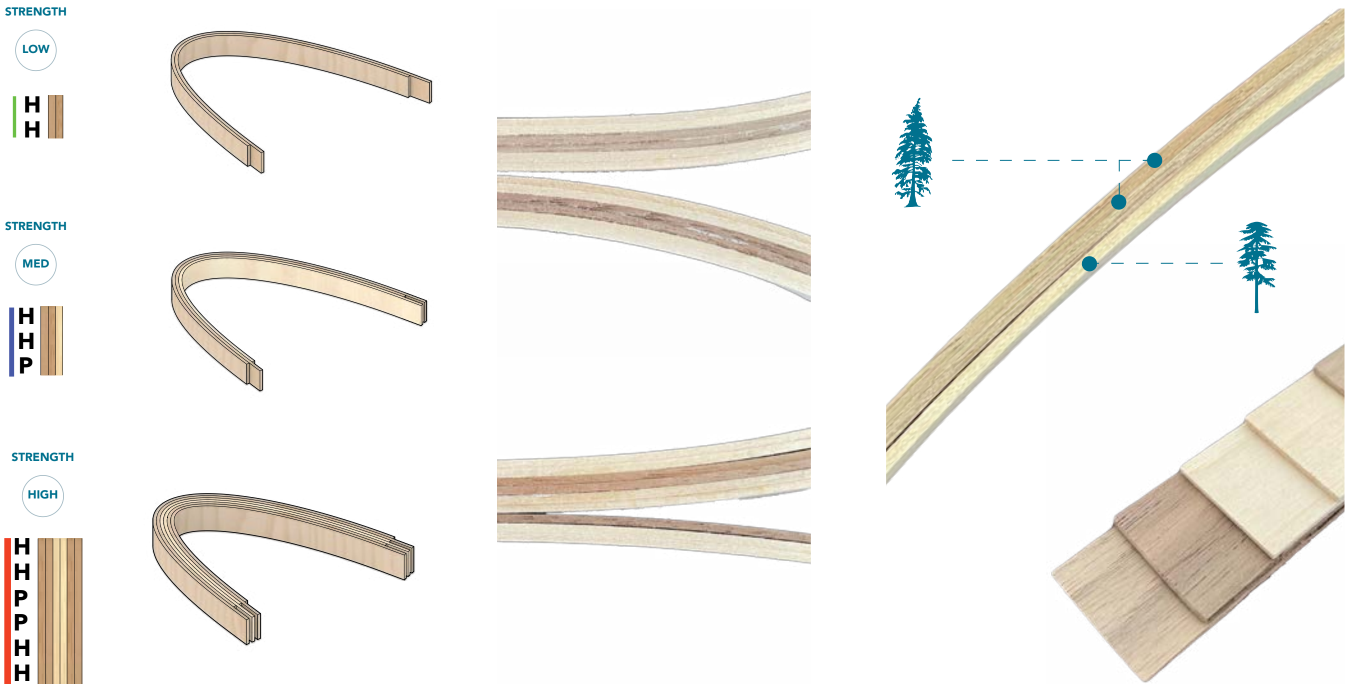

Figure 1. Strengths of laminates based on wood species (left), and physical studies (right). "H" denotes a layer of hemlock, "P" denotes a layer of pine. Jonathan Monfries.

in order to instantly determine the quality of the wood and how many dimensional pieces would come from that log of timber. This way, only the absolute minimum amount of timber material is utilized, cutting down on wastage.

These robotic fabrication facilities are also able to be deployed on-site through several methods of transportation. The factory in a box (FIAB) concept represents a strategy where two six-axis robot arms and associated facility space is contained within 20' shipping containers[11]. This way, the Robolab facility (or modular parts of it) can be shipped to site and opened up to form the actual fabrication facility that would be processing the materials and building components. This significantly reduces the cost and environmental effects of transporting materials and building components across land or sea and back to site for installation. Additionally, the robotic fabrication facility can be shipped using existing ferry and transportation routes in the area. It can be located such that the construction site can be a stopping point for shipping routes that would drop off the shipping containers holding the robotic fabrication system. This use of existing transportation routes to transport the machines once, rather than continuously transport the finished material, further supports the sustainability of the fabrication strategy.

## 2.0 PROTOTYPICAL CASE STUDY: HOPE ISLAND HEALTH AND EDUCATION FACILITY

A design to fabrication system based on using local resources and a series of customized robotic labs on a box (FIABs) that when deployed can work together was explored and prototyped. The workflow starts by defining a system for harvesting timber, steps to process the timber, followed by the fabrication of a wooden canopy that can be used in multi-functional community buildings. The process is outlined below as a multi-step approach from raw material to finished product using on-site resources, labour and tools that can digitize and upskill the community, allowing them to participate in the digital economy and bringing prosperity to the region in the form of new tools, skills, and economic development. This research proposes certain species and processes for the robotic fabrication system to operate. However, the methodology could be adapted to different community needs and different local resources. The use of a flexible machine such as the industrial robotic arm allows for a variety of tasks maximizing adaptation to resources and fabrication techniques with minimal cost

## 2.1 THE SITE: HOPE ISLAND

Hope Island is located near the northwest corner of Vancouver Island in British Columbia, Canada. The island is about a 3-hour ferry ride from the nearest town on shore, Port Hardy. A shipping route connects Port Hardy to Bella Bella, several hours north up the coast of British Columbia. A variety of goods are shipped along this route using ferry transportation, and the route itself is approximately 24 km east of Hope Island. Therefore, a slight deviation from the typical shipping route would enable the transport of micro-factory materials as a one-time delivery.

The robot arms, along with their end effectors and diverse fabrication machines required for the fabrication workflow (mitre saw, assembly tables) are first analysed. Different setups were tested based on the requirements of the geometry until

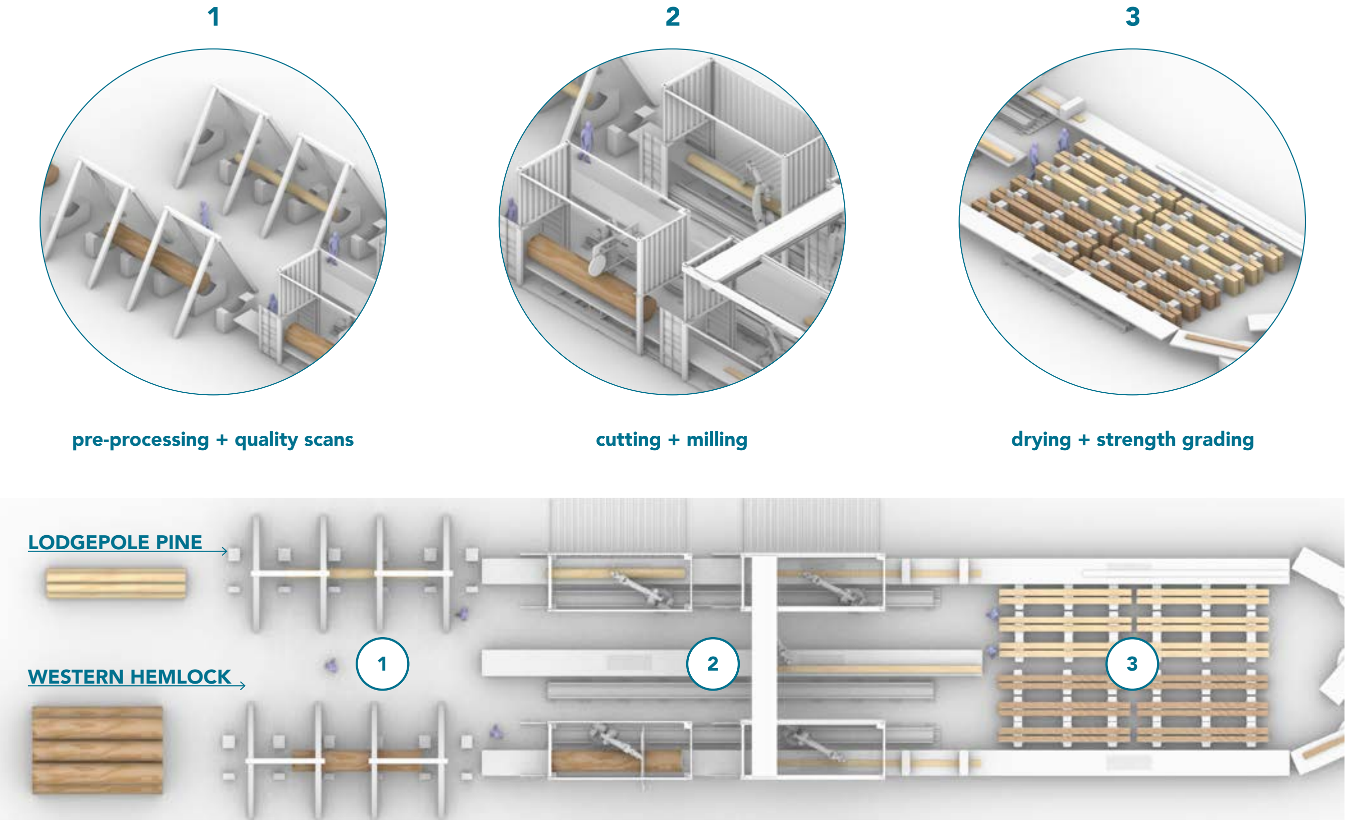

Figure 2. Robotic fabrication micro-facility showing initial steps to process and cut timber logs. Jonathan Monfries.

an efficient distribution was found which encapsulates all the steps required for the efficient processing of the local raw timber. The machines are then packed into shipping containers from which they will operate. The shipping containers containing the entire micro-factory system can then be delivered to Port Hardy, where they will be loaded onto a ferry that delivers the containers to Hope Island. On arrival, the shipping containers can be opened flat leaving only the structure of the container with the robot arms stored inside. The micro-factory can then be set up by locating shipping containers next to each other following the required fabrication sequence. The processes can be re-arranged to accommodate a variety of building processes based on with the same construction material (local timber species) and methodology.

## 2.2 TIMBER IDENTIFICATION AND HARVEST

Essential to the fabrication system is working with local skilled labourers to harvest trees in sustainably managed forests. Timber fabrication could not exist without a detailed analysis and understanding of different wood species and their properties. Based on Kwakiutl history and qualities of the wood, Western Hemlock and Lodgepole Pine were considered the most ideal species to fabricate the customized, high-performance glue-laminated beams. A material understanding of timber is necessary to determine the best wood species for this building application. An understanding of the orthotropic axes of wood – longitudinal, radial, and tangential – can enable us to determine how the wood responds to force in multiple directions[12]. Other considerations include the modulus of rupture and crush strength of the species. Western Hemlock has a modulus of rupture of 11,300 lb.ft/in$^2$, where as Lodgepole Pine has a lower value of 9,400 lb.ft/in$^2$. Crush strength is higher in Western Hemlock as well, with a strength rating of 7,200 lb.ft/in$^2$ compared to the pine at 5,370 lb.ft/in$^2$. Both timber species demonstrate significant strength in the orthotropic axes of wood, however Western Hemlock is the stronger material that also comes in larger trunk diameters (1.0-1.5 m compared to 0.3-0.6 m for the Lodgepole Pine). The bend strength is strongest for Western Hemlock as well, and moderate for Lodgepole Pine. These characteristics have implications for how the wood species are layered in laminates before being bent into curved beams

## 2.3 WOOD PROCESSING

The processing between the two species is separate due to the differences in wood composition and quality (Figure 2). The logs are 3D scanned using photogrammetry so that an inventory of logs can be stored in the system and the cut lines can be pre-determined based on any imperfections in the wood. Due to the need for laminates to be without any imperfections, the cut lines can take into account the longest sections of the log that is without knots or other imperfections that would lead to material failure later in the assembly process even prior to cutting.

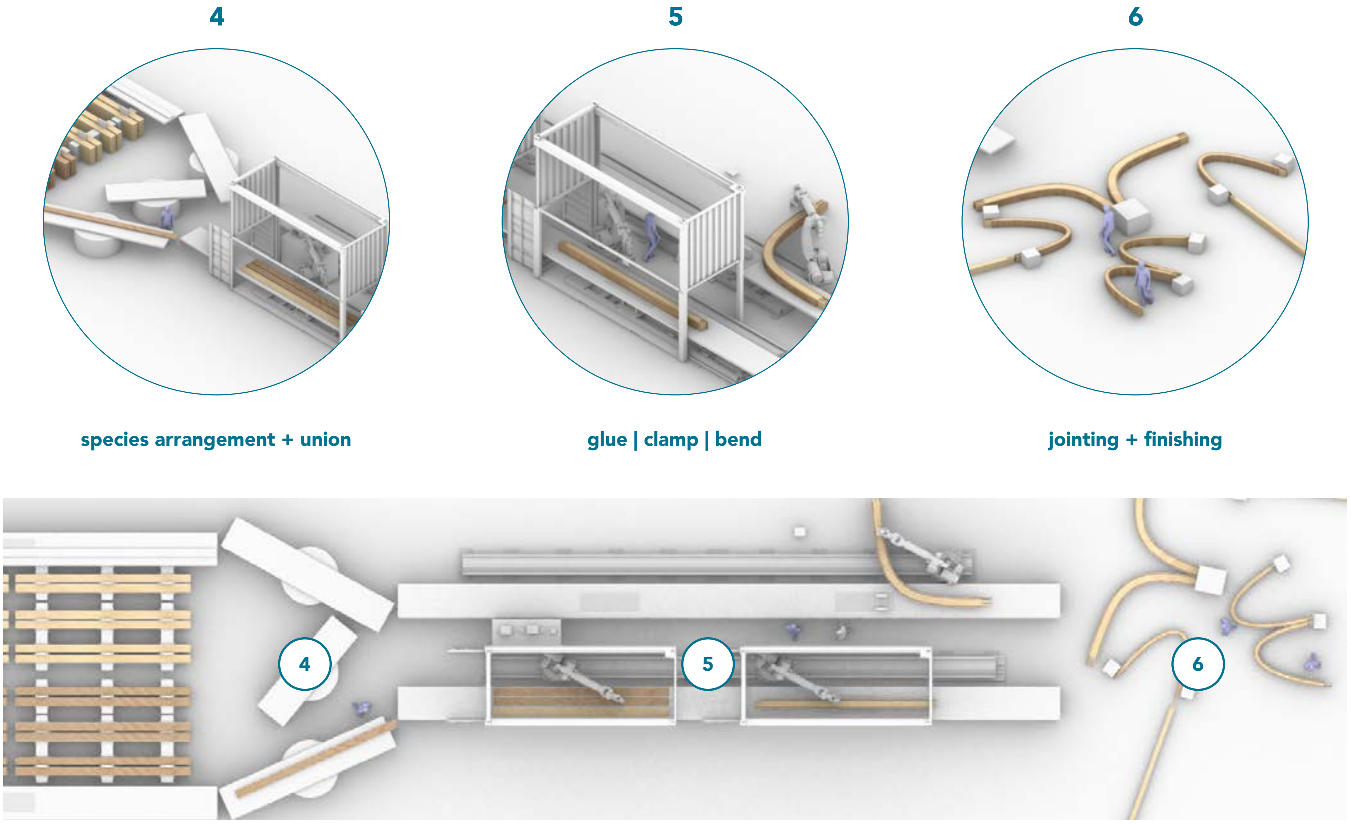

Figure 3. Robotic fabrication micro-facility showing final steps to combine wood laminations and flex into beams. Jonathan Monfries.

The robot arms are then able to utilize the cut lines taken from the photogrammetry scans in the previous step, and precisely cut the wood into dimensional lumber. The robot arms change their end-effector for a saw blade for this part of the process. Once a log is cut into dimensional lumber, the wood can move down the line, outside of the shipping container. This provides a space for the dimensional lumber to be dried outside to the required strength and humidity level. Under wet conditions another shipping container can be used as shelter for the strength grading and drying process. It is at this point that the lumber is milled down to laminations that can be assembled together.

## 2.3 GLUE-LAMINATED BEAM ASSEMBLY

Once the laminations from the different species have been dried, arranged and evaluated, the next step of glue-laminated beam assembly starts (Figure 3). For this case study, there is a customized demand for glue-laminated beams of varying strengths based on their location within a greater network of structural beams. Therefore, the required type and number of laminates are organized next to each other based on the structural requirements of the beam prior to being glued. A robot arm is then able to precisely apply the proper amount of glue necessary for each wood lamination. Once glued, the robot arm changes its end-effector to a clamp so that it can pick up one end of the assembly of laminates and begin to flex the beam under high pressure based on the specified radii for the structural beam that is required. This position is held in place and manual clamps are applied. The beam is then lowered to a staging area for drying and sanding. Finally, the beam is jointed at the ends so that it can be connected to the greater structural mesh of mass timber beams (Figure 4). This represents the fabrication process of one bent glue-laminated beam.

## 2.4 KIT OF PARTS AND STRUCTURE CONCEPTUALIZATION

The Hope Island Health and Educational Facility is conceptualized as a structure with an undulating canopy that spans two essential institutional community facilities. The canopy's undulations are a response to the use and occupancy requirements. Additionally, they work towards mitigating the effects of adverse coastal weather conditions. The structural network of curved beams consists of a primary and secondary dual-mesh resulting in a cellular-like arrangement of timber that reveals the construction methodology and beauty of the local resource. Each beam that is constructed is therefore required to be aggregated into nodes that are identified throughout the canopy structure. Once these nodes are fabricated, they are joined by simple glue-laminated beams in order to form the full canopy (Figure 4).

The kit of parts methodology is imperative for this system to operate efficiently. By being able to assemble beams first, followed by nodes, and then connections between nodes, the step-by-step process is able to successfully fabricate a building structure with a high level of accuracy and efficiency. This differs

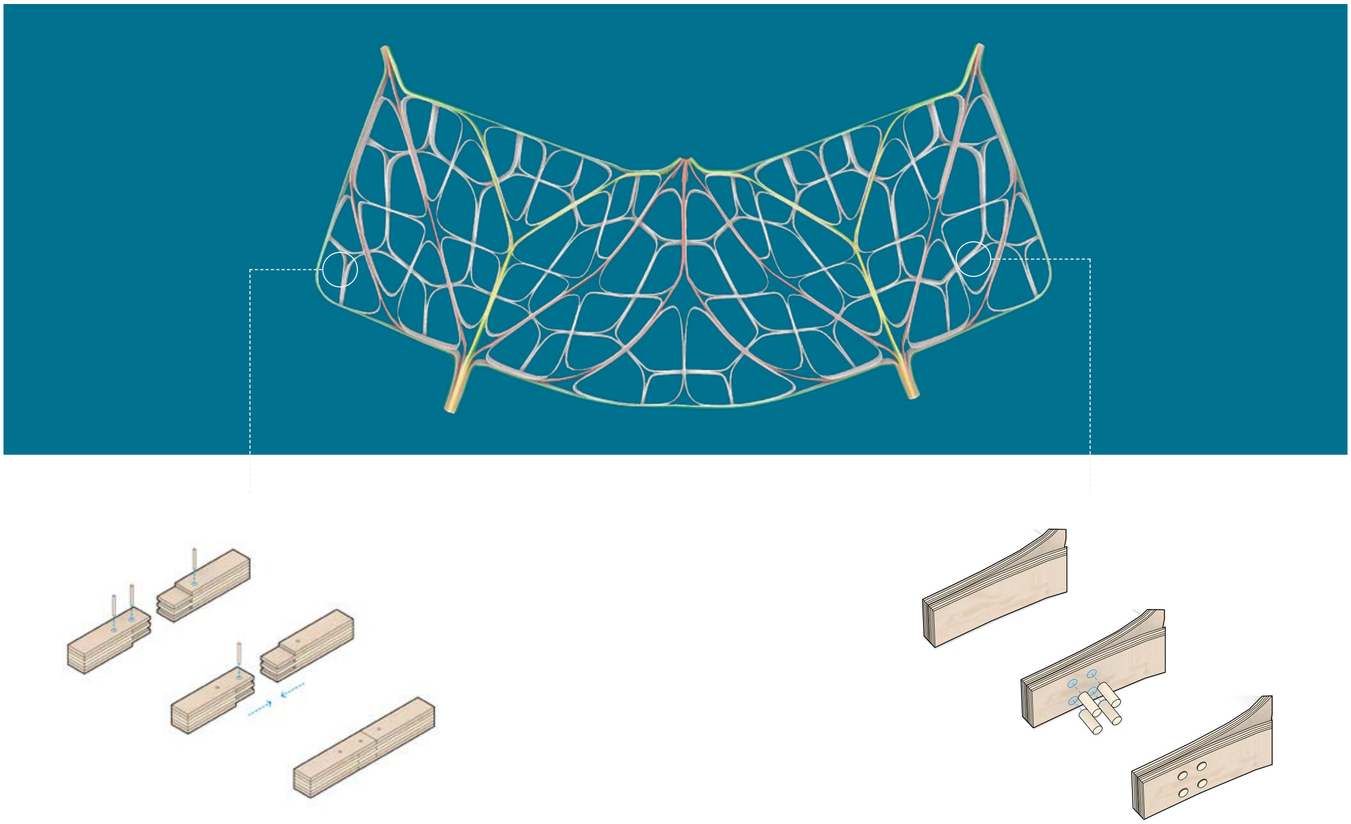

Figure 4. The dual-mesh structural aggregation of beams is presented with colour coding based on required strength. Joinery between nodes use finger joints with a dowel system to prevent bounce-back. Jonathan Monfries.

from traditional construction practices in that the micro-factory fabrication system enables a high level of engagement with the local residents by dividing the structure in pieces that can each be individually assembled. This also ensures materials waste is minimized by efficiently analyzing the raw material at the source. Once all beams and structural nodes are fabricated, the parts can then be assembled using simple joinery systems that local skilled labourers are familiar with. This not only engages the local workforce, but also supports their involvement through the entire fabrication process because the micro-factory is operating entirely on-site.

## 3.0 HOPE ISLAND HEALTH AND EDUCATION FACILITY DESIGN PROTOTYPE

The Hope Island Health and Education Facility is designed as a proof of concept that utilizes the micro-factory robotic fabrication system described above. The design to fabrication workflow is prototyped to ensure coherence and feedback between the different components. The raw material informs the architectural geometry and the configuration of the micro-factory.

### 3.1 AGGREGATED STRUCTURE

The facility's structure itself is the combination of two structural meshes that support an overarching canopy. The primary or upper mesh is formed based on the structural demands of the canopy exterior. In order to provide a second layer of support, the center points of the primary structure are taken to interpolate a secondary dual mesh structure. This not only ensures the canopy is appropriately supported, but also provides an aesthetically pleasing reveal of how the structural system is composed of local resources. The local pine and hemlock species have material properties that make them suitable for on-site ad hoc lamination into beams that also provide aesthetic value in their contrasting textures. You are able to see the different colours and textures of wood species used in the glue-laminated structure, as well as the areas of greater thickness versus areas of lesser thickness creating an intricate and appealing structure.

### 3.2 CANOPY EXTERIOR SHELL

The micro-factory is a fully customizable unit so that the assembly line can be reconfigured to process the different species of wood and fabricate different building materials. In this case study, the canopy exterior would be clad in Western Red Cedar shakes as roofing tiles due to their resistance to rotting and protection for high levels of precipitation. Therefore, the processing of the logs at the beginning of the facility would transition to the use of cedar (Figure 5).

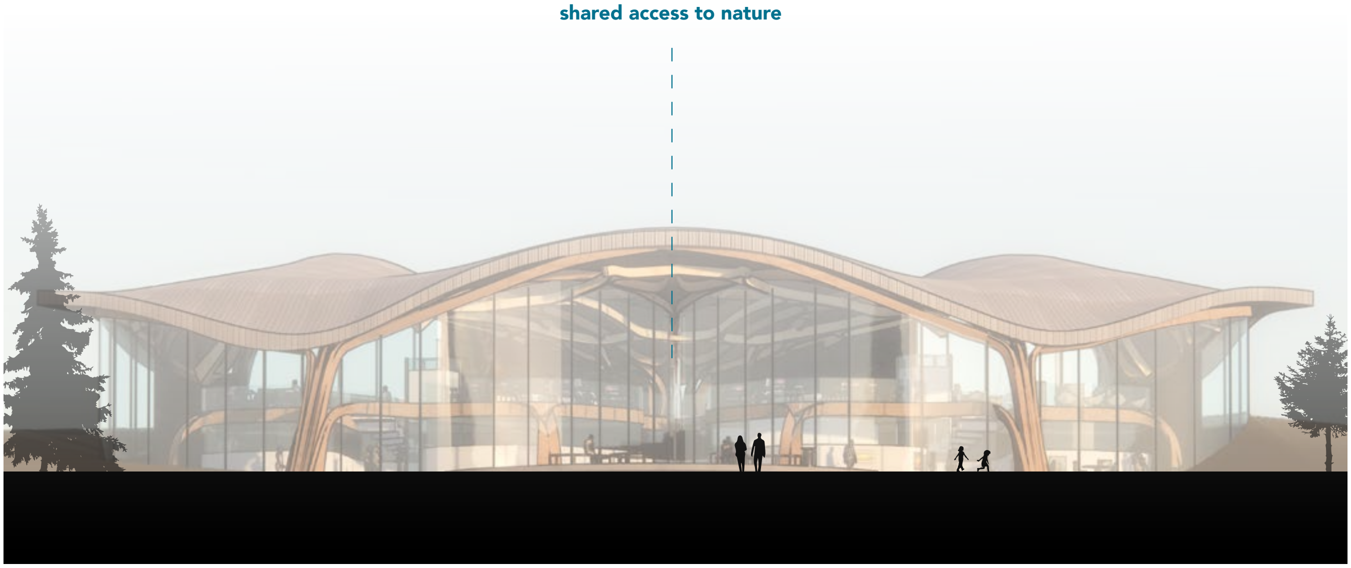

Figure 5. The dual-mesh structural aggregation of beams is presented with colour coding based on required strength. Joinery between nodes use finger joints with a dowel system to prevent bounce-back. Jonathan Monfries.

The facility seeks to become a landmark destination for island residents. The design develops programmatic flexibility allowing for expansion and change. The building adapts as the community grows while embracing a connection to the landscape. Multiple vistas looking to the ocean give a sense of porosity to the building. Residents should feel comfortable accessing the local facility, whether in medical need or simply for social interaction and wellbeing. An outdoor courtyard space separates the education and health program, providing the crucial connection to the nature that the community embraces whilst supporting human interaction. The resultant geometry is a fluid, curved timber shell structure optimized for digital fabrication and efficient material use while existing contextually within the oceanfront landscape.

## 4.0 CONCLUSION

This research project uses local resources and novel digital design and fabrication technologies as tools to help rebuild and upskill a community. A robotic fabrication micro-facility is designed and prototyped to enable community localism and digitization. The robotic fabrication micro-facility enables remote communities to process their own local timber and create sustainable, efficient, and unique timber structures without the need of prefabrication and lengthy transportation routes. While this strategy is proposed for a remote island in Canada, it can be applied to numerous other scenarios around the world and even different materials. For example, the prominent local resource in another locale may not be timber, however the micro-facility could be adapted to process the required local building material, and robot arms and their end-effectors can be designed and re-programmed to utilize onsite available resources (i.e. clay 3D printing).

A significant point to consider is the cooperation of the local skilled labourers with the robotic fabrication micro-facility. This system could not operate independently of human interaction, and it is not intended to do so. Remote communities have culture and skill that could never be replaced by a robot, and so it is essential that this strategy represents a cooperation between the two parties. The system serves to assist remote communities to construct buildings that would otherwise be difficult and costly to coordinate on such a small scale. The long-term benefits of deploying such transportable micro-factories are even beyond the sustainability of the system. By involving local residents in the process, they can become experts in construction innovation and gain new, modern skills in sustainable building construction. These new skills are complemented by their original culture and skill, which only brings an even greater perspective on how we should be envisioning the sustainable development of remote communities in the future.

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