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Turning Tree Forks into Structures: An Experimental Analysis of a Minimally Processed Material within the Age of Standardization

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Abstract

ABSTRACT: The building industry has dedicated enormous energy to developing processes that can take raw, idiosyncratic materials and produce highly controlled, specifiable products. This has served the building industry well for years. However, this process rejects some natural materials that do not meet the standards of uniformity, regardless of their unique potential. Recent advancements in technology may now allow us to understand these unique qualities and allow us to use these materials in a way that maximizes their potential.

This investigation explores this claim by beginning to develop a system of design and construction using traditionally discarded tree forks.

1. Introduction

Since the Industrial Revolution, the building industry has dedicated enormous energy to developing processes that can take raw, idiosyncratic materials and produce highly controlled, specifiable products. This has served the building industry well for years. Material standardization allows for standardized structural details and procedures that can be easily followed by the common builder to produce structures that can be analyzed and designed based on the uniform properties of the building product. Unfortunately, this process rejects those materials that do not meet the uniformity required, regardless of their unique structural potential.

Recent advancements in digital analysis allow for the ability to identify unique qualities within raw materials. Advancements in computational technology allow for the optimization of a structural design to accommodate for these idiosyncratic properties. The development of a platform, involving digital analysis and computational design, would make this method of design available to the common builder and architect. The development of a process, using common construction techniques, would allow the common builder to build structures using these idiosyncratic pieces. The development of this platform for design, and system of construction, would demonstrate that advancements in technology can initiate a movement towards more sustainable architecture by reducing the amount of processing necessary to use raw materials in a structural capacity.

This will be studied by obtaining an inventory of tree forks and scanning them into a digital inventory. A script will then be developed that optimizes fork fitment to different assembly logics for shell structures. Next, a joinery system and system of construction will be developed that processes the forks based on data outputs from the script. Success will be measured in joint precision and structural rigidity.

Keywords: Tree Fork, Dome, Shell Structure, Catenary Structure, Geodesic, Computational Optimization

2. Context

2.1. Wood Construction Using Logs

The earliest indications of human construction using wood dates back over 7000 years ago in the Mesopotamia region. These include water wells, shelters and sailing ships. These early constructions would have intricate joinery, often with no nails or steel fasteners. Carpenters would start with a log and use an inventory of tools to shape the logs as needed. Carpenters were in tune with the idiosyncrasies of the wood. Each piece would be hand selected and matched to its application based on the size and grain structure of the wood and the conditions of the application.

Louis Sauzedde is a shipwright, and he uses many of the same methods that shipwrights have used for millenniums. His show “Tips From a Shipwright” documents his construction of several different ships, from his selection of the lumber, to the ships maiden voyage. In Season 3 – Episode 2 “How to Choose the Best Lumber for Boat”, Sauzedde describes what he is looking for in a log for each piece of the ship. Some of his analysis of the grain structure is aesthetic. He searches for logs that will achieve beauty through the grain for areas of the boat where structure is less important. Another purpose of his analysis of the grain is for structural potential. Brace knees, for example, are nearly 90-degree angle pieces that connect the bottom of the boat to the sides. They can come under very powerful loads when waves are crashing against the sides. Sauzedde identifies a log with a nearly 90-degree fork (Image 1). He identifies that the grain is running parallel through the log and knows that when he cuts the log in half, he will have a very strong piece of wood that makes a 90-degree angle. This single piece of wood makes a much stronger brace knee than 2 pieces of wood joined together into a 90-degree angle. This type of grain analysis was very common in many early forms of wood construction.

Image 1: Louis Sauzedde analyzes a tree fork that he will use for brace knees [Sauzedde 2020]

2.2. Wood Construction Using Boards

The need for a carpenter to hand select a log for construction purposes was largely eliminated with the advent of the sawmill. The first evidence of sawmills dates back to 200 BCE. The sawmill allowed carpenters to work with flat lumber and wood construction started to look more like the conventional framing we see today. In 1800 AD Machined nails were introduced and wood construction took another step towards modern framing methods. Many carpenters became less interested in grain structure, because the machines of wood processing forced each piece to conform to the same dimensions. The idiosyncrasies of the wood were becoming negligible, and if a pieces’ idiosyncrasies would prevent the piece from conforming to the required dimensions or specifications, it would go unused.

2.3. Modern Methods of Wood Processing

In 1924 lumber standardization was introduced. Lumber standardization requires each piece to be milled to identical dimensional specifications, and then graded based on the composition of the piece. Wood is processed into other wood based structural products such as glulam, LVL, and OSB. The processes of production require large amounts of energy, but after production the pieces meet uniform dimensional and structural specifications.

These uniform dimensional and structural specifications have served the construction industry well for years. They allow minimally skilled laborers to follow pre-established processes and standards of construction. These uniform dimensional and structural specifications decrease the amount of time and energy required by the builder, architects, regulators, and inspectors.

2.4. Shortcomings to Modern Methods of Wood Processing

Modern methods of wood processing, and the processes and standards of construction that come with it, suit most aspects of the building industry very well. However, there are some shortcomings. Many parts of the tree do not conform to the uniformity required. These pieces are ground up and turned into other wood-based products or discarded as waste. Ironically, many of these discarded pieces have the most structural potential, but in order to harness the structural potential one would have to understand the complexities of each unique piece.

3. Argument: Technology Can Be Used to Develop a System That Takes Advantage of the Unique Structural Potential of Traditionally Discarded Pieces of Wood

Advancements in technology can initiate a movement towards more sustainable architecture by reducing the amount of processing necessary to use raw materials in a structural capacity. This study pursues one specific investigation of this claim by experimenting with new processing, design, and construction techniques using traditionally discarded pieces of wood. The investigation explores the possibilities of using these pieces as members in a shell structure. This investigation will use technologies available to the general public and employee a skill set held by the average carpenter.

3.1. Technology to Scan and to Assess Structural Potential

Modern technology has developed the ability to scan pieces of wood and create a digital inventory. This ability is demonstrated in a project by Chris Humphrey. He analyzed recycled structural materials removed from homes within Detroit, specifically boards that pre-date lumber standardization. He used Canny Edge Detection on images of the boards to identify grain structures and abnormalities in these recycled structural elements (Image 2). This same scanning technology can be used to create a digital inventory based on a real inventory of tree forks.

Digital technology can then be used to take the data from the scanned forks and determine their structural properties. This is also demonstrated through the work of Chris Humphry. He took the data from his scanned structural elements and predicted failure points. He then designed a system of peg lamination based on these predicted failure points.

Image 2: Chris Humphrey's use of Canny Edge Detection to predict structural failures in recycled boards [Humphrey 2023]

3.2. Technology to Optimize Design

Digital optimization tools can be used to best fit the inventoried tree forks to a surface that defines a desired structural envelope. This process would optimize fitment based on the size, shape, and structural potential of each tree fork. This is demonstrated through the process of optimization and form fitting used in the Robotically Fabricated Woodchip Barn built by students and faculty at the Architectural Association School of Architecture. They gathered an inventory of tree forks, digitized that inventory, and optimized the design of a structure based on the properties of the individual forks.

3.3. Technology to Create an Accessible System

The use of the forementioned technologies could allow for the development of a system that is easily learned by those currently building structures from standardized lumber and other wood based structural products. The use of these technologies would also allow architects to design structural envelopes using tree forks and accurately communicate those designs to those building the structures.

4. Design Investigation: Development of a System of Construction that Uses Traditionally Discarded Tree Forks to Build a Shell Structure

A script was developed that assists with the process of scanning an inventory of tree forks, assessing the structural potential of each fork, designing the system of assembly, and optimizing that system based on size, shape, and structural potential of each tree fork. An inventory of tree forks was acquired and scanned. The script was used to optimize the design of multiple assembly logics. The script then outputs a data set specifying how each fork should be processed, and a plan of the assembled system. The script can be developed further to perform a structural analysis of each fork and of the system as a whole. Several tree forks will be processed accordingly, and part of a structure will be assembled.

4.1. Assembling an Inventory

30 forks were harvested, scanned and loaded as a digital inventory. The lengths of the forks varied from about 1 meter to almost 4 meters. The diameters varied from 4cm to 17cm. The weights of the forks varied from several kilograms to over 80kgs. With more time available, a larger or more uniform inventory would have been assembled.

4.1.1. Identifying a Tree

Several plots of land with available trees were surveyed by an arborist. Based on the findings from the survey, a tree was selected. The selected tree was a silver maple. The selection process was based on 3 pieces of criteria: 1) Fork and lumber quantity and quality, 2) tree health, 3) location conditions.

Fork and Lumber Quality and Quantity: The selected tree grew in 5 stems, all with frequent, high angle branching. These qualities yield a large, high-quality inventory. The initial survey findings estimated 59 usable forks from this tree. The parts of the tree not used for this study will be well suited for high quality lumber production.

Tree Health: This tree was determined to be actively dying, making it a prime candidate. Removing it clears room for the sapling maples around it to grow in its place.

Location Conditions: This tree is on a steep hill, but there is an access trail and available shoots to drop the 5 stems. No live trees had to be removed. A few dead standing trees had to be removed to clear the shoots.

4.1.2. Marking and Cutting

A minimum branch length to diameter ratio of 3:1 was set based on findings from early experiments with forks and processing jigs. This length to diameter ratio was used to determine cut points while forks were harvested.

4.1.3. Scanning and Converting Data

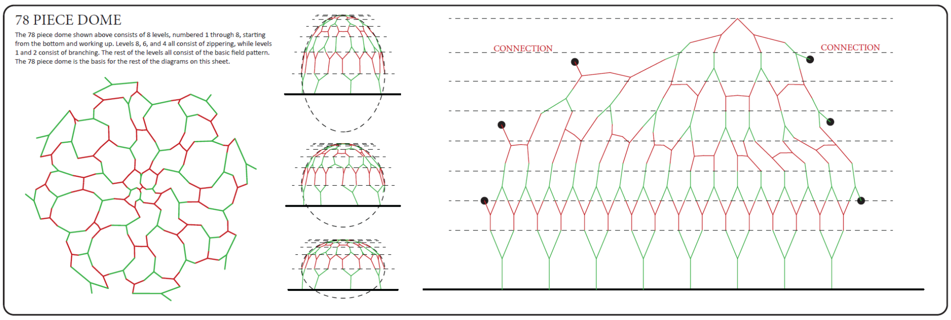
Forks were scanned using a phone scanning app. The app generated scans that were sufficiently accurate for the purposes of this investigation. Scans are exported as FBX files and imported into Rhino. The center lines of the imported meshes are traced manually in the rhino interface and a line is drawn representing the diameter of each branch of the mesh (Image 3). This process produces curved based geometry for each branch of the fork and curve-based geometry defining the diameter of each branch. This process is repeated for each fork in the inventory.

The process of converting the imported meshes into curve-based geometry could be automated in the future.

Image 3: Fork scanning process and its location within the tree [Author 2024]

4.2. Assembly logics

Initial studies for assembly logics were performed using 2-dimensional representation techniques of spherical arrangements of forks. 2 dimensional representations included plans, sections, and map projections (Image 4). After these initial studies, 3 dimensional geometric relationships and assembly logics were studied using Rhino and Grasshopper. These studies used geometric data from the digital inventory of the 30 forks acquired and scanned.


78 PIECE DOME

The 78 piece dome shown above consists of 8 levels, numbered 1 through 8, starting from the bottom and working up. Levels 8, 6, and 4 all consist of zippering, while levels 1 and 2 consist of branching. The rest of the levels all consist of the basic field pattern. The 78 piece dome is the basis for the rest of the diagrams on this sheet.

Image 4: 2-dimensional study of a 78-piece dome [Author 2024]

4.2.1. Top-Down Logic

The top-down approach studied in this investigation involved creating a surface that would define the location of forks. The curves that represent the centerline of the forks are then cut at controllable points, creating parametric geometry that can be applied to the surface. The relationship between each fork and the surface can be controlled. This approach gives the designer a large amount of control and is simple geometrically. However, the surface does not respond to the properties of the forks that are applied to it. The resulting structure is entirely surface driven [image 5].

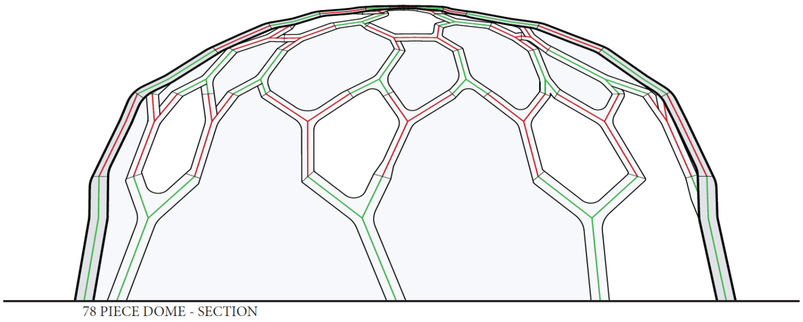


Image 5: A section extracted from a 3-dimensional study of a 78-piece dome assembled using the top-down logic [Author 2024]

4.2.2. Bottom-Up Logic

The bottom-up approach studied in this investigation involved creating a pattern that defines the relationship of each fork and the forks it connects to. After cut controls are applied, a unit of volume is derived for each fork as a function of branch length and branch diameter. This unit of volume, and the length between each fork's cut points establish the conditions for a hanging ridged body simulation. Forks are applied to their respective locations in the hanging geometry, and the assembly is inverted. The shape of the resulting structure is a derivative of only the forks and the dictated hanging points. However, the hanging simulation is very sensitive to small changes in cut controls making the overall shape difficult to control.

4.2.3. Hybrid + Tiling Logic

The hybrid assembly logic incorporates concepts from the bottom-up approach and the top-down approach. This logic of assembly also incorporates a tiling concept. Pieces are arranged into multiple similar arrangements called tiles. These tiles can then be arranged to connect into a larger field of multiple tiles. This simplifies the geometric processes of assembly and improves data measures and controls.

A distribution algorithm is used to distribute inventoried forks to locations within the tiles. The aggregate arrangement of forks is then used to create a catenary surface. The surface is defined by lengths and volumes of the forks within the aggregate arrangement. In the future, a strategy of optimization could be implemented to control the distribution algorithm. In this investigation, forks were categorized, and distributed manually.

Cuts are controlled through the same methods listed above, and cut forks are applied to the catenary surface. In this investigation, a 13-piece assembly was designed using this method [image5].

4.3. Joint Alignment

The script that performs the process outlined above outputs a metric for joint alignment. If two forks line up perfectly, the angular difference is 0. If 2 forks are not inline, a measure of angular alignment is calculated in units of degrees. If the cut point of a fork forces it outside of the geometric bounds of the assembly, then a value of 180 degrees is automatically generated for each connection. After 4 hours of manually editing the cut points of the forks, an average joint alignment of 26.8 degrees was achieved [image 6].

4.4. Optimization of Joint Alignment

An evolutionary optimizer was used that searches to minimize the summation of the square of each connection's misalignment. It minimizes this metric by controlling the cut points of each branch of each fork. After running the optimization tool for 5 minutes an average joint alignment of 94.7 degrees was achieved. After running the optimization tool for 30 minutes an average joint alignment of 52.5 degrees was achieved. After running the optimization tool for 4 hours, an average joint alignment of 22.7 degrees was achieved [image 6].

4.5. Cut Data

The script outputs cut data that can be used to process the pieces. Several methods of cut definitions and joinery methods have been studied. The joinery method that was selected for this investigation is the Lap joint. The cut definitions studied were dependent on different geometric relationships within the system.

One cut method studied in this investigation is defined by the alignment of the individual branches. The cut bisects the branch curves and the lap joint face is cut parallel to this bisection. This results in a versatile joint that can accommodate high levels of angular misalignment, but the cuts are difficult to achieve without the use of a robot. This is because the cut orientations are not defined by the fork as a whole, but rather by the relationship of each of its branches to the adjacent fork branches.

The other cut method that was studied is defined by the relationship of each fork to adjacent forks. By extracting all 3 cut points of each fork, a plane is created for each fork and is intersected with the adjacent fork planes, creating a cut line. A pitch is extracted, and the cut can be made using 2 pieces of data: the cut line and the cut pitch. This method is much easier to execute without the use of a robot, but the joints are not able to accommodate high values of joint misalignment.

Both of the above-mentioned cut methods will be studied further when a section of a 13-piece shell structure designed using the hybrid + tiling logic is built.

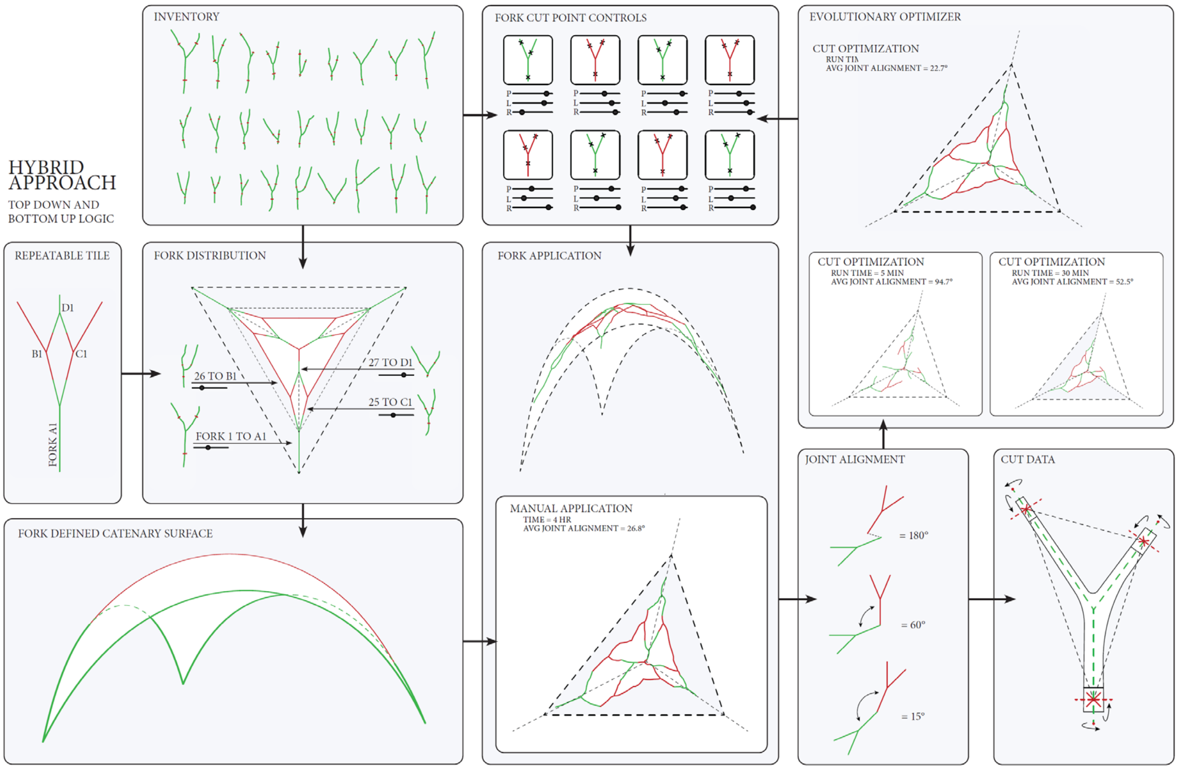


Image 6: A diagram demonstrating the logic for the hybrid assembly and optimization. [Author 2024]

Image 7: Rendering of a small structure designed using the scanned inventory and the process illustrated in the diagram above. [Author 2024]

5. Results and Conclusions

The intention of this investigation is to build a section of the structure illustrated above [image 7] and test the system's rigidity and feasibility. The final installation will be built in a similar manner to the built assembly shown below [image 8]. The investigation is still ongoing, and the installation has not yet been completed. However, at this point in the investigation, several insights for future investigations can be made. While this system would still require a lot of development, based on the results of this investigation, implementing new technologies can help us develop new building systems that use natural materials in a minimally processed form.

Image 8: 4 forks assembled during an early investigation of cutting and joining. [Author 2024]

5.1. Inventory Size and Properties

Based on the variety of pieces that were harvested, and the fork distribution algorithms used, the inventory size of only 30 pieces became a heavy constraint. There is a large variety of diameters to the pieces that were collected. Finding a group of pieces that fit the geometric proportions for a tile in the tiling assembly logic was quite frequent, but their varying diameters were often problematic. After the 30 pieces were sorted by optimal position in the tile, they were sorted again by diameter. With this sorting method, several tiles had to mix piece diameters resulting in difficult joining conditions. In future investigations, the pieces required to inventory ratio should be increased or the diameter of the inventory would be more uniform.

5.2. Cutting and Joining Methods

The cut and joining method that best accommodated high levels of angular misalignment was a very difficult cut to perform without the use of a robot. The use of a robot could make these cuts more achievable. The cut method that was the simplest to perform could not accommodate high levels of angular misalignment. This method could be more achievable by fitting the forks to a form of less curvature.

5.3. Computational Power and Optimization Logics

The access to greater computational power could allow for more complex logics of optimizations. This might include a staged optimization approach. An approach like this might first optimize fork distribution based on a standard unitization of the tile, the surface could then be optimized for this tiling arrangement and then fork cuts could be optimized for joint alignment. angular misalignment. This method could be more achievable by fitting the forks to a form of less curvature.

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I would also like to thank my late grandfather, Ed Chartrand, and my father, David Chartrand. Both are poets. My grandfather spun his poetry on a bandsaw while my father spins his on a lathe. Both taught me their skills and many lessons along the way.

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