EXPERIMENTS IN NEW-WOOD
THROUGH DIGITAL MAKING

by

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NEW WOOD + DIGITAL MAKING

This thesis builds on the foundation of dimensional wood. It investigates the field of digital fabrication to identify the adjacently-possible tectonics and design-build processes which are unlocked by the mass-customized logic of this new technology.

Following the process of design-research, a digitally-guided method is generated, leveraging the unique properties of this computer-aided craft. This method is used to make several building forms which serve to define the tectonics that emerged from within the performed research.

ACKNOWLEDGEMENTS

I would like to extend by sincere gratitude to those who helped make this work possible. To my parents, for giving me life and showing the joy of creative process, and the fruits which these seeds are able to bear. To my friends, who were there every step of the way, both in hardships and moments of laughter. To my partner in life, without who's loving support none of this would be possible. And to all the staff and members of the Ryerson University team, especially my supervisor and second reader who despite all circumstances were understanding and patient in helping me navigate this academic environment.

To all those, and everyone else who is part of my life,

Thank you...

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PART ONE

THEORY AND CONCEPTS

1.1 INTRODUCTION

We live in a material world, or at least so it would appear. Our bodies also occupy this physical space, and striving to minimize human suffering we shape the world around us by those means and methods which we are able to source. In so doing, we craft various objects, the largest of which are of the architectural type.

Like the human body, any building that can be occupied is also inherently physical; made from other materials to become a primitive hut, a comfortable home, or a large royal palace. The agency of an Architecton in crafting these solid objects is one of a creator; a maker who partakes in the constructing the matrix of objects which frame our collective existence.

Thus, this question of how architecture transforms an idea into physical space lies at the core of this thesis. In pursuing this question, it looks at the three categories of traditional, industrial and digital crafts in order to systemize the logic of making within each paradigm. Understanding and mastering each one of these models holds a key to enabling meaningful manipulation of matter. Let us therefore begin by examining how exactly an object is born.

1.2 FOUR ELEMENTS OF PHYSICAL CRAFT

"How many things is a 'thing'? Any number you want. Because a thing is a 'think' - a unit of thought"

- Alan Watts

When a wood joint is carved by a carpenter, an arch laid by a mason, or a vase blown by a glass maker - an object is made that has not existed before. It can be seen, touched, smelled and perhaps most important of all, it has a use either in function or as artefact. Being of physical nature, it takes its atoms from the surrounding environment, with the nature acting as a donor for the human creative potential. This ability of intellect to project purpose onto matter is what transforms a stone into hammer, and the edge of that broken stone into a primitive knife. At the core, it is these two elements which could be said to produce a separate object:

Material (environment) + Function (intellect) = Object

Naturally, this formula applies to only the simplest of 'things', with all other objects being crafted through casting, weaving and other methods in order to produce greater complexity of aesthetics and function. Serving as an extension of the human hand, the tool becomes an important part of this process; its role within each given epoch is implied in the names of the 'stone', 'bronze' and 'iron' age. The process by which material is transformed into object can generally be split into additive or subtractive. Used primarily to make monolithic objects, the subtractive approach involves removal of 'extra' material in order to reveal the desired form; and the aesthetic look of the finished object can sometimes be affected by the tool marks left in the process, unless polished away after the fact.

Image 1: Illustration of a wood hand-carving proces

In contrast, the additive methods involve the joining of smaller elements into a unified whole, which for architecture is most common due to the scale and complexity of these man-made objects. Thus being a sum of its parts, it's not how material is removed, but rather how it is joined together that can define the method-aesthetics of this crafted architectural object.

This process-oriented account of architectural tectonics is given by Gottfried Semper, who's analysis of a Caribbean Hut through the four elements of hearth, earthwork, framing/roof, and membrane walls allows for each element to be regarded as directly resultant from its method of making. Amongst all of the methods, Semper considered the knot and weave most fundamental, able to both join the light wooden frame and create wall partitions without the use of any specialized tools.

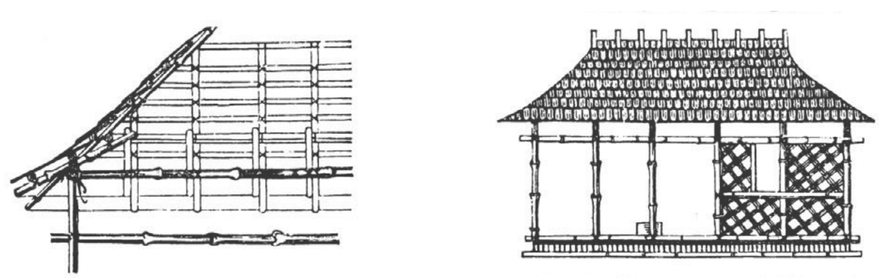


Image 2: Illustration of the Caribbean Hut

This approach, in which vertical members create the structural skeleton while the wall infill provides environmental separation is one of two categories which he identified as tectonic and stereotomic respectively. Unlike the light-weight wood framing, the masonry-like logic of joints within the stereotomic approach produces monolithic wall enclosures with no separation between frame and wall elements - a more permanent method which is rooted down into the earth (Frampton, 2007). Within the context of wood, such examples can be seen in traditional cross-log construction, where the method of joining is done through an inter-locking technique that links horizontal members at the corners and down their entire length.

Both in sourcing and joining these large wooden members this vernacular method depends on the use of metal instruments such as a saw, chisel, drill and an axe - an integral part of the building craft. The relationship between method and instruments can be also seen in the Native American Plank House, where traditional tools and techniques are used to split Red Cedar down the grain to produce wooden planks (Wallace, 2017). This new type of wood member is then shingled and knotted to create panelized cladding that's supported on a large wooden frame.

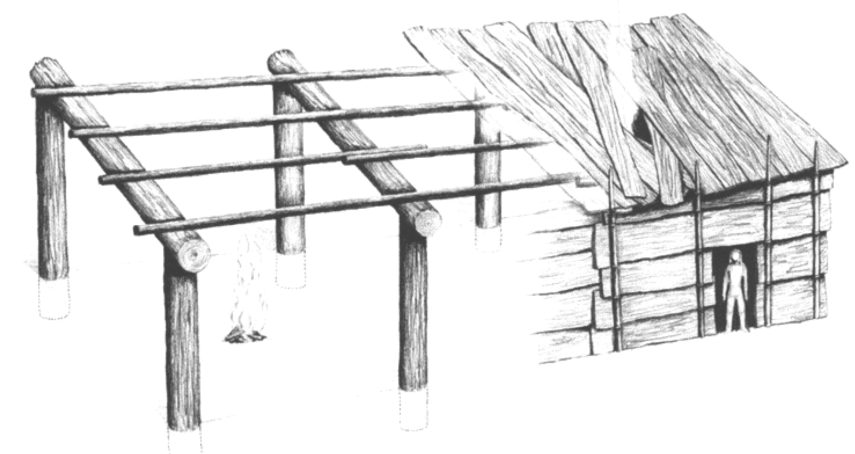


Image 3: Plank House structure and cladding

In this way, different tools could be said to enable various methods which are best suited to them, and change of the instrument could lead to a change in technique. For example, even subtle variation between the Western and Japanese wood saw is said to make the latter more favourable in producing finer detail and intricate joints (Sato & Nakahara, 1995).

Beyond access to different materials and tools, the method of building will inevitably reflect those conditions which exist within the local environment. To this regard Kirean and Timberlake architects have observed that the beauty of vernacular methods emerge from "...a record of lean thought that becomes poetic by virtue of its fitness." (Kieran & Timberlake 2003).

An example of this adaptation can be observed in Japanese architectural tradition which responds both to the subtropical climate and local seismic conditions. Within this tradition, the increased depth of roof overhangs shades the hot summer sun and diverts water from the foundation which in turn necessitates the increased cantilever supports associated with this oriental vernacular (Karmiol 2002). Furthermore, the structurally-isolated mast which penetrates through the floors and roof of Japanese pagodas works as a tuned earthquake mass-damper (Karmiol 2002); while the special curvature and masonry pattern found in some tall castle walls serves to absorb and divert lateral seismic shocks vertically up through the structure (Nishimura & Kono 2017).

In addition to the effect of climate, the method of crafting architectural buildings can also be influenced by the adjacent crafts which work with the same material and tool combinations. Such overlap is known to exist in the architectural and naval tradition of Nordic culture, where the methods of ship frame construction mirror those used in the making of roof trusses

Image 4: Hōryū Temple Compound

present in stave church designs (Lindholm 1969). This link can also be observed within dragonesque decorative elements used both in ships and buildings, further illustrating the cross-influence of information between these naval and terrestrial crafts.

Image 5: Norwegian ship and roof frame comparison (left)
Image 6: View of stave church roof truss from the interion (center)
Image 7: Exterior stave churchv (right)

Once a local method of building is formulated, it encodes lean principles of efficiently building within the local constraints. Whether kept inside a system of guilds, embedded into the local language or formalized into a legal document, this knowledge of how materials are to be joined produces an architectural syntax from which different variations can be arranged. To draw an analogy with computer programming, each software program is coded within a certain language (Java, C++, Python) which provides a set of logic and syntax that can then be manipulated to produce individual programs. The same is true for architectural craft, which in the case of the Russian vernacular uses the local method-syntax to produce homes, windmills, bridges and churches such as those examples illustrated below.

Image 8 & 9: Examples of Russian vernacular construction (left top & bottom)
Image 10: Kizhi Pogost church (right)

This brings us to the fourth element of craft, which uses a specific syntax to describe the object itself. Similarly to the example of carving, where an image of the result must be visualized in order to remove the 'extra' material, individual buildings can emerge from within the possible forms which are allowed by the utilized method. This principle can be applied to all the techniques outlined above, with each dictating the rules of object variance to a lesser or greater degree.

One of the most structured systems exists within the Japanese vernacular, where different buildings all utilize the standardized dimensions of the tatami mats to derive the dimensions of structure and wall-panel elements. This produces a modular logic of the Japanese syntax which guides the design of homes, sheds, and castles alike.

Similar ordering principles can be observed within the stave church construction, wherein each object is rationalized through different rectangular configurations of the vertical member, onto which the wall and roof components are joined.

Lastly, the possible objects which can be made with the vernacular Russian method are also bound by the nuance of method, with the stereotomic logic of horizontal joints being the vertically-grown axis which is guided by a building projection in plan. Like the previous two examples, there exists a direct correlation between the logic of a method and the possible form variations.

In this way, we can group the method and object-variant as being the informational elements of craft, while the materials and tools comprise the two physical elements. Together, these for parts allow for objects to transform from idea to matter.

Figure 1: Four Elements of Craft

CRAFT
- *Material (P)* - provides the atomic matrix
- *Tools (P)* - allows the matter to be 'edited'
- *Method (I)* - defines how 'editing' can be done
- *Template (I)* - defines the parameters of an object

In the making of architectural objects, all four parts of building craft either enable or limit different kinds of earthwork, framing and wall components; and change to either materials, tools and/or methods can generate a new building tectonics.

The object itself could be said to arise when these three elements combine with a template, which is in turn generated within the inherent logic of each given method. With architecture being generally made by an additive process, the combination of method and template together define the material and geometric parameters as reflected by the relationship between members and joints.

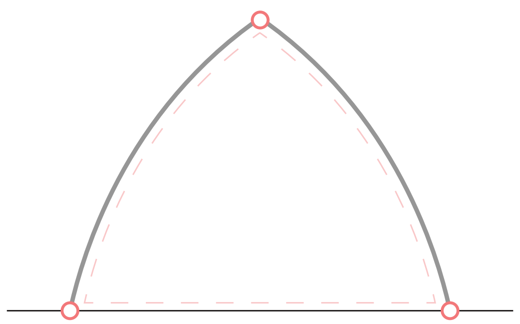


Figure 2: Join, Member and Geometry

Working within this outlined model, the following chapters aim to identify how the mass-produced logic of wood, and mass-customization properties of digital fabrication could generate a new method of making architectural objects.

Image 11: Tools used in building a Norwegian stave church

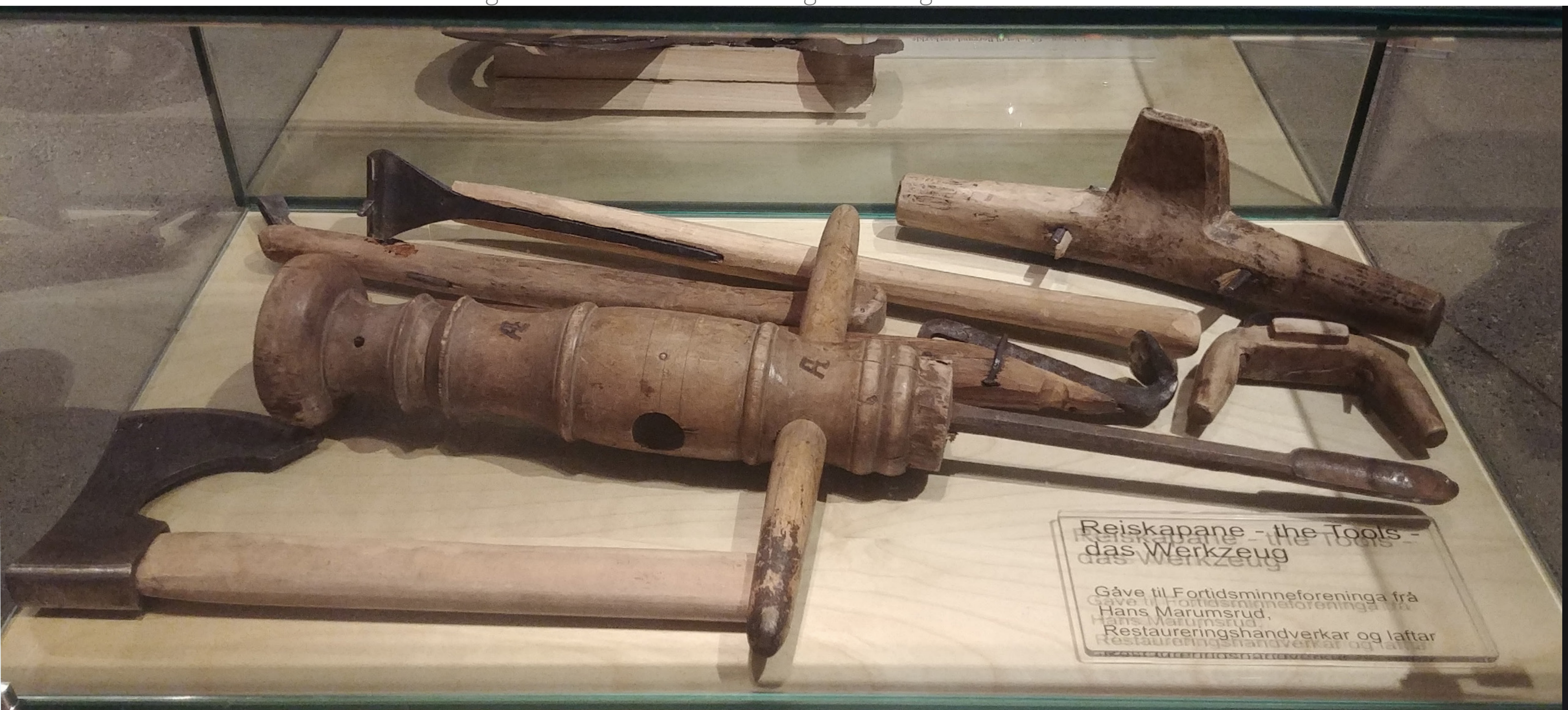


Image 12: A scale model of the Borgund Stave Church

1.3 MASS-PRODUCED MODULARITY

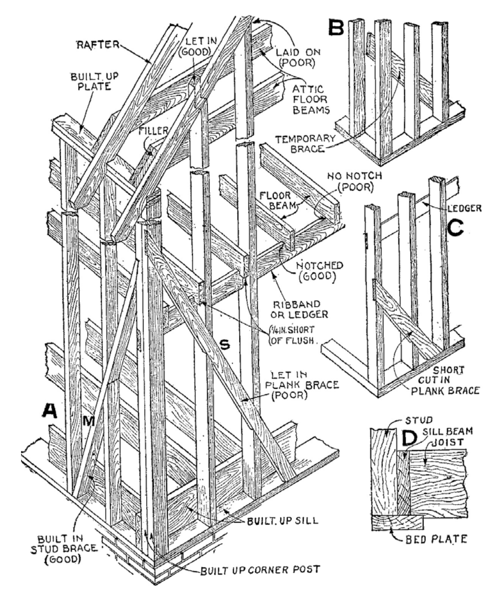
"My receptiveness to the beauty of handwork does not prevent me from recognizing that handicrafts as a form of economic production are lost... Our needs have assumed such proportions that they can no longer be met with methods of craftsmanship"

- Mies Van der Rohe

For the longest time there was the undisputed symbiotic relationship between the human body and physical tools, with the first providing physical energy, while the second giving advantage of mechanical type. With rare exceptions of mills powered water and wind, it was not until the advent of industrialization that the process of converting wood into shelter has transformed this traditional craft into an industry of building production.

On the material side of the equation, new factory tools enabled the conversion of wood into sawn lumber - a component which traditionally required great effort to produce in large numbers. This mass produced process has made sawn wood widely abundant; and in contrast to traditional carpentry which often involved careful sourcing and personal harvest of trees, this commercial access to dimensional lumber effectively replaced the natural environment with that of the lumber-yard market.

Compounded by mass-produced nails, these two new members and joints provided the foundation for a new method of building with wood. Unlike the traditional approach where the joint is carved into the member, sharp metal nail allowed for a fast and easy connection of two small adjacent wooden components in an additive rather than subtractive technique. This in turn greatly reduced the skill threshold required to work with this method, with carpenters like George W. Snow having developed it into what's known as 'Balloon Framing' (Bergdol & Christensen, 2008).



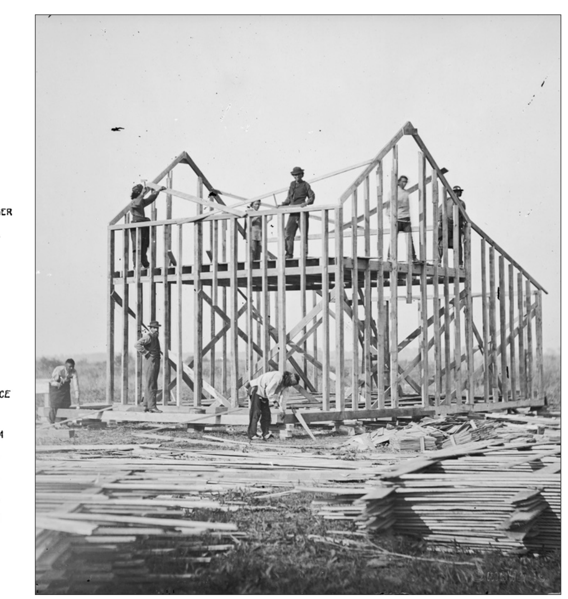


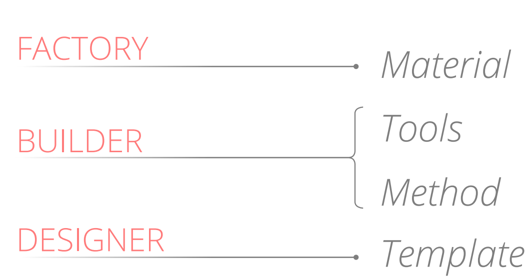
Image 13: Illustration of balloon-framing (left)
Image 14: Photograph of construction using this method (right)

In speaking to the effects of this method, Vandervoot H. Walsh observed that:

> "To layout and frame a building so that all its parts will come together requires the skill of a Master Mechanic, and a host of men, and a great deal of hard work to lift the great stick of timber into position. To erect a balloon building requires about as much mechanical skill as it does to build a broad fence." (Kahn & Easton, 2000)

Such significant reduction of skill threshold meant that part of the role once held by the Master Builder could now be transferred onto the builder and/or the end consumer. Combined with the move away from physically hewing wood members by the craftsman and towards mass availability of dimensional wood, this functionally fragmented the building process into the three faculties of manufacturing, construction, and design. With the two physical elements of craft now being outsourced, Architect as Master Builder gave way to Architect as Designer (Kieran & Timberlake 2003).

Figure 3: Agents of Industrial Craft



This method of making does not entirely reject the craft; however, instead it separates the act of making the original object from the process of its mass-reproduction. In describing this phenomenon Lars Spuybroek quotes John Ruskin in saying:

> "The equal relationship between craft and matter has inherently been challenged by the designer, who tries to control and impose form on matter but, even acting in good faith and possession of the right techniques, cannot fully inhabit matter and must assume the position of the mold." (Spuybroek 2016)

This concept of the 'mold' becomes instrumental in analysing the industrial making process, as it shows how this 'template' of the object variant becomes the original object of craft, while the conveyor belt process enables mass-production of input design. Furthermore, this original mold does not need to be made as a physical object, needing only to describe the informational template about the material and geometric parameters. In this way, a patent which outlines a product and/or process serves as the original 'thing' - a seed for engineering of the manufacturing process. In contemporary architectural practice this can be seen with a set of construction drawings which while describing the geometric and material specifications, nonetheless do not constitute a physical house in and of itself.

In distributing this mold to the public, the mass production of paper print in the early part of the 20th century enabled building designs to be marketed through catalogues like The Sears. In addition to having a selection of different homes ranging from budget to luxury, some companies also offered a complete kit of parts which included all the precut lumber, as well as materials such as drywall, siding and asphalt roof shingles (Smith 2010).

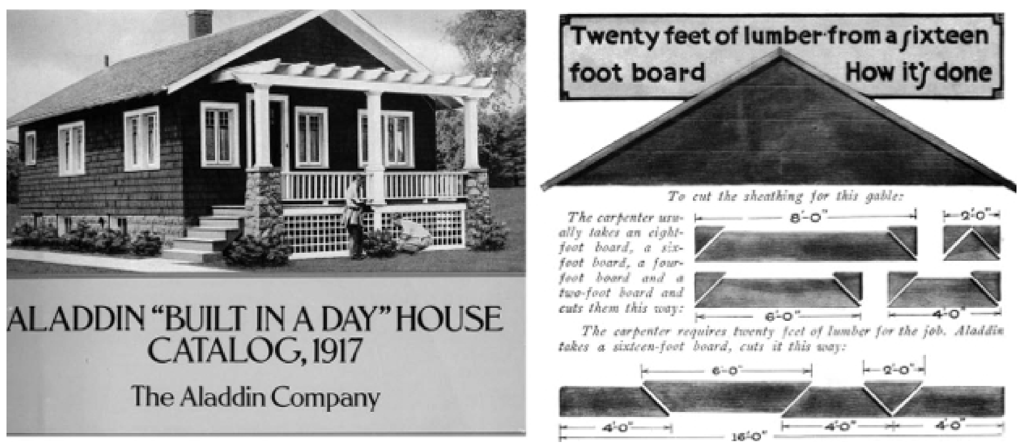


Image 15: Part of The Aladdin Company brochure for a DIY house

Like with all building methods, designing within this method is inevitably constrained by the logic of the common materials used in stick-frame construction. In this way, the North-American standard for the dimension of lumber and other building products imposes a 2′ x 2′ grid in section and plan; while the thickness multiples of 1/2″ dictates the size of the detail. This in turn means that in pursuit of the lean, the logic of designing with what is now a vernacular method works within this imperial grid in order to maximize the amount of useful material.

Similar to the Japanese tatami mats, this becomes one of the most fundamental ordering principles of design variations. Further to this implication on building geometry, the ability to mass-produce components away from the site brings about another change to the logic of industrial making. If, for example, a design was made which would utilize all the building materials only in their factory size, the process of site-intensive construction would shift towards one of assembly.

This approach, however, would still be comprised from a large quantity of members and joints; and in order to better optimise the process each building component could be pre-assembled on factory and only then delivered to site. Working within the prefabricated logic, architects like Konrad Wachsmann, Walter Gropius, Marcel Breur and others sought to design modular systems which could integrate design and fabrication in the making of mass-produced homes (Kahn, 2004). The complexity of this approach meant that any mistakes made in the factory were difficult to correct on site, with each system requiring careful calibration of components prior to entering the convey belt line.

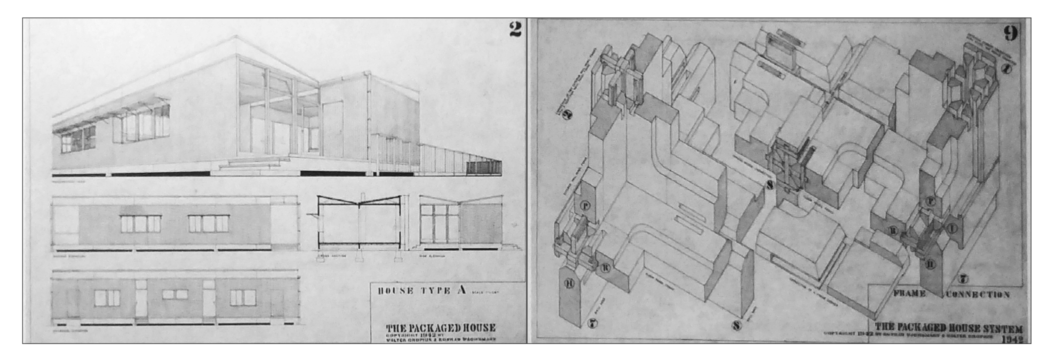


Image 16: The Packaged House System by K. Wachsmann and W. Gropious

The main challenge of transitioning from site- to factory-intensive method of project delivery lies in the level of detail required for this form of design-build integration. It is no longer enough for the drawings to remain at the level of representation, outlining primary design parameters and having the rest filled in by the builder working within the vernacular code. Instead, the architectural mold needs to take on the resolution of a virtual simulation in which all of the building components, sub-assemblies, and their related joints are fully accounted for; thus allowing for premade members delivered on-site to be quickly assembled (Kieran & Timberlake 2003).

Images 17-19: Examples of linear, planar and volumetric prefab

If effectively realized, this approach offers opportunity for optimizing a project's parameters of time, quality and cost by shipping to site linear, planar and volumetric prefabricated components (Smith 2010).

For example, in Sweden, where the practice of modular construction is well-established, the rate of actual volumetric component assembly on site following the production for this type of a 6-storey building can be as little as 2 days (Lawson, R, et. all). Such extreme rate of rapid assembly enables a tight control of the installation weather and helps to avoid potential water damage to unprotected building elements often present in site-intensive construction.

Within this approach both the design and production elements of craft take place as part of a single process, and by blurring the line between architectural and engineering design, different firms utilize this model of project delivery. One such example is embodied in the Lobby House, designed and built by Kieran & Timberlake Architects which uses existing prefabricated aluminium framing and wall infill to assemble this unique design.

Image 20: The Lobby House, by Kieran & Timberlake Architects

In addition to a one-off approach, the advantages of prefab design could be leveraged in creating different object variations within the logic of a proprietary method. One such example is the design-build firm by the name of Wikkelhouse which offers a modular small-building solution for alternative living.

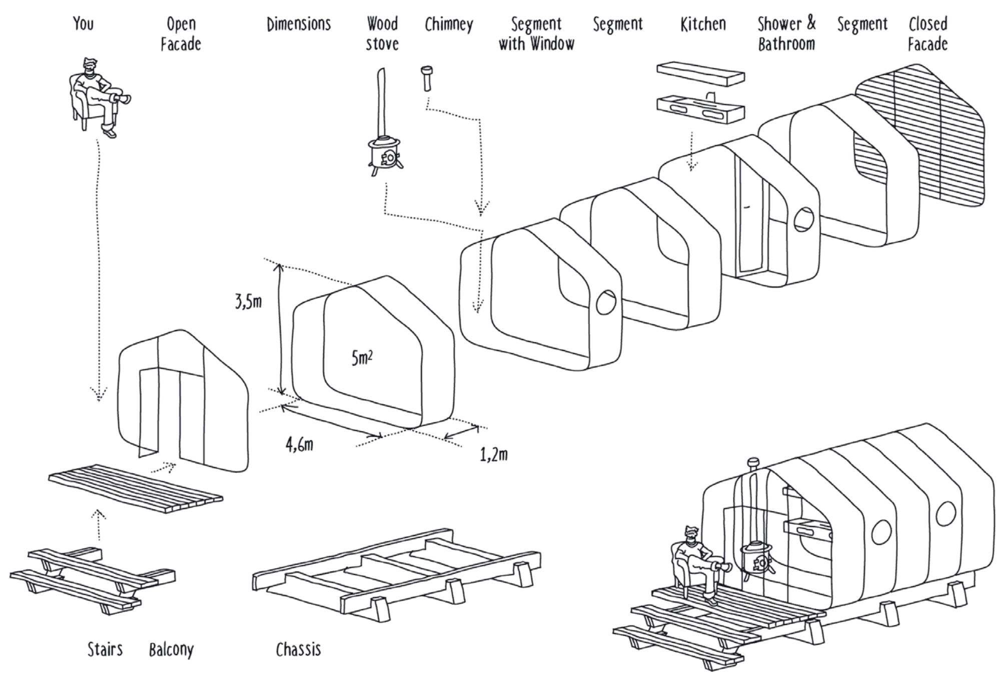


Image 21: Components of a Wikelhouse modular system

It is made out of modular bays which are spun into an egg-shell design with laminated layers of corrugated cardboard. These modules could then be programmed as bedrooms, washrooms and living room space and configured into a linear array to crate clusters which meet individual client requirements.

Another system that employs a modular variability goes by the name FlatPak House, and utilizes a panelized approach in producing homes that can scale and adapt to site and budget requirements. Similar to the previous example, using rigid modules severely limits the possible forms which could emerge from each method; however, in exchange this system offers clients the opportunity to co-design a house by means of this LEGO-like system.

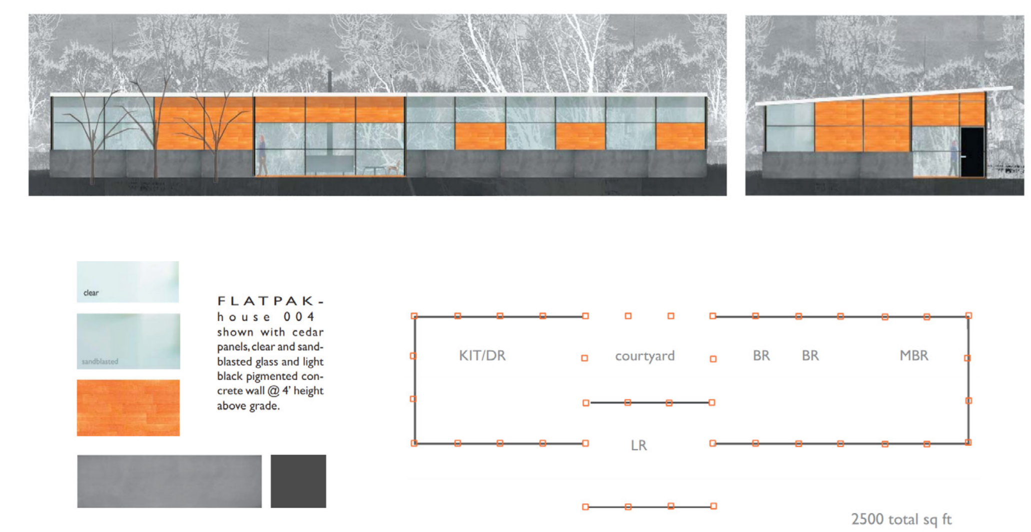


Image 22: A design variant of the FlatPak system

There are many other examples which help illustrate how the modular logic of factory-made components can be utilized to create different prefab assemblies and their possible combinations. In the context of building with wood, the size matrix of dimensional wood members enables this modularity, with the next chapter aiming to examine the tectonics which emerge as result of this modular property.

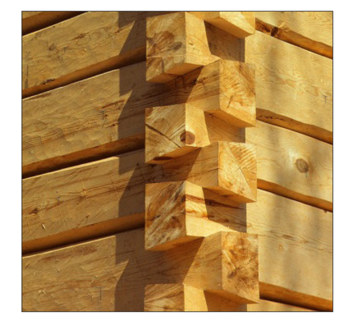
1.4 NEW-WOOD TECTONICS

"If you write out the basic facts of trees, but framed as technology, it sounds like impossible sci-fi nonsense. Self-replicating, solar-powered machines that synthesize carbon dioxide and rainwater into oxygen and sturdy building materials on a planetary scale"

- The CryptoNaturalist

Up to this point the above discussion of building crafts has been kept primarily within the context of wood. This is no accident, for while there are many materials which can be made into buildings, wood has a long history of being used in construction, while at the same time becoming increasingly relevant in today's eco-conscious environment. Being a renewable resource, forests make up about 30% of the Earth's terrestrial area (3.9B ha), with the boreal forest covering approximately 1.9 billion hectares of this global forested area. If responsibly harvested, this provides a sustainable building material which is abundant, malleable and works as a carbon sequester. In addition to being used for its structural properties, the aesthetic character of wood carries with it a timeless quality, generating both a physical and phenomenological warmth. As discussed in previous chapters, these aesthetics can be highlighted with various methods which shape this material into members, joints and complete architectural objects.

The tectonic expression of material and method in turn depends on whether or not these elements are revealed. In traditional vernacular construction, exposing the structure was a function of lean design, but with emergence of the stick-frame method dimensional lumber often became concealed between the layer drywall and siding.



Images 23-25: Examples of cross-log, timber-frame, and stick-frame wood joints

The enclosure of wood into sandwich assemblies is done for many reasons which deal with performance and aesthetic finish of the visible layer, resulting in wood which is hidden from view. This, of course, does not mean that manufactured wood products can't be used as expressive parts of architectural expression, with many architects showing how the properties of this new wood material can be leveraged in building design. One such example is the Saint Benedict Chapel by Peter Zumthor. In this project, the precision of machine-cut lumber creates a vertical rhythm of wall studs, further articulated by an offset from the inner face of the walls. Unlike naturally-occurring wood which is difficult to replicate in large numbers, this repetitive nature of dimensional wood is also explored in projects by Matt Innauer, Herman Kaufman and other designers who utilize the modular aesthetics inherent to this material.

Image 26: Building addition by Matt Innauer (top left)
Image 27: Interior of the Saint Benedict Chapel by Peter Zumthor (top right)
Image 28: Interior of the Boxing Ring roof, by FT Architects (bottom)

Further to this rhythm-generating characteristic, the precision of wood modules allows them to be scaled into bigger components - a property explored by FT Architects in the design of the Archery Hall and Boxing Club. These two spaces also illustrate how metal screws and bolts could be used as elements of ornament, complementing natural wood and revealing the joining techniques.

Following this composite logic, standard dimensional lumber could be joined together into larger inter-connecting members such as that done by architect Scott M. Kemp in designing his family house. This use of multilayered components allows the joints to imitate the traditional logic of a mortise and tenon without the need to fully carve out this intricate joint. In addition to using metal fasteners as functional ornament, this project also illustrates how the smaller size of dimensional lumber can generate light-feeling tectonic.

Images 29-30: Interior and detail of the own house, by Scott M. Kemp

The ability of this wood component to be stacked allows multiple pieces of lumber to be laminated together to produce large straight or curvilinear members. Unlike naturally curved wood which is naturally unique, projects like Frank Ghery's AGO atrium in Toronto demonstrate how these structural components can be both repetitive and accurately variant.

By using this method of cross-gluing, -nailing or-dowelling wood into dimensional panels it is possible to produce structurally monolithic wall and floor/ceiling members which - depending on the number of layers - can be either a load-bearing or installed within a primary structural frame.

In addition to cutting a log into pieces, laminating peeled sheet veneer produces another planar component in the form of plywood. This new-wood product is often used as part of a stud-wall assembly due to its resistance to shear, while high contents of glue makes panels thicker than 1/2" perform the role of a vapour retarder. Depending on the grade of finish veneer, this material has wide applications both structurally and/or as aesthetical finish.

Image 31: Interior of the Enough House, by Brian MacKay Lyons

In the latter case, the look of this material is influenced by the unrolling process which by means of an industrial lathe reveals the otherwise hidden radial texture of annual rings. This somewhat uncanny, but nonetheless natural-looking texture still retains most of the 'warm' qualities of wood which are utilized in the Enough House by Brian MacKay Lyons.

As discussed in the previous chapter, this material imposes a 4' x 8' and 5' x 10' grid but can also be easily cut into any required geometry. One of the earliest experiments combined these two properties, seeing how a single sheet of plywood could be used to produce different architectural components.

Image 32: Experiments with a plywood components at 1:6 scale

Plywood's ability to bend either by steaming, scoring or kerfing is another way this material can transcend the flat plane, taking on sculptural qualities such as those captured by Charles and Ray Eames in their iconic duo of the Lounge Chair and Ottoman set. In addition to gluing elements of lumber and veneer into

Image 33: Eames Chair and Ottoman

larger components, the process of chemically-bonding smaller wood fibres can generate other new-wood products such the oriented-strand board (OSB) and laminated strand lumber (LSL). It could be argued that this level of processing natural wood compromises the visual quality of natural grain; however, these structural products are most useful where the cost/performance ratio is prioritised.

Through a combination of these linear and sheet-wood products emerges another composite component - an engineered wood truss. By using material only where it is needed most, this is the most cost-effective method of covering medium-sized spans.

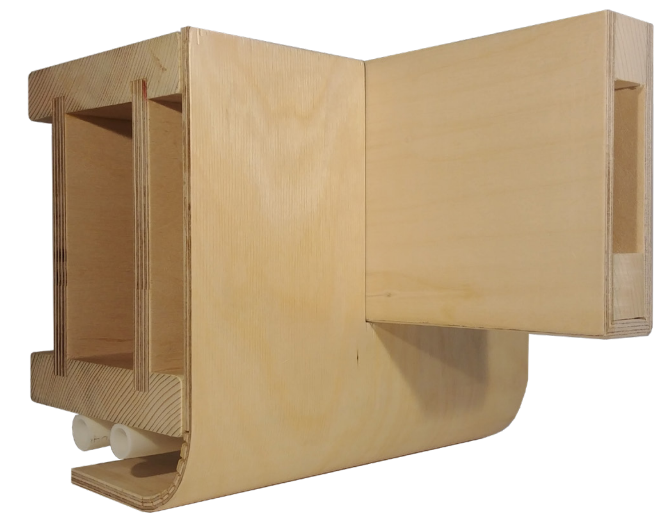


Image 34: Plywood-encapsulated double I-truss

Looking at possible ways to combine the aesthetic quality of plywood with the efficiency of an engineered truss, the above is an experimental component which was produced at a 1:2 scale. Unlike the box-beam approach which creates an illusion of a solid-wood beam, the use of plywood as finish material makes for clean aesthetic while hinting at the hollow nature of the concealed elements. These spaces can in turn be used for routing of services and/or a pressurized air-exchange cavity.

1.5 THE LOGIC OF DIGITAL MAKING

"The great opportunity in the maker movement is the ability to be both small and global, ...creating the sort of products the world wants, but doesn't know it yet."

- Chris Anderson

All of the wood products described in the previous chapter provide the material foundation to this thesis, following the logic of mass-produced process. In addition to traditional and industrial crafts, today we have access to a third model of making called digital fabrication which builds on the foundation of computer-aided design (CAD) in the making of physical stuff. Commonly used to produce drawings, models, and visualisations, the use of CAD allows the geometric, material and other parameters of an object to be encoded in virtual space.

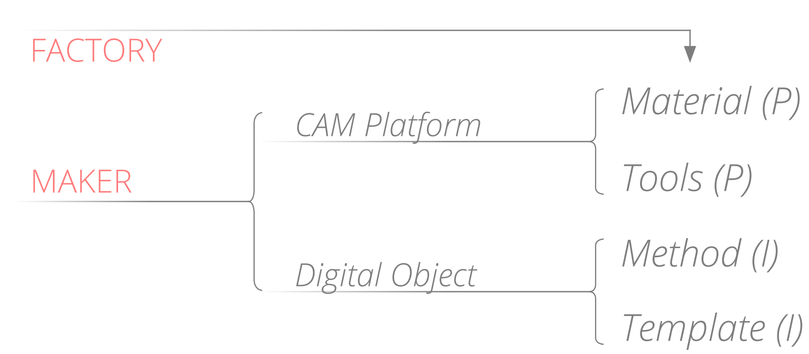
In addition to computing this data for the purpose of structural, energetic and financial analyses, this code can be made to guide the physical fabrication process - otherwise known as the file-to-factory model. This method of using computer-aided manufacturing (CAM) is founded on the use of a neodymium stepper motor - a universal component which is able to convert digital signals into physical movement of tools. By animating such computer-numerically-controlled (CNC) machines such as table routers, 3D printers, laser cutters and robot arms, this small

component is able to guide additive and subtractive processes and could be said to be the muscles of digital craft. In speaking on this new type of craft Laris Spuybroes writes:

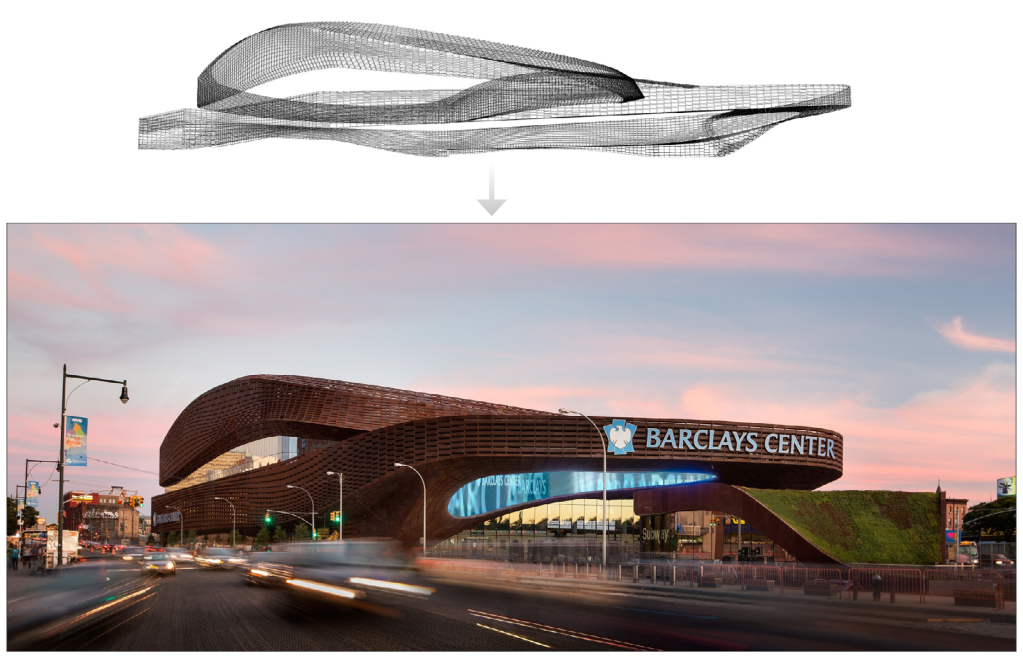
> "Within the framework of human design and production, such a shift means not only the transformation of design from hand-drawing to code-scripting but a move from hand-carving to the laser- and water-cutting of glass and metal sheets under the guidance of numerically controlled machines..." (Spuybroek, 2016).

The use of the word craft is fully appropriate because digital fabrication encapsulates both the physical and informational elements of making. The digital object thus encodes both the mold and the method of fabrication, instructing the tools in how to shape wood, stone or plastic into various physical objects.

Figure 4: Components of Digital Craft



Within this new model of craft, the factory still plays an integral role in supplying sheets, blocks, filament and powdered material. Unlike the industrial process of mass-replication, however, digital fabrication allows these materials to be made into different unique forms without the need to set up a new conveyer belt for each of the items. Hence we can speak not of mass-production but rather mass-customization, where each part can be geometrically variant within the allowed parameters of the given machine. The object mold can therefore be flexible and modified depending on project requirements. This property of no cost to complexity together with the file-to-factory process was utilized by SHoP architects in the design and production of the modular envelope panels at The Barclays Center stadium in Brooklyn, NY.



Images 35 & 36: The Barclays Center: digital model (top) | 3D render (bottom)

The digital object thus becomes the focus of craft which can then be translated into a set of G-code instructions used by CNC machines. In this way, the maker needs at the minimum the knowledge of CAD, and basic understand of material and machine; but first-hand experience with the machining process is integral to grasping the logic of converting code into object.

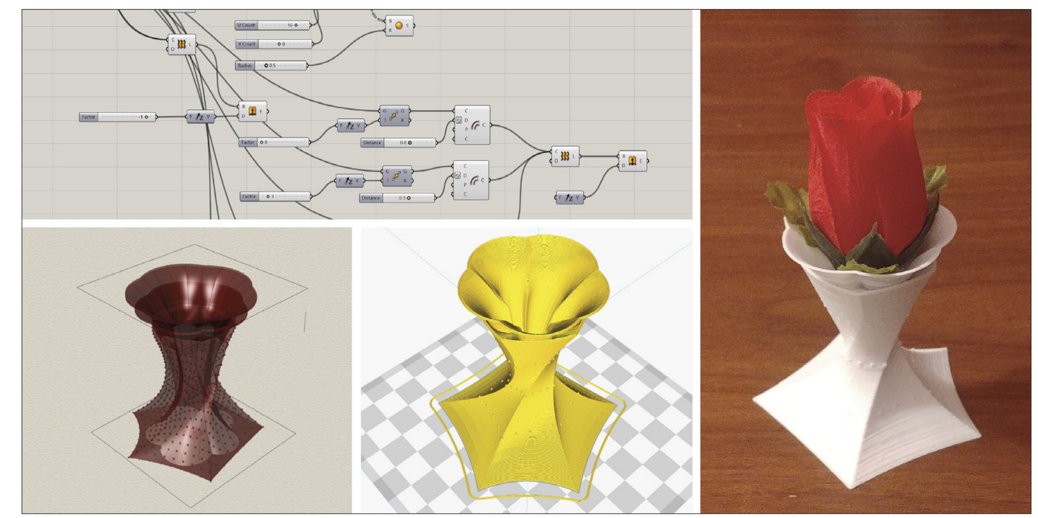
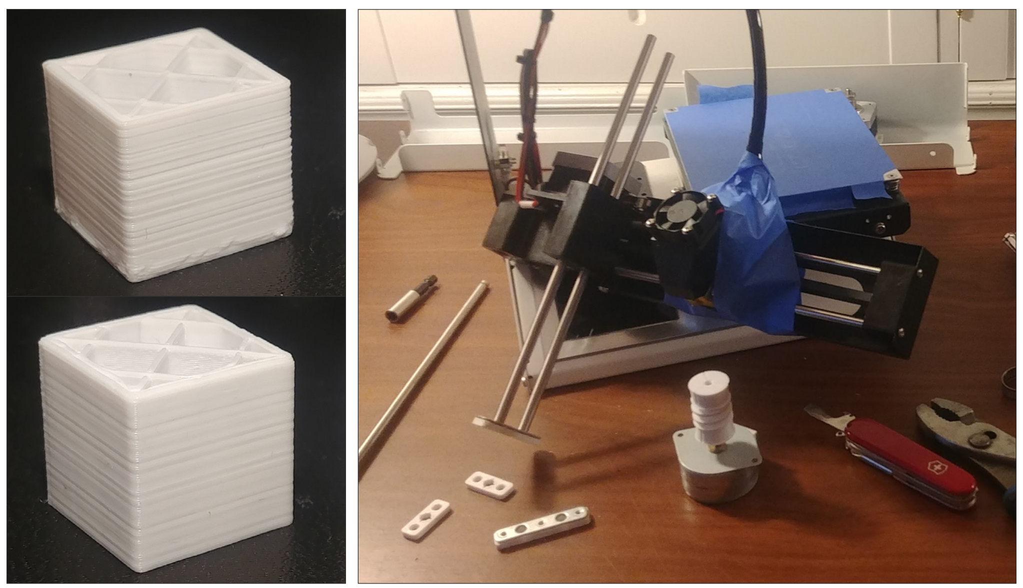


Image 37: Process of digital fabrication: from a parametric code to physical object

The threshold of entry into this digital craft has recently dropped due to collective efforts of the open-source community in developing accessible software and hardware which made possible for individuals to own their own desktop machines, giving them the ability to craft objects of various kind. Once made, many choose to share their creations by uploading them online onto different free and paid platforms, effectively generating a communal data pool of digital objects which can replicated by anyone who has access to this flexible form of production.

Access to this kind of communal knowledge concentrated into a file proved extremely useful during the development of a 3D printable architectural kit. Owning an affordable and popular machine, I was able to download and fabricate various hardware upgrades which noticeably increased the accuracy of prints and enabled the high tolerances which were necessary for a functional kit.



Images 38-39: 3D printed modifications (right) | Before and after results (left)

This way of making objects, however, still has many limitations which are the result of the relatively simple additive and subtractive operations these machines are able to perform. Experimenting with the aesthetic component, another experiment which used digital craft was done during my exchange at the Bergen School of Architecture in Norway. There I had the opportunity to use the local open-source CNC in replicating a hand-carving of an oak leaf made the previous day.

Understanding general limitations of the machines and not attempting to replicate hand carving directly, a virtual copy of the hand carving was made from a 2D photograph and manual measurements. With help from one of the local students who was fluent with this specific machine, the process of replicating the carving took just over two hours, and after brief clean-up the created object displayed its own unique aesthetic which reflected the method of CNC carving.

Image 40-41: Hand-carved leaf (left) | Digitally-fabricated leaf (right)

Each one of these objects reflected the process of making, with striated artefacts of the digitally made leaf producing a different, yet nonetheless appealing aesthetic. Furthermore, in contrast to the labour-intensive manual carving, very little manual labour went into physically making this piece; and once the G-code was made it could be downloaded and cut on any other CNC milling machine.

It goes without saying that far from everything can be downloaded and printed as of today, though many people are working on pushing the boundary of what's possible to make with these emerging new tools. Within architecture, one of the pioneering projects in open-source fabrication is lead by Alastair Parvin of Wikihouse Foundation.

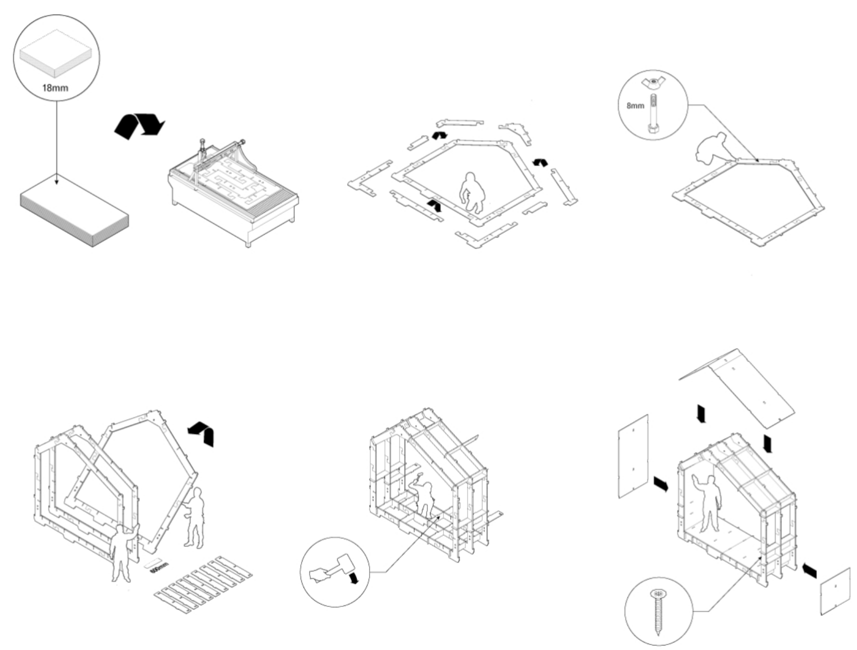


Image 42: The Wikihouse CNC Building System Schematic

The digitally crafted building code of this system consists of a unified joint logic that can create various beam, floor and stair components. All of these modules are designed to be produced on a single CNC table router and use Plywood or OSB as the native building material of the machine. This open source building code has successfully been utilized by people in making their own geometric derivatives.

A similar use of these materials and tools is found in making the Instant Cabin by Marcel Botha, Lawrence D. Sass from MIT. Using their own ecosystem of CNC joints, they laid the foundation for the later experiments in digital fabrication of ornament. Made as part of the 2009 MOMA exhibition, The House for New Orleans offers digitally fabricated tectonics to the traditional shot-gun typology, and serves as a strong example of how inherent geometric flexibility can be used in producing decorative elements.

Another project which focuses on the aesthetic properties of plywood and CNC cutting is the Kerf Pavilion. Made by a team of graduate students from the MIT Department of Architecture, this project is an example of how dimensional and planar plywood can be made flexible through precision of cuts.

Image 43: Close-up of the Kerf Pavilion

Different in choice of materials, The House 4178 made by a team from Swiss Federal Institute of Technology in Zurich utilizes a multi-axis robot arm for cutting and placement of dimensional wood components to create the project's nonstandard structural frame. Together with previous examples it shows how accuracy of position and cuts can scale into a complex composite system.

Images 44-46: House 4178 - exterior, interior and fabrication process

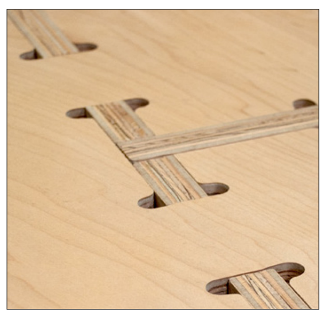
In the case of the Wood Chip Barn made by a team called Design+Made, a Kuka robot arm is deployed to connect the organic geometries of natural wood. To achieve this, a detailed 3D scanning of each log element was required in order to map the unique axis and create the structural array from which each joint geometry was derived. This use of the digital method allows for complex geometries of members to be reconciled into a single structural frame.

Images 47-48: WoodChip Barn - fabrication and structure

Concluding this list of precedents, the Pahu Pavilion in Finland combines dimensional lumber and machined plywood ribs in creating the illusion of a two-way interior curve. Contrasting this aesthetic, the dark exterior cladding was also made with a CNC router as part of the commercially available cladding library offered by Jukola Industries in Finland.

Images 49-50: Pahu Pavilion - exterior, fabrication and wall detail

All of the above projects offer various insights into how the material of wood can be processed using the available tools of digital fabrication to produce different designs, and in some cases even entire building systems. In this context, the combination of sheet plywood and a CNC table router seems to be the most common and accessible option for digitally fabricating large wood components. Furthermore, access to dozens of existing joining techniques and cut patterns has this material+tool pairing benefiting from a culture of digital sharing.

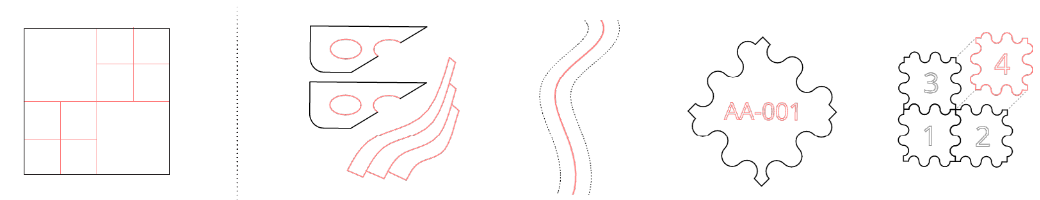


Images 51-53: Two CNC joints (left & center) | Laser-cut kerf patter (right)

The structural properties of plywood, however, are limited by the perpendicular grain of each layer. On the other hand, CNC cutting of dimensional lumber wood is available on an industrial scale and could be used in combination with plywood to digitally fabricate architectural objects larger than a single pavilion. Similarly, the use of a robot arm allows natural wood (logs) to be processed by CAM machines, assuming the digital code is crafted in a compatible way. These material and instrument variants provide the two physical components for this thesis inquiry. Further design research will focus on developing a possible method and logic which could provide informational elements for digitally crafting architectural objects.

The development of this method is based on the mass-production and mass-customization logic of the two models of making. The main principle of industrial process is based on the observation that a standardized set of components provides a dimensional matrix, within which the manipulation of a mold-variant is possible. Within the imperial system, this translates into a 2′ x 2′ grid for linear, planar and volumetric components; while 1/2″ increments are generally used at the scale of a detail. The logic of digital fabrication, on the other hand, offers the following advantages: i) geometric variability; ii) high degree of accuracy; iii) component labelling, and; iv) modular scaling of unique elements into larger components.

Figure 5: Economies of Scale + Scope



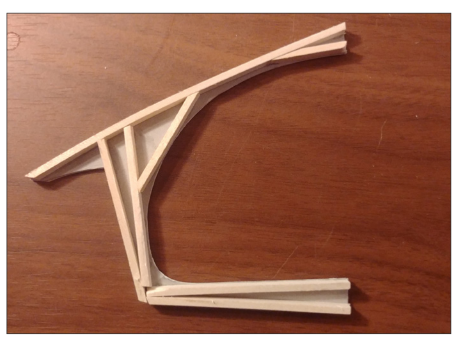
Together with the tectonic qualities of new-wood described in the previous chapter, these five principles lay a foundation to the second part of this thesis. Comprised as a series of experiments, it outlines the development of a digitally guided method from the original concept into a set of adaptable prefab components which could be used in design, fabrication and assembly of varying architectural objects.

PART TWO

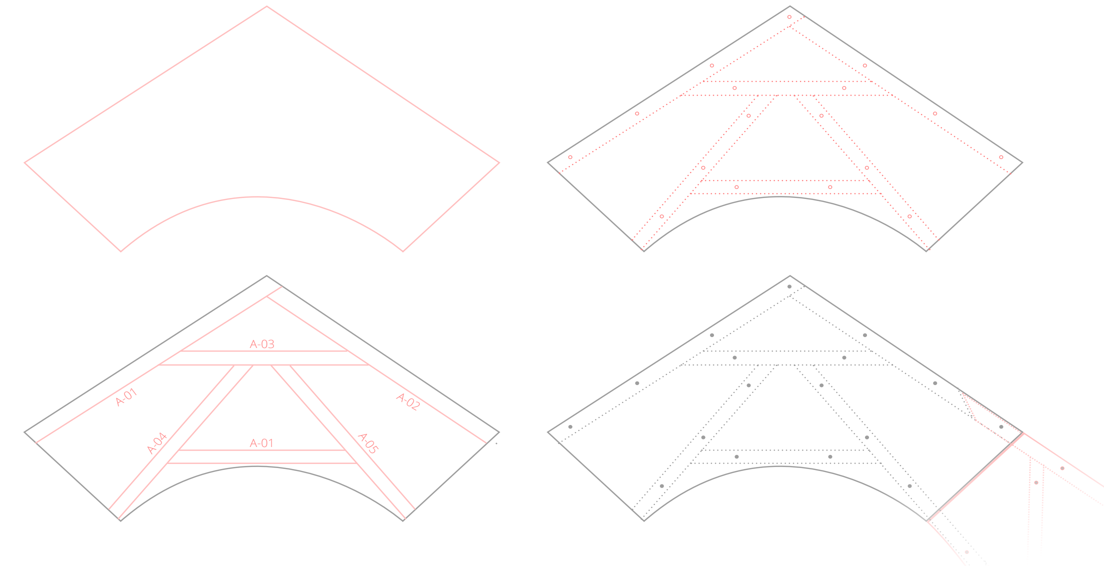
DESIGN RESEARCH

2.1 A HYBRID APPROACH

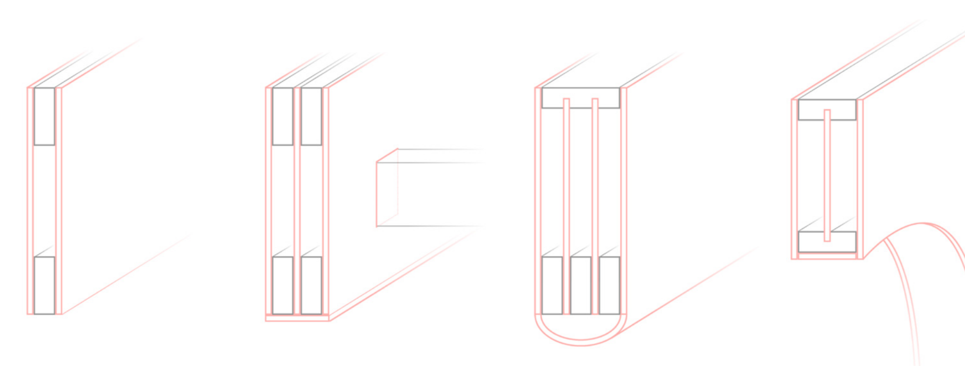
Parallel to the theoretical body of research, the question of how to use this new technology in the making of wood architecture at a scale larger than a pavilion lead to the conclusion that plywood alone was not sufficient as building material. By utilizing machines such as the German-made Hundegger to accurately measure and cut dimensional lumber it was possible to imagine an industrial operation which could produce flexible composite panels. This flexible property was explored through sketch models in order to better understand the possible logic of this reinforced-rib method.



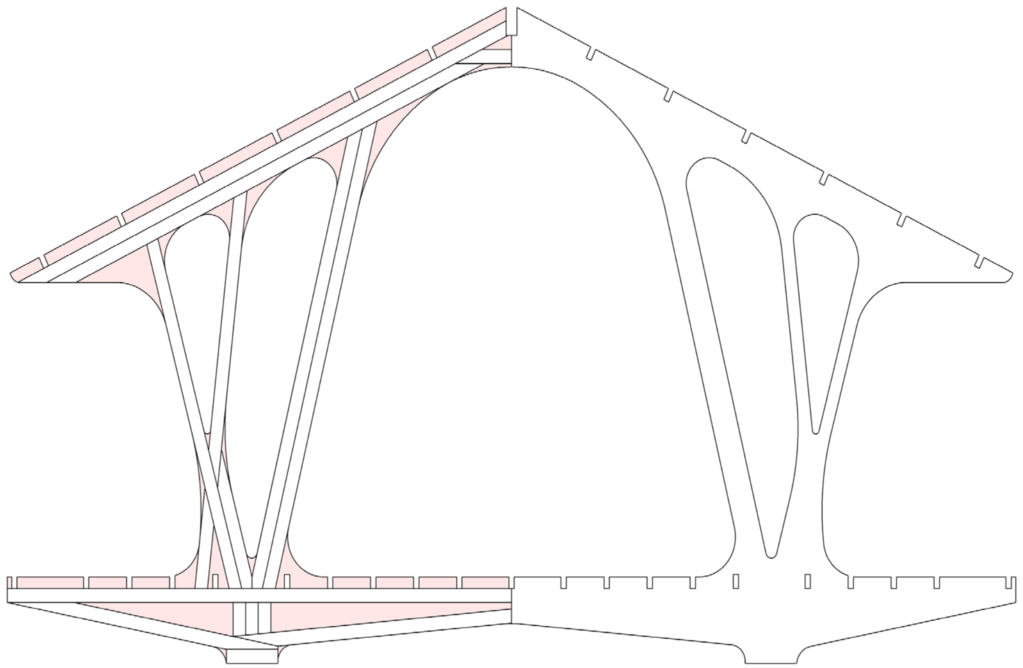
As a result, the following order of operations was proposed in making flexible hybrid elements: i) cut the modular fins to the precise shape required; ii) etch the profile of lumber onto plywood and predrill pilot holes; iii) cut and install matching members of lumber; iv) close the assembly and connect it to adjoining structural members.



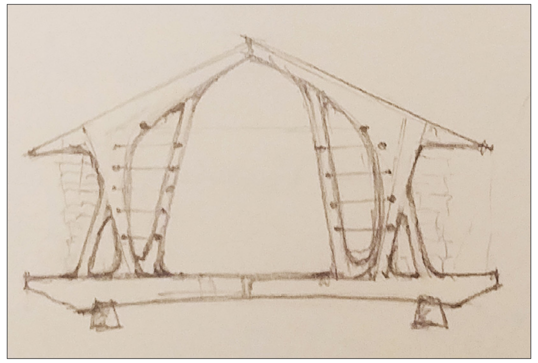
Such a method could produce various box beams and composite trusses, with assembly relying only on one power tool and self-drilling screws. The size of lumber and plywood, as well as the amount of layers within a component can vary depending on project parameters, with this kind of method effectively creating a 1:1 fabrication template to be assembled in factory or on site.



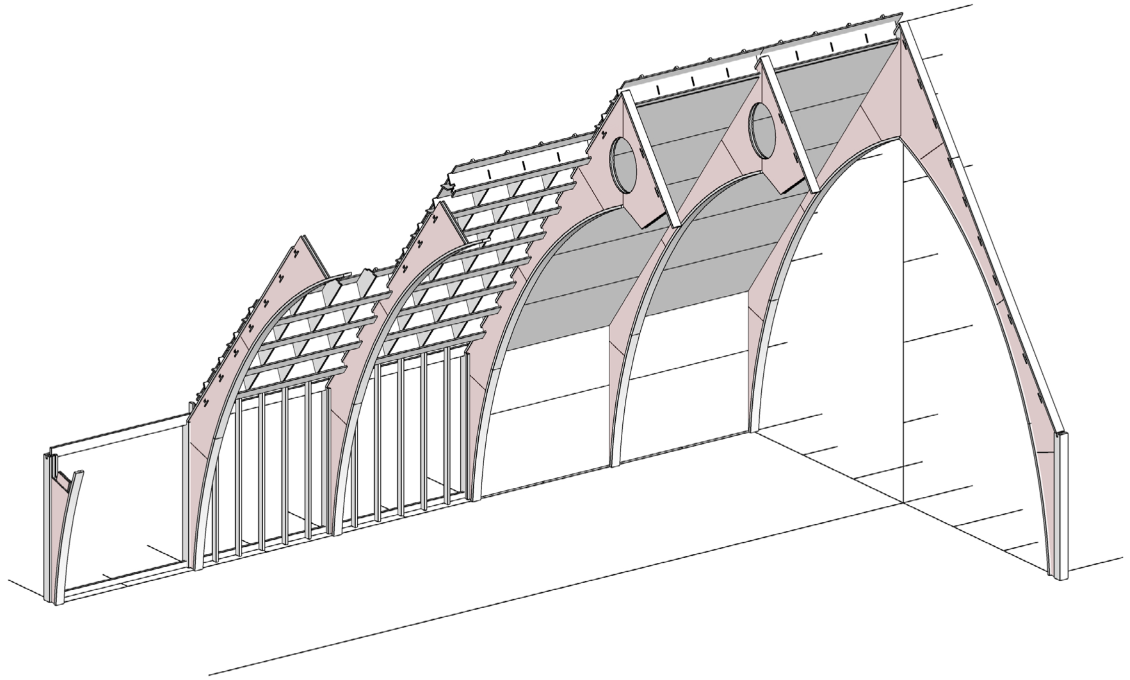
The next part of this experiment looked at applying geometry onto this method. For this, a small sketch was used as the 'seed' which would guide the creation of a 3D model design, with two insights arising as a result of this experiment.



Firstly, the hollow space between the curved plywood and straight lumber created an undesired aesthetic, and a version of the design where they were filled in lead to the idea that these small segments could be used to physically guide the installation of lumber instead of just a scored outline.



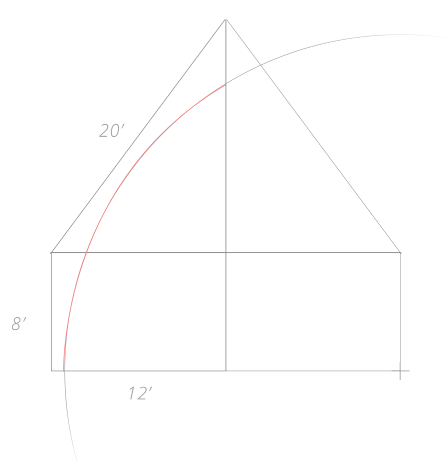
The second insight arose when running the perpendicular roof and floor members through the sectional ribs. As a result, the created notched openings help accurately position and join these two perpendicular elements.

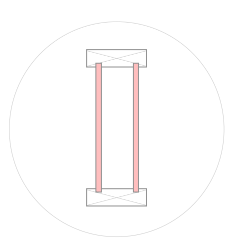


In addition to being an exercise in different joining techniques, this experiment developed the concept of separating the traditionally homogenous stick framing system into primary and secondary structural orders, thereby allowing the dominant form-defining elements to create method-expressive tectonics; while the panelized walls still taking advantage of standardized efficiency by the vernacular grid.

Furthermore, these wall membranes can be made not only from dimensional plywood or drywall, but can also have modular CLT panels which in some cases could compliment the material palette of the composite structural ribs.

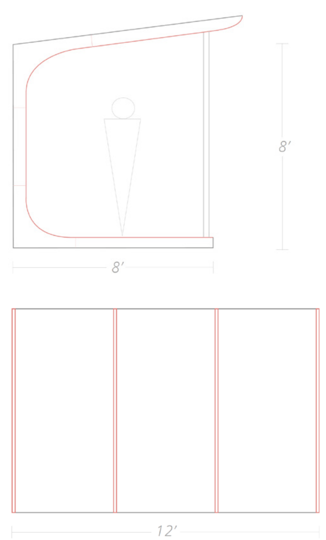
In contrast to the form-first approach of the previous experiment, the next experiment aimed at deriving project geometry from the dimensional logic of the materials, while still retaining some flexible form. To achieve this, a 4' x 4' grid was used in relation to a 3-4-5 proportion in order to define the geometry of the gabled roof.





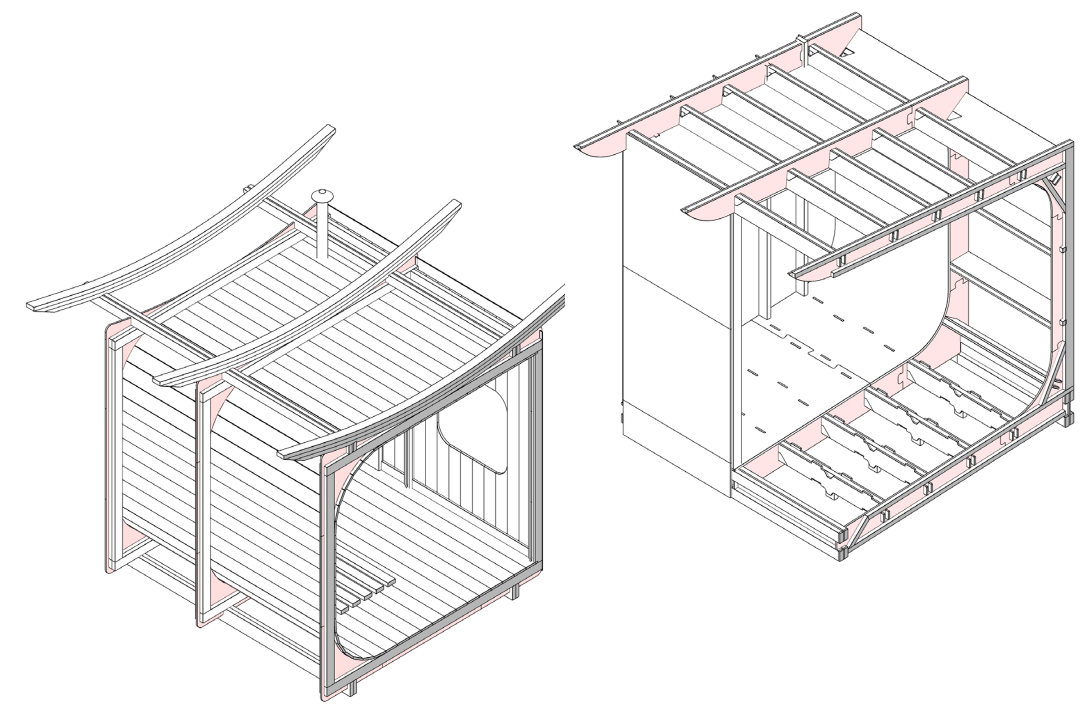
2.2 INITIAL DESIGN SIMULATIONS

A key influence on the pursuit of process-oriented architecture came from the architects Kirean and Timberlake, who argue in favour of designing as simulation rather than representation. Wishing to test out the emerging system in the context of a fully detailed design, the next experiment focused on creating a virtual simulation of a 100 sq.ft cabin.



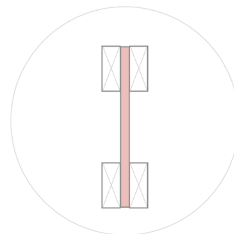
Within this ‘realistic’ scenario, only access to a CNC table router was assumed, and the geometric framework was chosen as primarily modular/pragmatic in order to minimize the amount of manually-cut wood. In plan, this translated into a 8’ x 12’ footprint, while no formal constraints were placed on the digitally-variant sectional ribs. Four variations of the design were made, each one offering further insight in developing the method.

In the initial attempts at physically modelling the first prototype out of scaled 4’ x 8’ sheets it became clear that, at least on a smaller scale, the plywood ribs need to be first assembled into a complete sectional profile, after which the lumber infill can be installed.

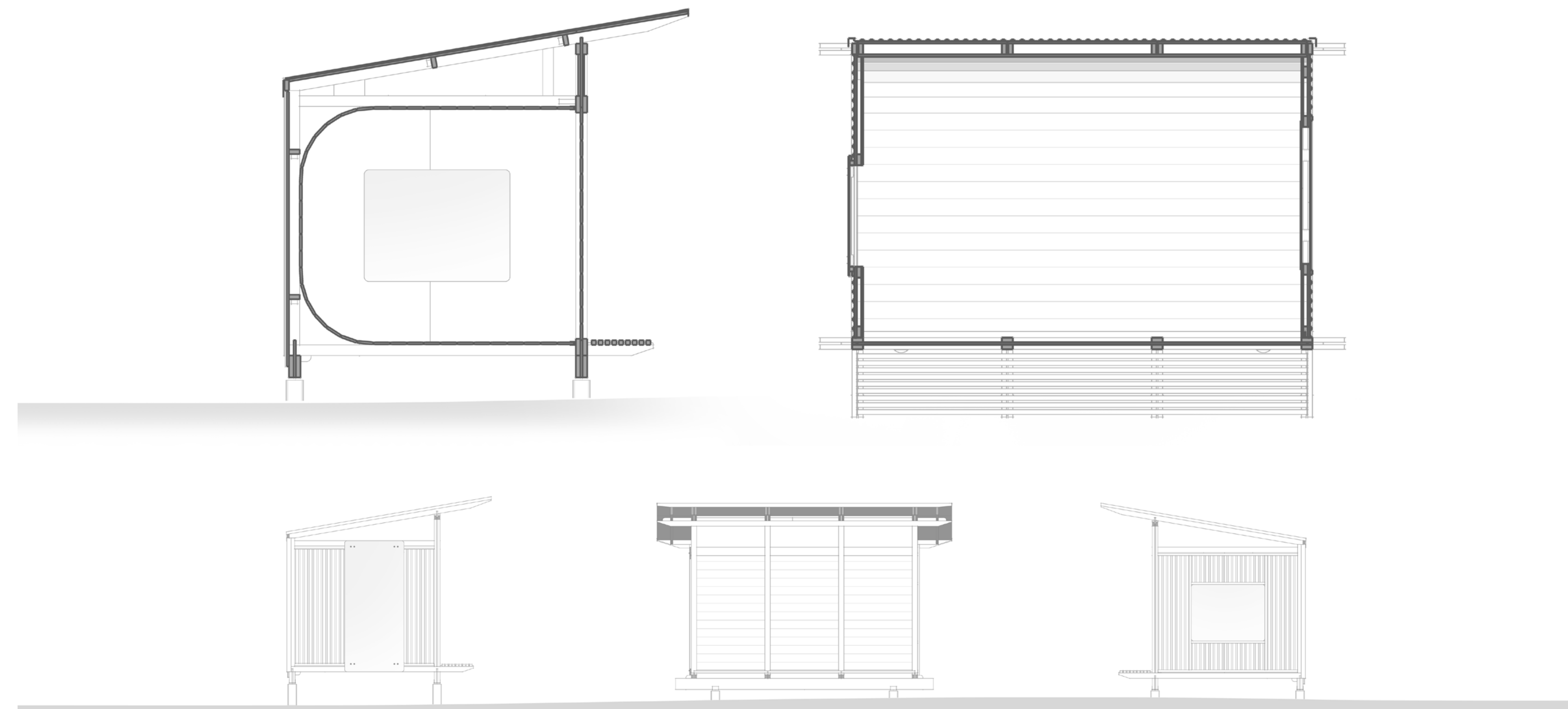


The design of this open C-frame necessitated diagonal corner supports which could then be made into curves that would guide the geometry of the interior finish. This property of a smoothed-out reinforced corner later became a key aesthetical feature of this method’s tectonics.

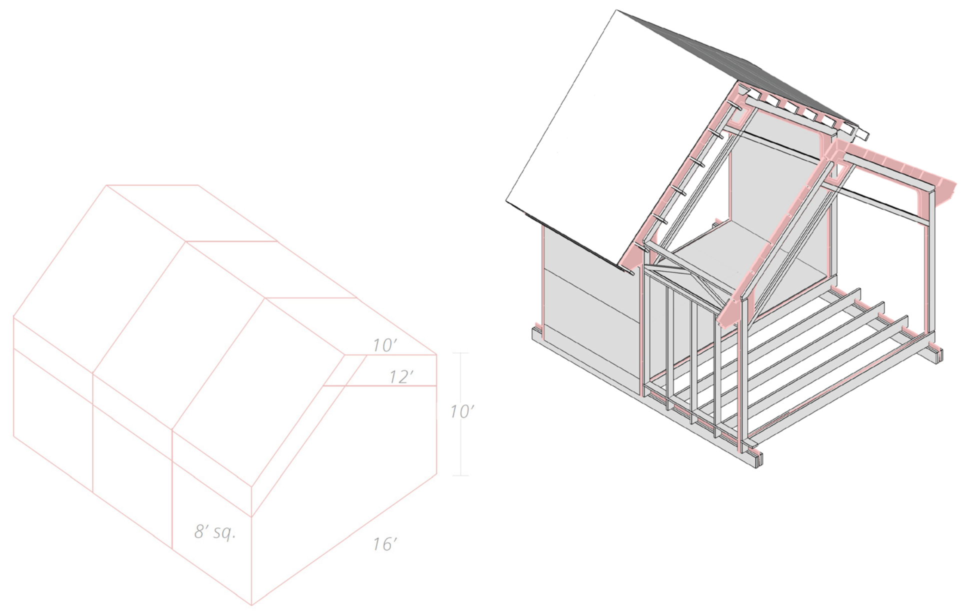
The rounded interior which came as a result of this corner detail was emphasized in the third and final designs by switching from a plywood interior into linear tongue-and-groove planks.



Another key insight which occurred by inverting the sectional rib to have plywood be positioned between two layers on lumber. This change allowed for a clear expression of method-tectonics which was utilized in the final design.



The next phase of design simulation was to explore a larger typology, while looking at articulating the method tectonics within a building's interior. Taking the largest readily available dimension of 16' lumber as primary constraint of the grid, the building module was laid out in sections of 8 feet in length. This necessitated a larger and more complex primary structural frame which was inspired by the stave church roof framing designs.

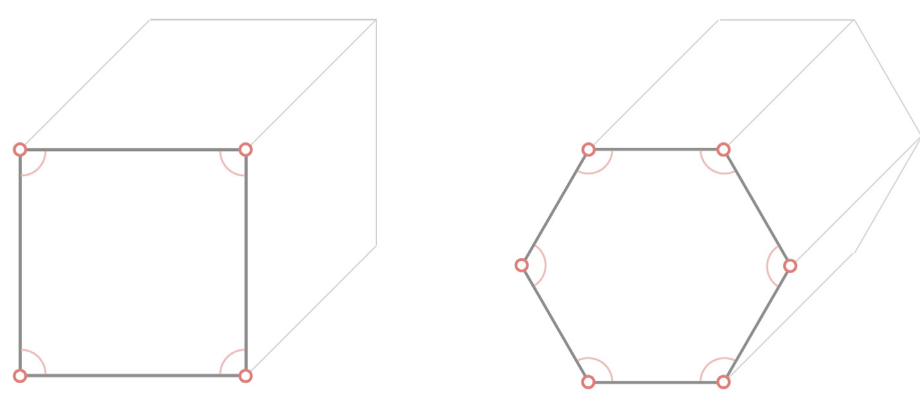


This sectional profile in turn allowed to work with articulate expression at the scale of a joints, and by building on past experiments, the positioning layers of oak plywood were offset and partially rounded to physically guide the position of dimensional wood. Having two layers of 3/4" plywood in between each wood member enabled creating a precut connection for the housing of perpendicular dimensional lumber at mezzanine floor joist supports.

Similar to the lateral reinforcements installed at the base of stave church trusses, the top two feet of the 10' wall height were dedicated to permanent shear support, which left the 8' x 8' bays as modular door, window and other panels. The use of birch plywood as interior finish of these bays was enabled by predrilling pilot holes that would mirror the spacing of wall-module studs. If decorative fasteners were to be used (such as round-headed brass-coated type), this could work as a subtle element of the method tectonics for a structural element that is otherwise hidden.

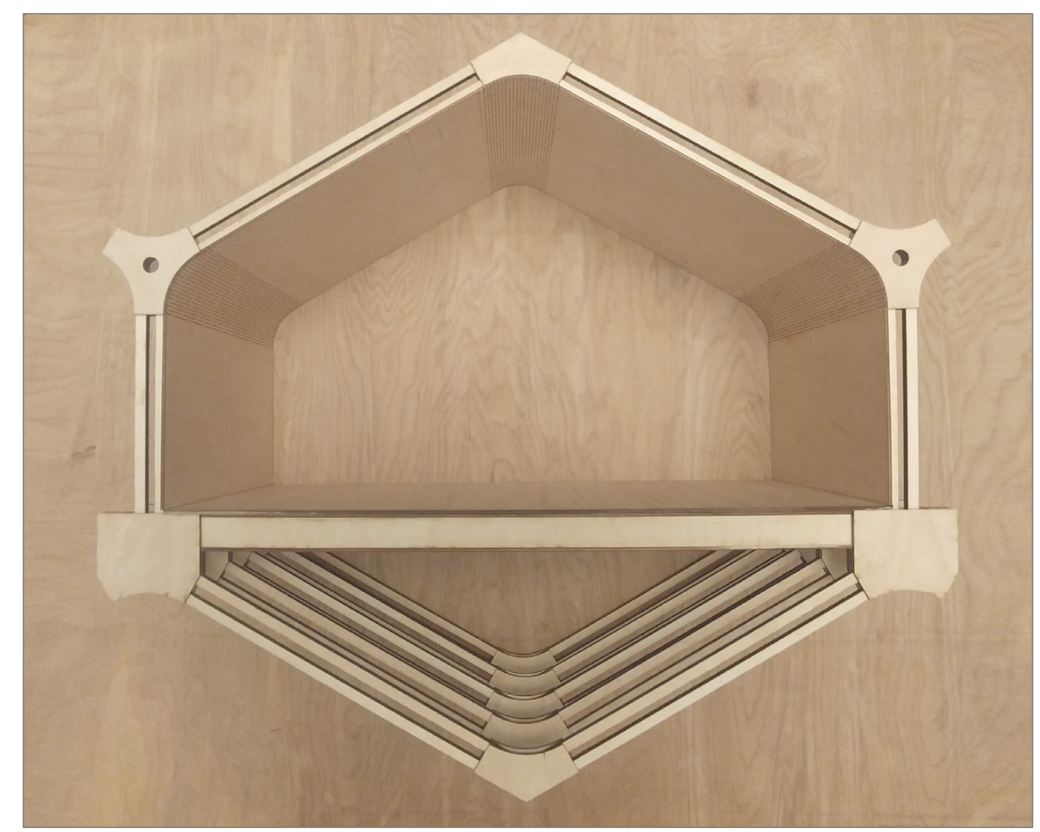
2.3 ISOLATING THE JOINT

So far, all of the experiments generally unified the components of member and joint in defining the overall 'rib' geometry of each project. The previous experiment in clear articulation of the joint provided opportunity to experiment with reducing this rib method into a separate joint.



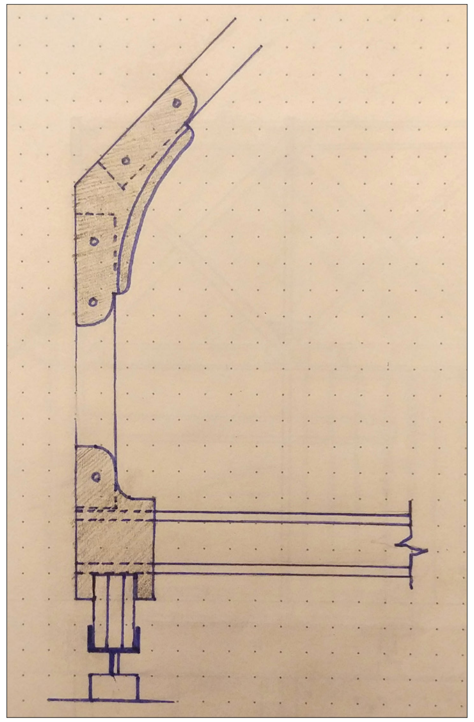
In analysing this concept it became clear that the advantages of 'no-cost complexity' offered by digital fabrication could enable these joints to take on any angles, thereby creating different geometries while using the same set of dimensional wood. Furthermore, reversible screw connections could theoretically make this modular way of assembly re-usable in projects that require the same angle parameters.

This concept was utilized in creating the hive-like cell structure which utilized standard sizes of lumber and engineered wood trusses together with these flexible joints to scale into larger typologies by means of modular stacking. Emerging from the corner geometry of this method, the curved profile edges necessitate a kerfed bend of interior plywood, which in turn became another subtle attribute of this method's tectonics.

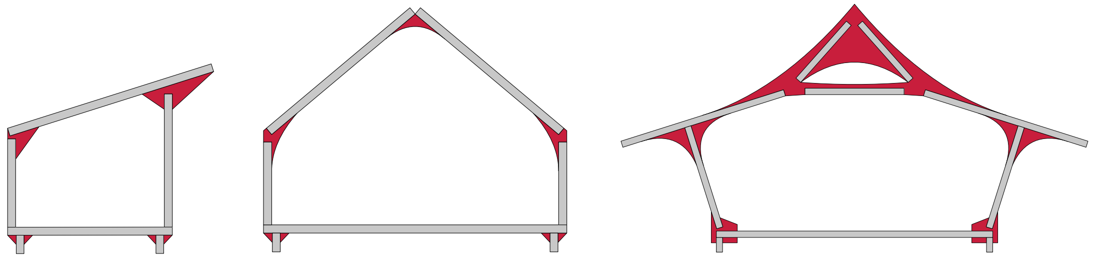


Looking to further develop the expressive character of the joint, the below 1:2 prototype gave opportunity to physically 'feel' how this method of connection could scale into an ornamental way of joining dimensional lumber. A more favourable variation of this joint uses the aforementioned double-inversion, where two or more members would create a more robust primary frame.

The next experiment looked at translating the sketch of an ornamental structure into a 1:12 model, with all the joints laser-cut and assembled to produce a kit-of-parts that assembled from fully prefabricated components. This project helps demonstrate how the geometric flexibility of such joints could be exaggerated to match the desired project aesthetic.



This iteration of the method assumed the use of fully uncut dimensional members, with joint complexity being compensated by infill layer of plywood. After research into the compressive properties of OSB and plywood, however, this logic was revised only be included in places where this load is acceptable.

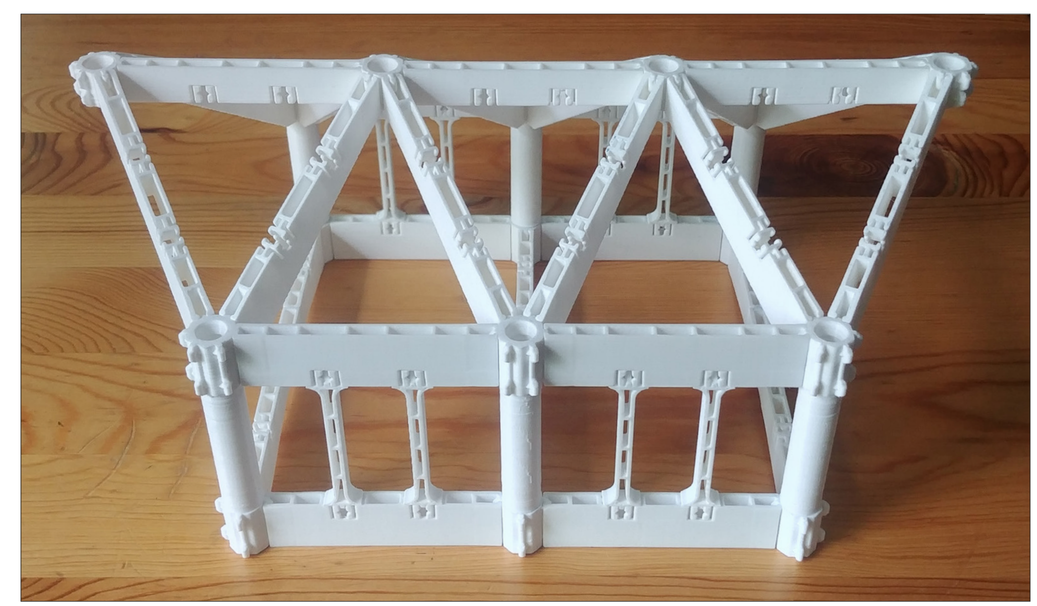


2.4 EXPLORING LARGER TYPOLOGIES

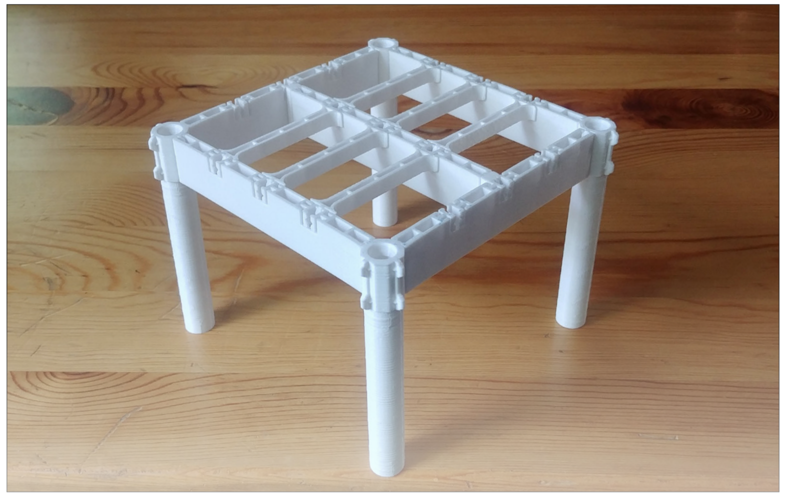
Having explored the initial concepts of digitally-fabricating light wooden frames, the next set of experiments looked at how to create larger digitally-guided typologies.

For the horizontal supports a variation of the double I-truss was used, such as the one described in the first part of this thesis (page 32); while a simple log was used as the column element. Contrasting the raw aesthetics of natural debarked wood with the radial grain of plywood covered engineered beams, this duality of new and old wood was one of the strengths of this heavier method. The main challenge arose from creating secure connections which could utilize the benefits of digital-fabrication. Parallel to working on these 1:1 connections, a scaled 1:25

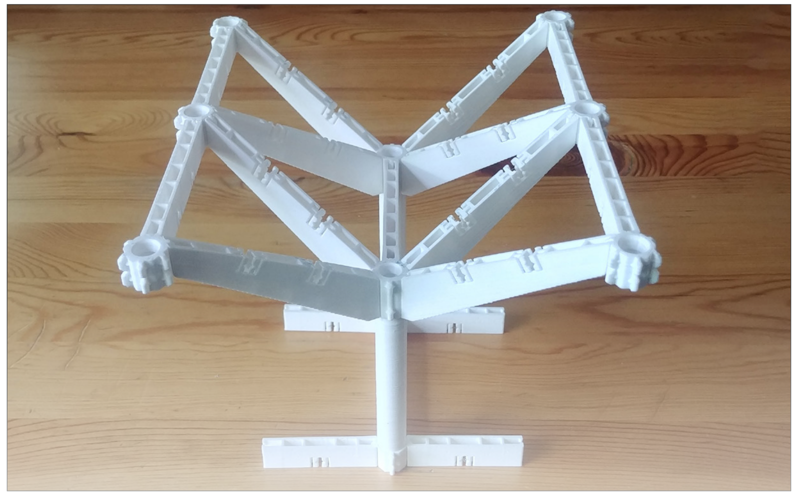
system of these posts and beams was created in pursuit of iterating different typologies which can emerge as a result of this hypothetical modular system. Working with this kit of parts, two more designs explored variations of form and materials.



This project is a re-imagining of concrete-steel open-plan office. The cross-sectional hybrid of columns+shear walls allows for this type of structure to be scaled vertically, while the horizontal floor-ceiling partitions are made out of CLT/NLT to further articulate the new-wood material palette of this design.

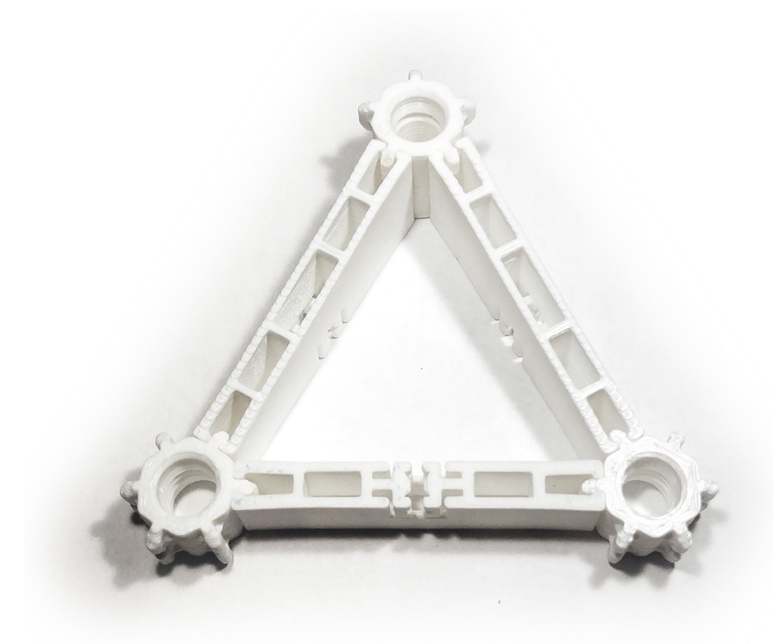


This project imagines the kind of atmosphere possible when curved wood geometry is used in a public environment. Inspired by the Gothic vaults, the scale of this market enclosure is meant to evoke both a feeling of grandeur and lightness by employing the reinforced-rib component.



PART THREE

A KIT OF PARTS



3.1 THE DIGITALLY-GUIDED METHOD

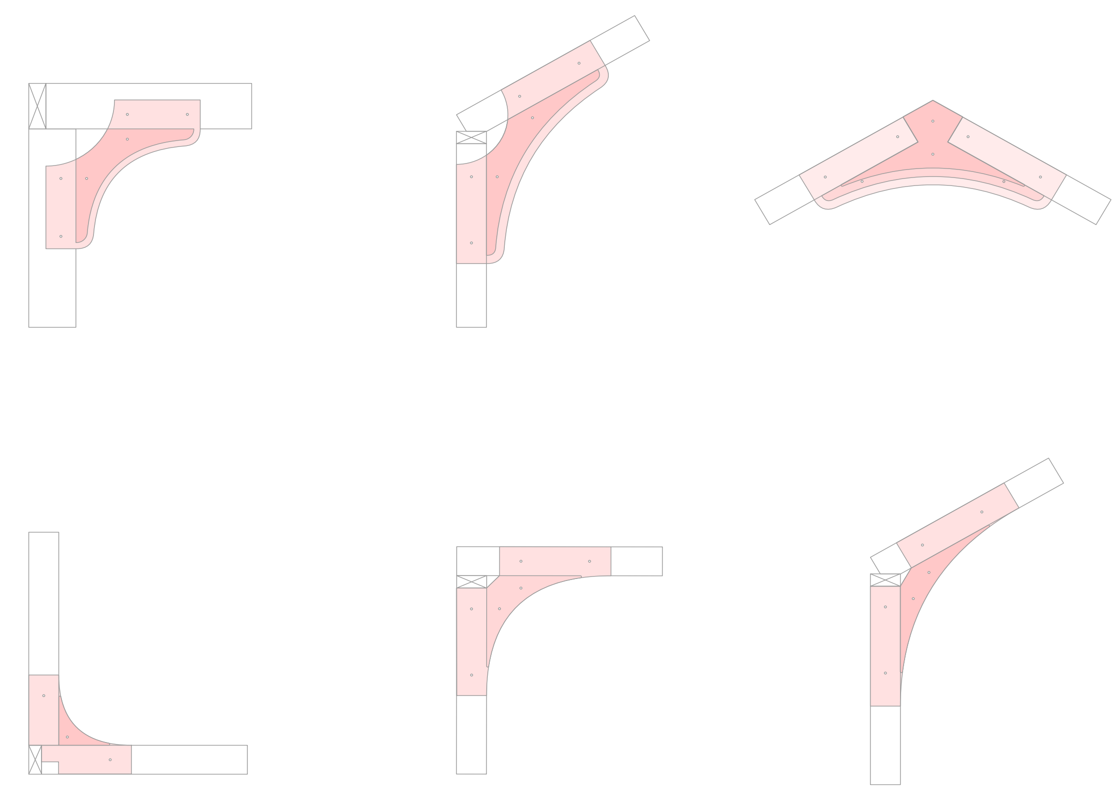
Working within the established logic of dimensional lumber and digital fabrication, the above experiments were instrumental for developing the modular logic of designing and fabricating different architectural objects.

Being assembled from the separate physical elements of members, joints and wall panels, this light-framing system utilizes the flexible geometries of computer-guided fabrication to translate a sketch into a physical form. In addition to this economy of scope, mass-produced benefits offered by the industrial process are also embraced by operating primarily (but not exclusively) within the geometric matrix of a 4' x 8' grid.

By following these two principles, the emerged Digitally-Guided Method can be used to generate a custom kit-of-parts for off-site prefabrication of building components. Furthermore, by gradually developing a universal ecosystem of tested parts this method could lend to an open-form design process, producing geometric variations based on design exploration through the making process. Lastly, the accuracy and accessible nature of digital crafts could make this system accessible to individuals both uploading and downloading designs, as well as user-friendly process of modular on-site installation of prefabricated parts into a functional architectural object.

3.2 THE VARIABLE JOINT

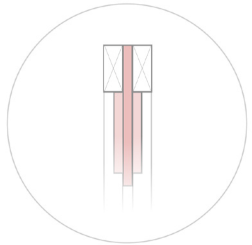
The first category of the digitally guided method is the Variable Joint, which can be used in combination with modular or custom-cut dimensional lumber. Benefitting from digital variance, any angle can be produced, which combined with variation of member length can define the geometry of an overall frame.

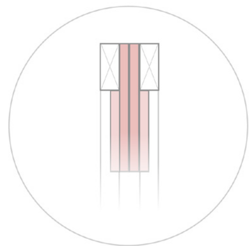


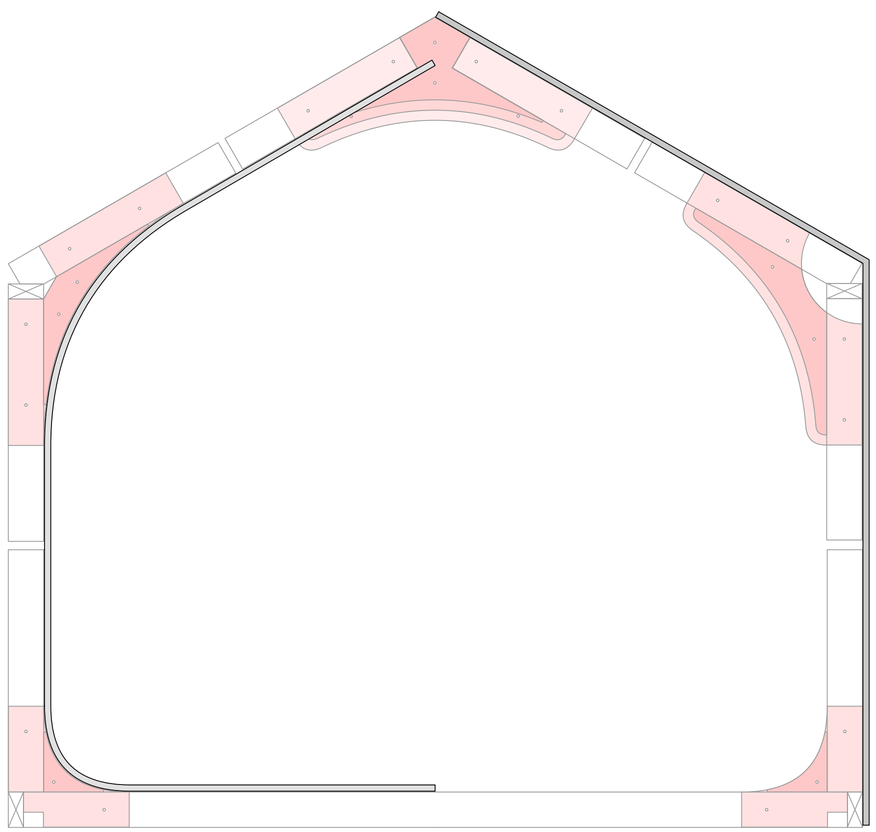
These joints utilize the 1/4" modularity of dimensional lumber and plywood, with different variations of layers possible depending on project parameters. A minimum of two pieces of lumber and one plywood core are required for this type of connection which is used to produce a primary structural frame, with created openings later filled in by self-supporting wall-membrane panels. Depending on the structural load distribution, lumber may need to be precut at the ends or left as is.

The tectonics of this joint emerge from the two properties of i) the layered logic of this method, and; ii) the curved corner transition between wood members. Depending on project requirements these properties can be explicit or implicit - either exposing or concealing this native geometry.

The micro-design shown below illustrates how these materials could be used in a semi-revealed tectonic variant. It uses a 60-degree hexagonal matrix and 8 feet long 2" x 4" wood members to generate a simple example of a rationalized grid. Many different variations of this principle can be used, both within a rigid matrix, or to generate free-form designs.

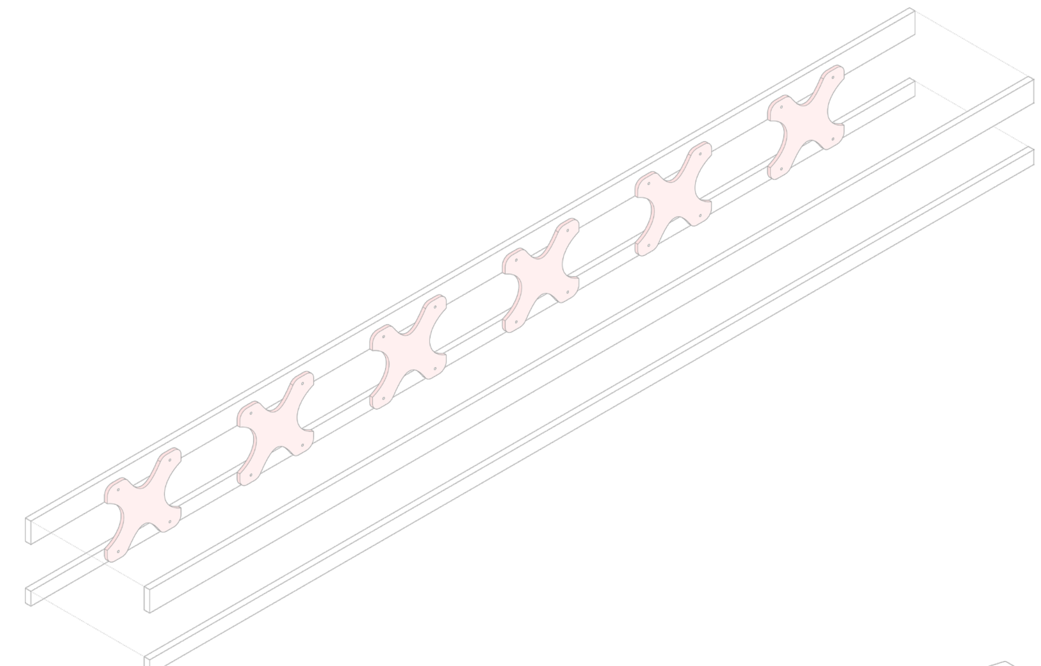


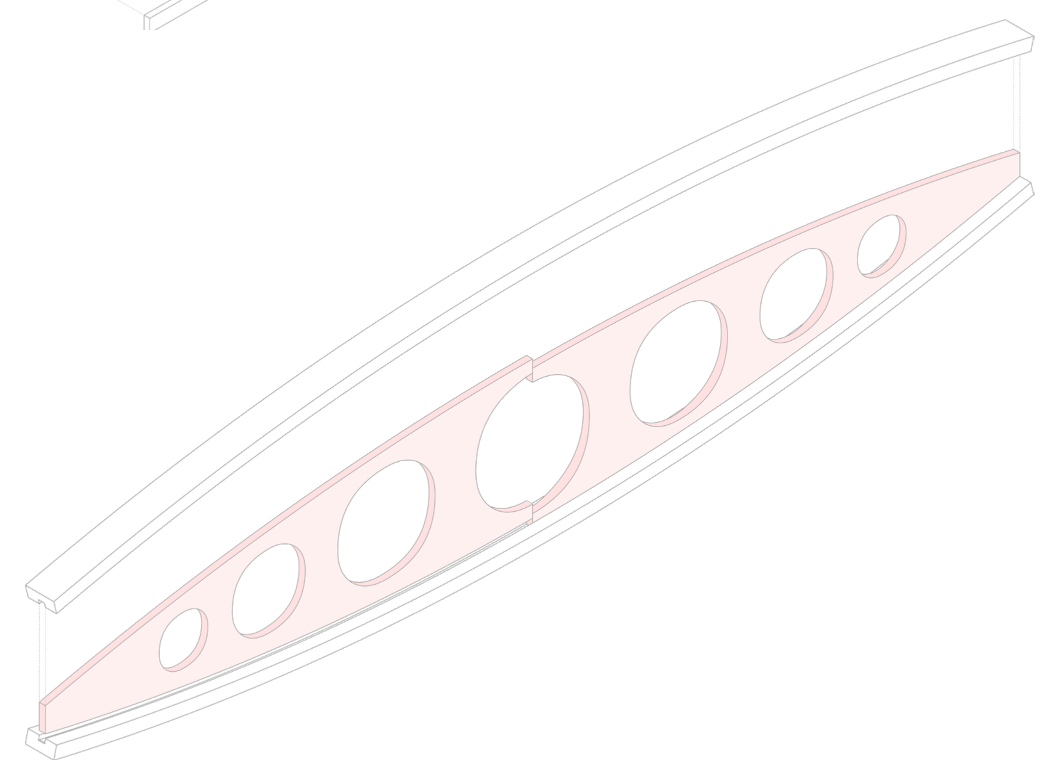




3.3 THE VARIABLE TRUSS

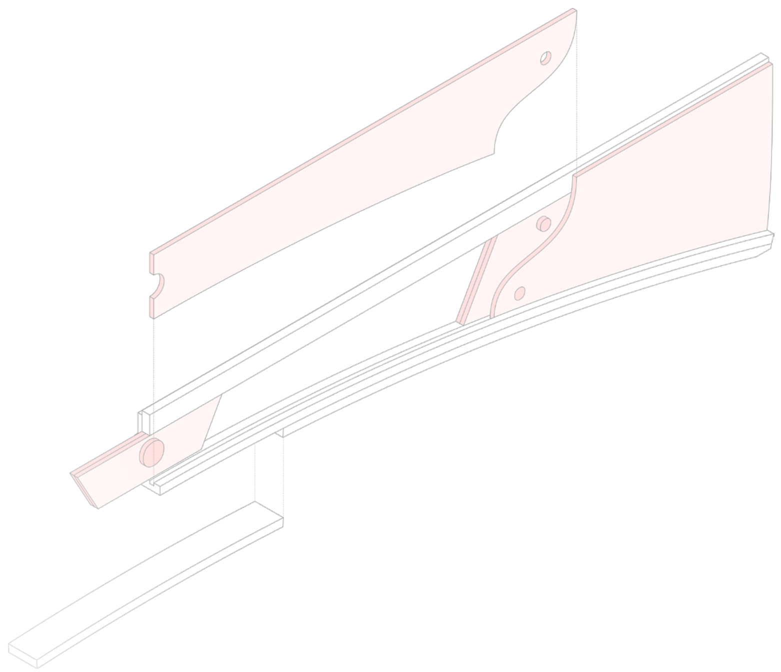
In addition to using off-the-shelf lumber, custom wood truss members can be fabricated by leveraging the flexible geometries of CNC cut plywood and lumber. This allows the truss web to take on different shapes, which while being structurally functional, could produce elements of ornamental design. Furthermore, a precise cut of a curved plywood web allows to produce non-linear composite members, with the curvature of the upper and lower wood flanges being defined by this element.

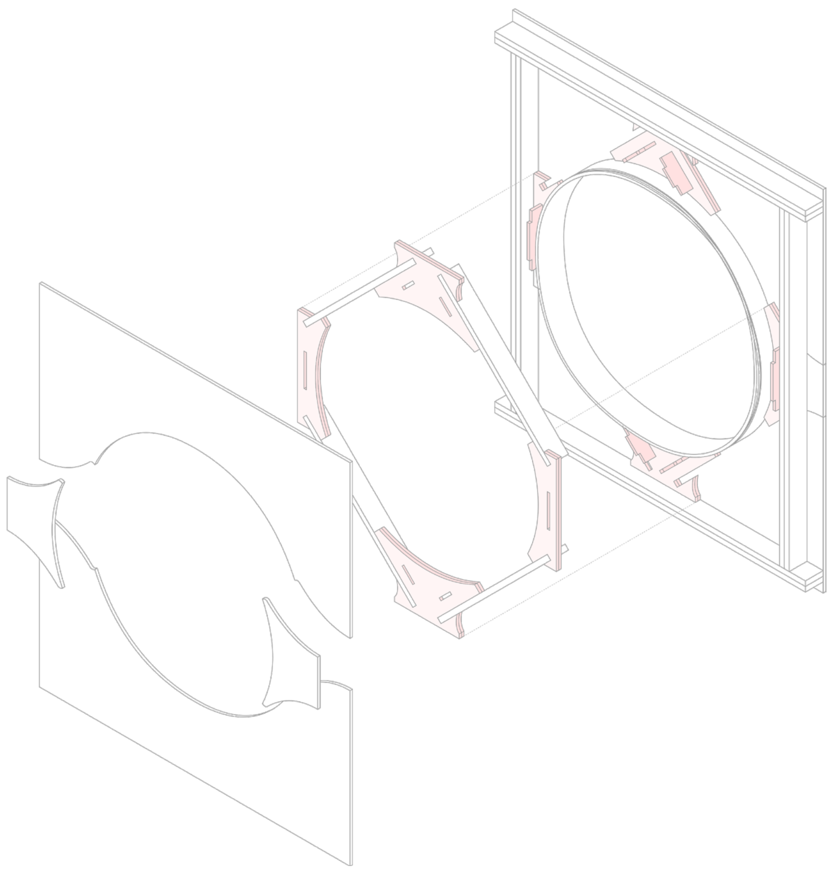


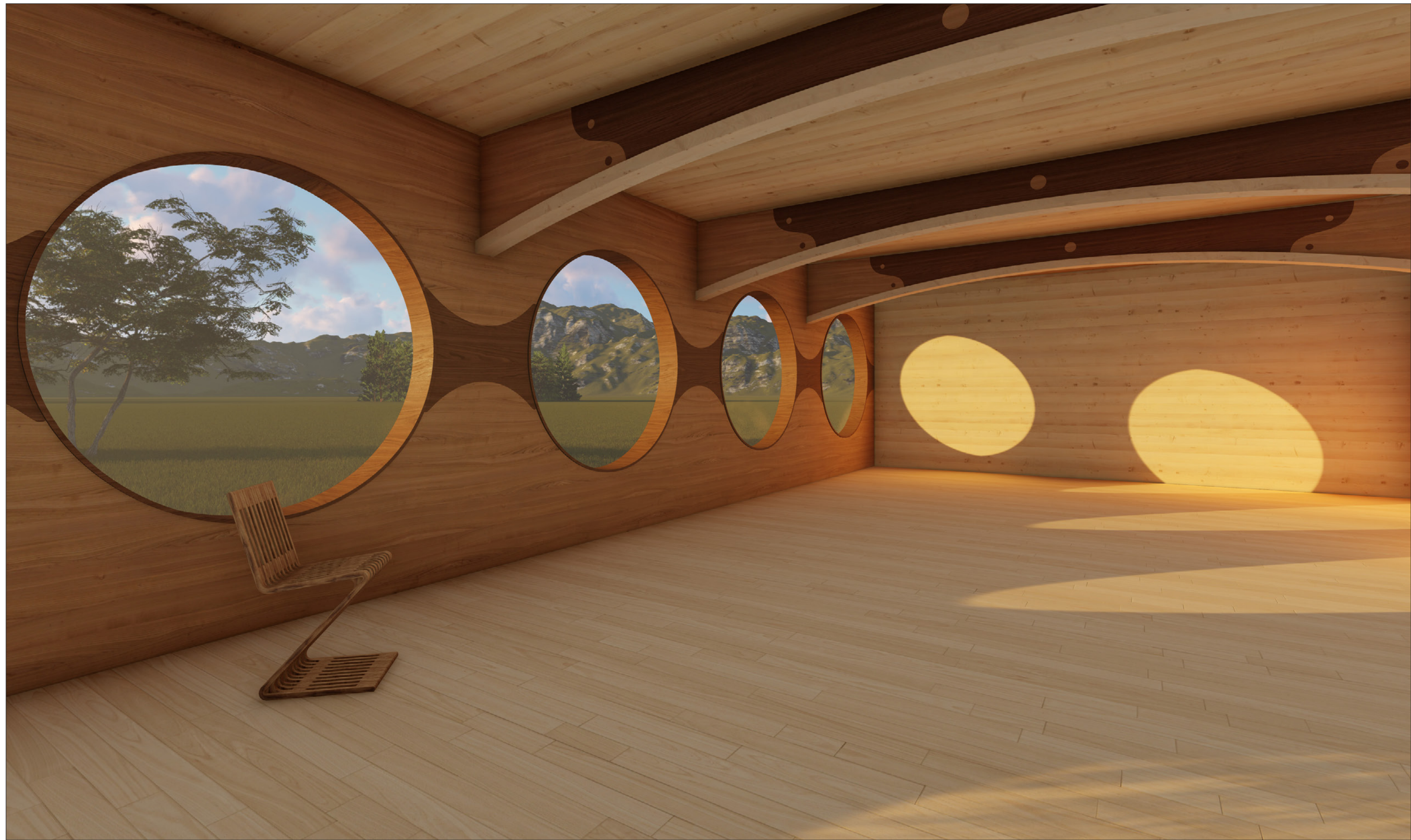


3.4 THE ADAPTABLE PANEL

This third component of the digitally-guided method can likewise be made to take on any geometric mold as appropriate for the project. Furthermore, in some cases it may be possible to have the infill benefit from a sub-variant of the flexible joint which could be designing to accommodate a no-waste cut pattern of lumber components. This design shown below uses two types of plywood for the flexible walls and truss, accurate joining of which is also enabled with a digitally-fabricated seam overlap.

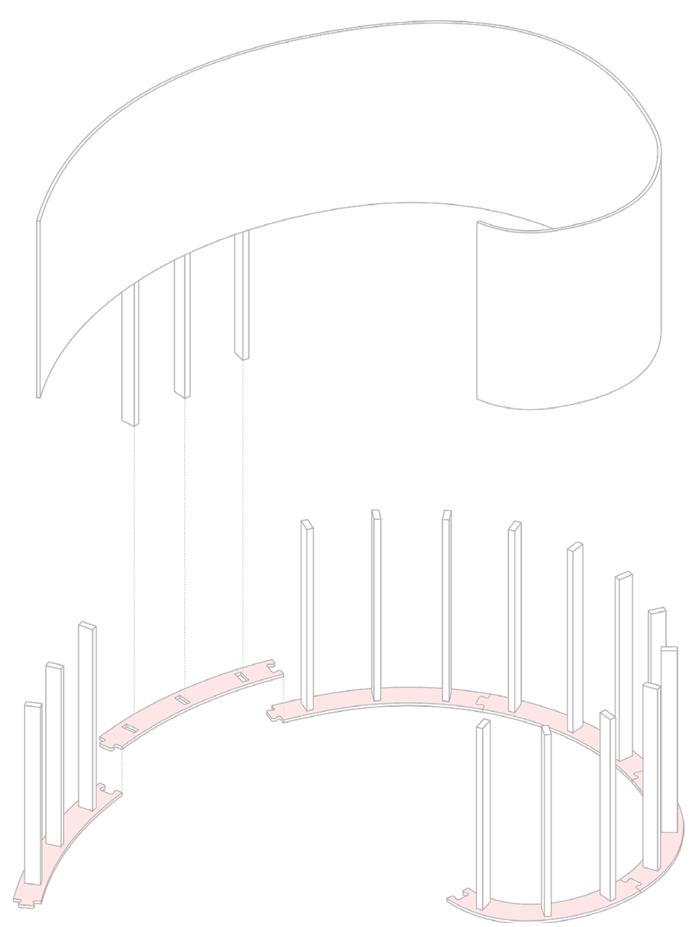






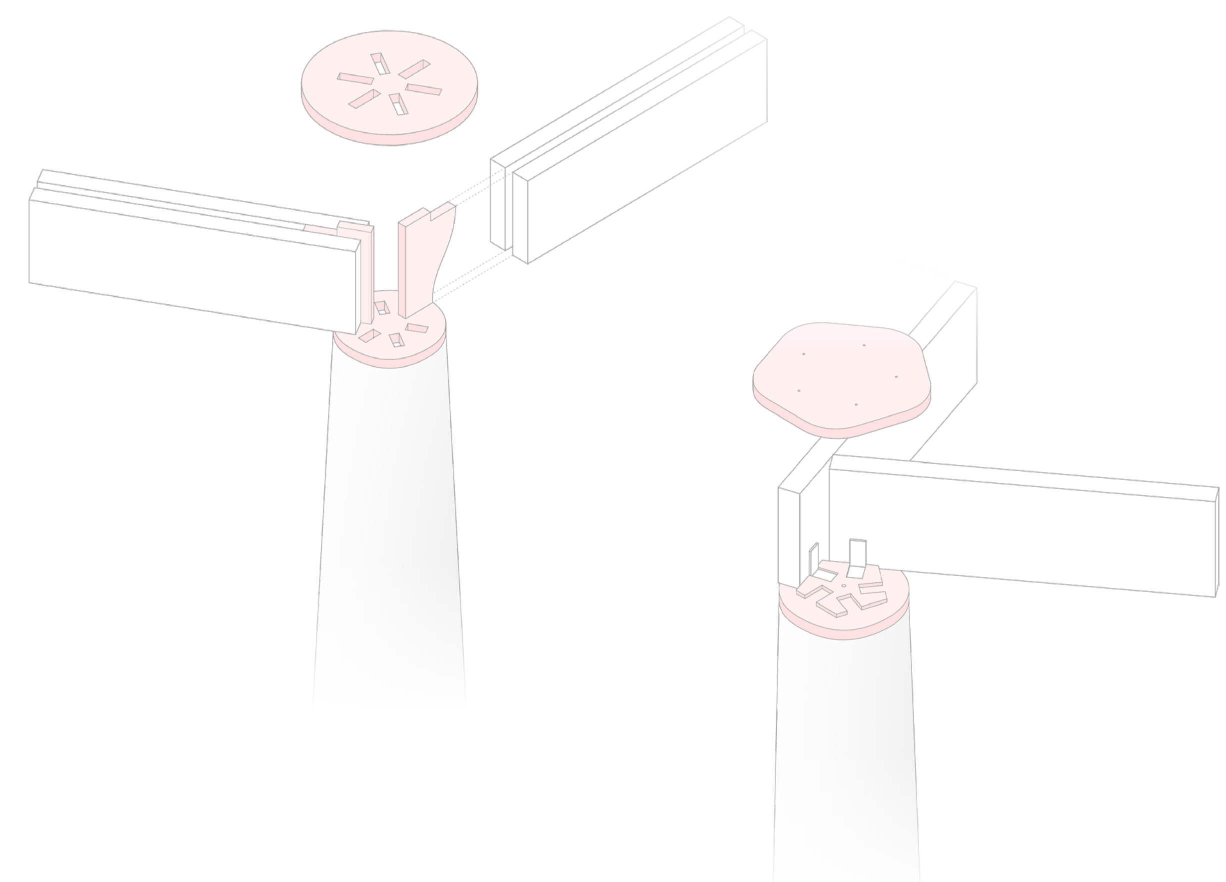
3.5 THE ADAPTABLE SOLEPLATE

The guiding principles of digital fabrication can also be applied in situations where non-standard wall profiles are required. By fabricating a tiled set of sole-plate templates, vertical studs can be precisely positioned into any configuration that would otherwise be difficult to replicate manually.



3.6 THE ADAPTABLE CAPITAL

Despite primarily using manufactured wood components, the logic of this system permits the use of unrefined wood columns which could be locally sourced and prepared on site. Depending on the size of the column it could be compatible with the relatively light-weight framing offered by the previous elements, or require the use of a double-I composite beam described the in previous chapter.



As part of the research, a scaled 1:2 of this flexible joint has been made; with critical review of this and other experiments indicating that several methods of prefabricating a modular capital and key stones need to be further explored.

One possible direction of research could include the use of a robot arm for milling out the joints into sections of log or engineered wood, which could then receive the modular column capitals cut to fit different wood components and angels.

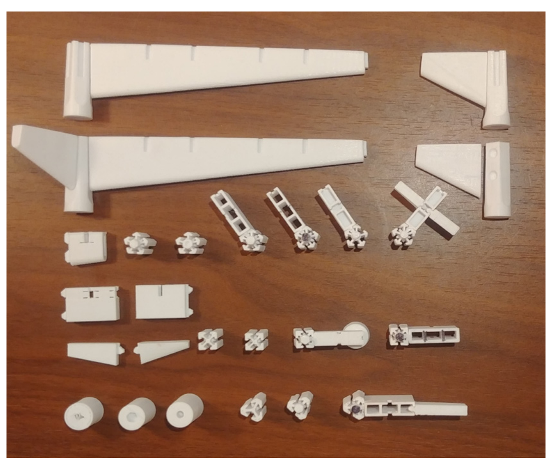
For now, this method still relies on the manual squaring of wood columns with the use of a digitally-fabricated guide to define the angle and depth of the cut. This example uses two such connections, relying on metal fasteners concealed within individual members. The composite component is used in this design only as a key-stone element in connecting the curved wood members alongside the ridge.

PART FOUR

REFLECTIONS

4.1 LIMITATIONS OF SCALE

The experimental components described in the previous chapter are the result of design research which was done either in virtual space, or physically modelled at up to 1:2 scale. Each of these joints, members, and panels reflects the level of technical development reached at the time of writing this thesis; and while having developed a conceptual model for this kit-of-parts, further research is required at a 1:1 scale in order to test the limits of fabrication and structure.



In this pursuit of the next tech-readiness level, the performed experiments in 3D printing a scaled kit of parts can offer an insight into the iterative nature of this experimental design-research. Even at a smaller scale, approximately 80% of the efforts were aimed at the development of a functional connection which would optimise the combined logic of material and process.

It may therefore be safe to assume that the same could also occur at a 1:1 scale, where testing would be done on combinations of new-wood and CNC tools like the 3-axis and the robot arm. This ability to rapidly prototype components through digital fabrication plays a pivotal role in intensifying the cycle of production, testing, deficiency analysis and improvement.

Upon reaching the phase where fabrication and load-bearing capabilities are optimised for each of the digitally-guided joints, these parameters could be combined with the existing data for dimensional and engineered wood components in calculation of structural limits for each building geometry. These in turn can be formalized into standard planar and volumetric 'blocks' which could be used in modular designs. The scale limits of these components would in turn be defined by size availability of those wood products which are used in making these modules.

Once delivered to site, the size and weight of these elements should reflect the on-site installation restrictions which are naturally different in a DIY kit-house as opposed to large volumetric units which can be craned into place. In both cases, the prefabricated components should require minimal on-site adjustments in order to assemble the architectural object.

This bring us to the next question of how these members, joints and wall panels scale into an overall structure. Drawing on the experiments performed in the second part of this thesis, there appear to be two primary categories of this scaling:

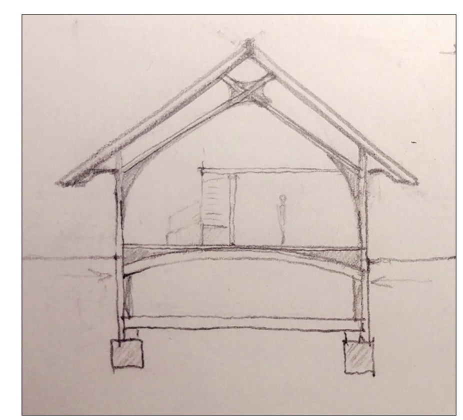
The first approach works by combining linear and planar elements in order to produce either integrated planar components such as those used in the 100 sq.ft Cabin; or as separate framing and wall-infill components utilized in the larger Cottage module. Both of these examples, as well as the experiment in ornamenting the joint (page 62) use the prefabricated logic to create snap-fit connections, secured in place with self-drilling screws.

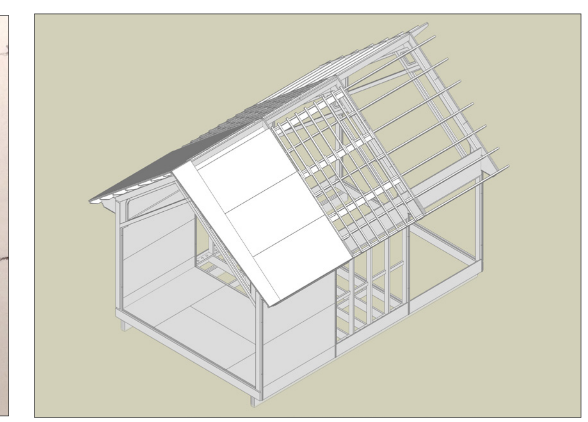
A more robust way of scaling components involves making pre-assembled volumetric modules similar to those utilized in the Wikkelhouse system. For stackable typologies like those explored in the hive-like experiment, this approach of scaling a final building out of identical or variable modules can be utilized where the size of the module is small and rigid enough to be transported in one piece.

The conceptual model of fabricating digitally-guided joints, members and wall panels can be scaled first and foremost based on the known structural properties of these components. Combined with the size of available materials these parts can scale into linear+planar and/or stackable volumetric modules that can be designed and fabricated to meet project intent.

4.2 TOWARDS OPEN-FORM

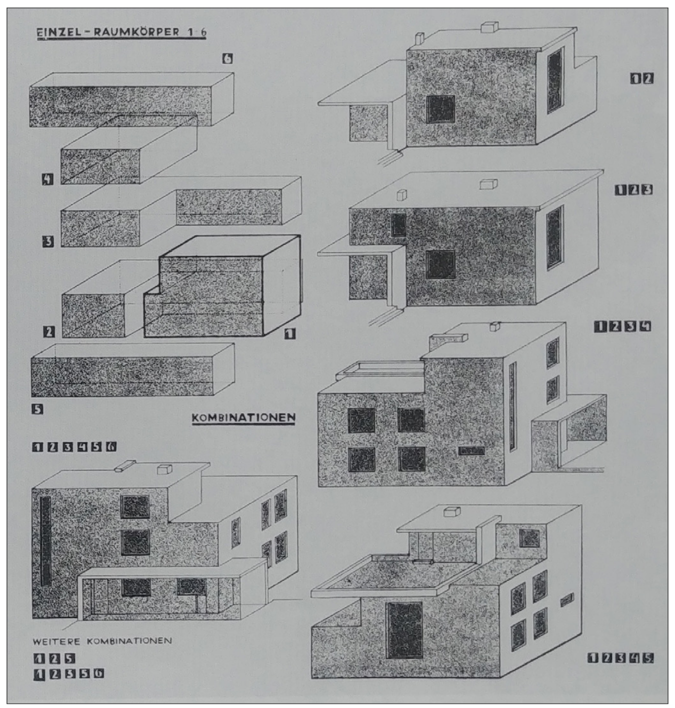
In regards to the logic of designing with this method, it could be divided into three distinct categories. The first approach involves creating a completely proprietary design which could be translated from physical drawing or model into a 3D simulation. This traditional way of designing a 'mold' can benefit from the digital fabrication process by taking advantage of formal flexibility and file-to-factory approach. This can be true for those buildings whose input geometry is too complex for conventional construction; or when the expressive aesthetics of this method are used as part of building tectonics.





In pursuit of modularity, a project could be designed at the scale of individual bay which can then be configured based on project requirements. A simple example of this principle can be seen in the Cottage typology (page 58 and above), where the number of bays determines the linear profile of this building typology.

The process of designing with modular blocks could benefit from including various components which could be linked together in different combinations to produce different variations of form. An example of this approach can be seen in the Baukasten system developed by Walter Gropius and Adolf Meyer:



Images 54: Illustration of the Baukasten System, by Walter Gropius and Adolf Meyer

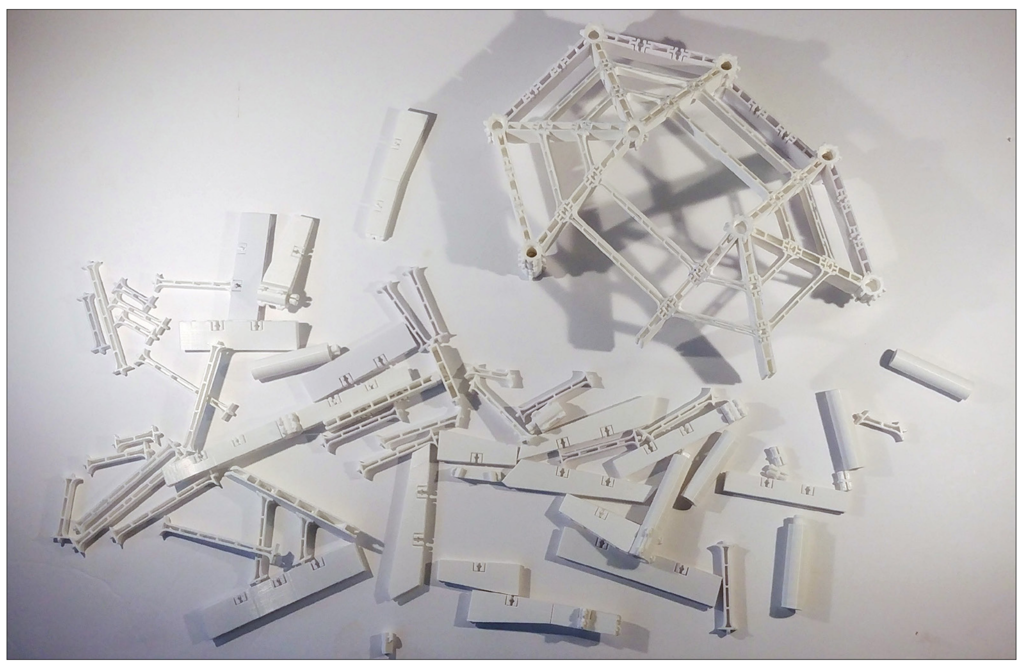
Beyond simple manipulation of adding and stacking different elements of design, the flexible nature of digital tools allows these volumetric blocks to be twisted and bent in various ways; with each element being dynamically updated to reflect these parametric relationships in virtual space. In being modelled to allow for these manipulations, standard modules like the above Cottage could be manipulated into different nonlinear arrays,

with final design made to follow the natural bends of a street or a river as just one example. The data from the dynamic components could then be used to fabricate the physical pieces which would encode the geometric relationship of members and joints, thereby scaling into the required physical form.

In contrast to creating a one-off project, modelling with such a flexible set of components could generate new combinations and variations which emerge as the result of a form-finding approach. Taking this idea further, these modules could be used as a playground for a bottom-up approach, where the architect and client are actively engaged in a process of generative design. Such an Open-Form approach would “not exclude the energy of the client’s initiative but on contrary treat it as a basic, organic, and inseparable component element” (Hansen, 1961).

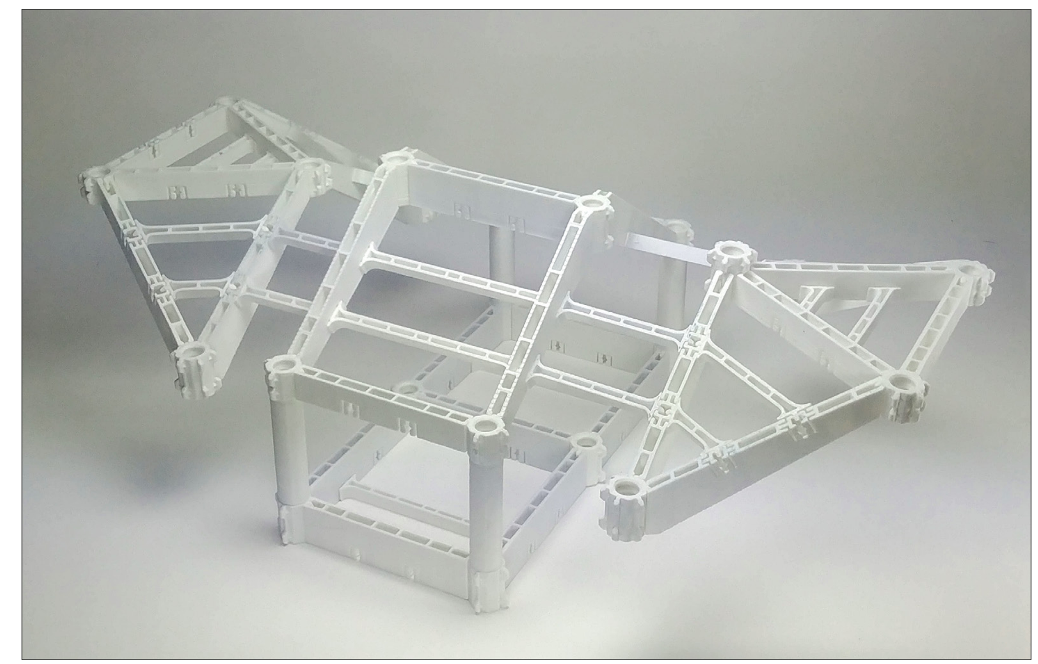
In pursuit of this principle within the modular logic of the digitally-guided method, part of this thesis research focused on developing a scaled kit-of-parts which could be used as a LEGO-like sandbox for iterative design exploration of different morphologies within the material and dimensional framework of the utilized method.

To achieve this, an in-house budget 3D printer was used to develop and fabricate an ecosystem of parts which would represent different elements at a 1:25 scale (1″ = 1mm). This system was then used to prototype various simple spaces such as the market and office experiments (pages 65 & 66), as well as other modular variations in order to test out the process and limitations of this modular kit.



At the time of writing this paper this kit still remains at the stage of early development, with components such as the flexible joints not yet developed to be easily fabricated. Furthermore, the modular logic of this system currently works only within a rectangular and hexagonal grids; which makes the pieces inter-compatible but also limits the type of geometries that could emerge.

Despite these current constraints, experiments in designing through play showed a high level of user engagement with this system - an observation that arose from two informal sessions where different people were able to interact with this open form architectural toolkit. In expanding this toolkit, the flexible nature of a 3D printing process could create various shapes and sizes of components which would integrate with the clickable joint.



Furthermore, because this kit is primarily digitally-crafted, exchange of parts and ideas within an open-source community could catalyse development of new co-created components and assemblies. This could potentially generate a shared library into which people could upload and download their designs, as well as use this open form model to create new design iterations to potentially translate them into a 1:1 scale.

4.3 AESTHETICS AND CONSTRUCTABILITY

The modular system explored in this thesis emerges from the combined logic of digital flexibility and mass-produced standardization. The system itself heavily bases on traditional architectural elements, looking at how a beam, joint, wall and column capital could be prefabricated in the context of new tools and materials. The aesthetic qualities which emerge from this combination play an integral part in this digitally-guided tectonic; however, tectonics of digital fabrication itself extend far beyond the territory of preformed research.

Projects like the Pahu Pavilion and the House 4178 show how the flexible properties of digital fabrication could be used to make unique architectural objects which explore the potential of this technology. In contrast, the aim of this thesis aligns closer to the Wikihouse system, in which the development of a method focuses primarily on the aspects of user constructability.

Here digital fabrication is utilized primarily as a new instrument of surgically machining dimensional new-wood to make architectural objects which are both constructible and aesthetically expressive. In contrast to Architecture as the craft of spaces for human experience, designing a series of simple structures provided a platform for iterative development of the method which could optimise these two criteria.

4.4 BEYOND WOOD

Wood as a building material lends itself very well to the digital fabrication process due to being mailable and abundant. In the case of laminated new-wood products, dimensional constancy makes them well suited for digital processes. Beyond milling these wood products on 3-axis CNC or by means of a robot arm, the boundary of digital fabrication in architecture extends into other material and tool combinations. Many experiments are being performed in this field - from a fluid geometry of machine-laid masonry to fully 3D printed concrete houses.

In all cases, the model of a flexibly variant mold which then drives the digital code for additive or subtractive operations lays at the foundation of this new crafting method. With architecture being made as a sum of different parts, the ability to water-jet stone, plasma-cut metal and 3D print plastics allows buildings to take on new forms; building on the growing foundation of materials which are specifically created for the digital process.

Today homes are made from much more than wood, and with convergence of design and fabrication we see architects regaining control of physically making everything from glass panels to bronze handles; carving and casting each raw material such that it can be combined into a holistic puzzle that would be in exact alignment with one’s imagination, purpose and will.

4.5 CONCLUSION

In its most basic form craft converts material into functional 'stuff', and once this function has been depleted, this same set of atoms turns into the question of waste. In this regard, one of the most inspiring works in the field of digital fabrication comes from some makers who are developing (and sharing) a method of converting plastic bottles into 3D printable filament.

Now imagine a scenario where nearly all the waste of a society is converted back into resources. This might seem unlikely at first, but the problem of garbage is primarily a question of sorting and cross-contamination. Unlike traditional manufacturing which produces complex products that are difficult to break down into separate 'atoms'; flexible manufacturing platforms work within a limited set of materials, thus allowing both off-cuts and simple objects to retain a high level of purity.

In his vision of cradle to cradle, William McDonough suggest the idea of 'upcycling', and this is exactly what happens when a plastic bottle that's no longer useful transforms into another object which will give these old atoms new form, function and life. In this way, digital fabrication could be seen not only as another tool of the human craft, but a technological platform which could take us one step closer to a meaningfully sustainable collective reality.

LIST OF IMAGES

All Other Illustrations are produced by the Author.

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