

# Tree Fork Truss: An Architecture of Inherent Forms

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Design & Make 2016



I'm tired.

Too many people have contributed to our work over the past year and a half to thank them all by name, but without a few of them, the impossible would have remained just that.

to Chris for the trees,  
to Jack and Tim for swinging sledgehammers,  
to Martin and Charlie for making difficult ideas easy,  
to Pradeep and Swetha for taming the robot,  
to Sahil for nonsensical conversations,  
to Toby for pushing us to be crazy,  
to Emmanuel for help through the end,  
to Georgie and Tia for food to stop me missing home,  
to Barry and Emanuel for a needed push to come to Hooke,  
to Sanjay and Kevin for letting me hide away in the forest,

and to my parents, without whose support so much more than my work over the past sixteen months would not have been possible.

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# Abstract

The Tree Fork Truss which was developed as the Design & Make project at AA's Hooke Park Campus employs twenty distinct beech forks within an intelligent structure. Deriving non-standard timber components from wood's inherent forms, the truss is presented as a unique timber structure, utilizing the capabilities of new technologies. Within a complex and overlapping process involving architects, engineers, foresters and craftsmen, digital technologies played an integral role in each step in the materialisation of the Tree Fork Truss. This process of creating the truss is presented in this paper under four headings, with each section outlining an important part of the work for any future project which attempts to apply digital technologies to naturally occurring forms - timber or otherwise. In the first section, *Establishing a Dataset*, found forms are catalogued, and various digital representations of each created. The use of found materials adds complexity and constraints to the design phase of a project, the second section, *Organizing Inherent Forms*, explores the design of both a suitable structural arrangement and the development of a means for arranging these forms within. Carried out in this case by Hooke Park's new 6-axis robotic arm, in *Materialising Information* the relationship of one piece to another is applied to each fork by way of milled connections. With the finished 'components' prepared, *Assembling by Hand* discusses ways in which these complex materials are brought together – informed by a 3D model, but performed manually. These four sections are not intended to present the process as a directly chronological one, as the development of many pieces occurred simultaneously. Instead, as architects continue to explore organic forms, the innovative digital workflow used to gain control over these complex forms explores the exciting potential of architecture developed from a unique interaction of natural materials, traditional craftsmanship and new technologies.









# Introduction

Wood has served as an essential structural material for millennia. Early builders, limited in their ability to apply energy to this inherently varied material, developed complex jointing systems which used wood's 'embodied information' to their benefit. With the development of machinery, industrialization allowed for the application of increased physical energy to shape building materials. Variation, once valued, became an obstacle to overcome, with machinery enabling repetition and standardization over customization. Buildings of the industrial period were therefore shaped by the rhythm of standardized materials as seen in the predominance of building systems such as the stick frame house.

Over the past 30 years, rigid mechanical processes of standardization have begun to be replaced by digital manipulation, allowing for the mass customization of components. Wood has seen a resurgence as a 'high-tech' material, utilized by architects and fabricators to construct complex 'free forms' at enormous scales.<sup>1</sup> Regrettably, in most cases, these organic forms are not attributable to solely the properties of timber. Instead, digital tools are used to create complex components from homogenized wood products which, stripped of their embodied information by being sawn in to ever smaller square sections, are glued back together before undergoing a subtractive machining process. This inefficient means of creating unique components might be better identified as 'hyper-industrial' than 'digital' – as they fail to take full advantage of the potential of these information rich tools.

Drawing an analogy between natural and industrial processes, artist Giuseppe Penone's work reminds us that organic materials such as wood already present a 'non-standard series'. If some level of embodied information remains within the large sawn beams he works with, Penone's transformations of a contemporary glulamated beam describe the concept of 'hyper-industrial'.

Using only a hammer and chisel, Penone's work remains a heroic artistic practice. Inspired by Penone's intent to 'follow its [material] lead',<sup>2</sup> this year's Design & Make project explores a different vision for the potential of 'digital' wooden building. Misapplied in the development of complex forms from standardized materials, digital tools have the potential to allow: "a nimbler exploitation of organic building materials like timber or stone, which may be structurally unpredictable due to natural variations. Nonstandard technologies could interact with such irregularities, and adapt form and design to the variability of nature almost as aptly as artisanal manipulation once did."<sup>3</sup> Referring to the traditional use of irregular timbers such as tree forks, in the fabrication of curved components for wooden boat hulls, the con-

1 Buri, Hans Ulrich and Yves Weinand. "The Tectonics of Timber Architecture in the Digital Age", in *Building with Timber: Paths into the Future*, edited by Hermann Kaufmann et al (Munich: Prestel Verlag, 2011), 58.

2 Enright, Robert, "The Perfection of the Tree and Other Material Concerns," *Border Crossings* (December, 2013. Accessed December 29, 2015. <http://bordercrossingsmag.com/article/the-perfection-of-the-tree-and-other-material-concerns>)

3 Mario Carpo, *The Alphabet and the Algorithm* (Cambridge: MIT Press), 105.

struction of a large span arched Vierendeel<sup>4</sup> truss composed of twenty beech forks is presented in this year's Design & Make project as a full scale materialisation of this idea. Through an innovative and digitally informed workflow, forks from the Hooke Park forest were harvested to create a structure with minimal processing.

Surveying Hooke Park's beech compartments, a database of potential 'components' was established, and from it, a structural concept was developed. Based on the criteria of this structure, 25 forks were harvested from the forest, brought back to the campus and scanned in 3D. An organization script was used to generate a final arrangement of forks in collaboration with engineers from Arup.<sup>5</sup> This model was then translated into fabrication information with which Hooke Park's new robotic arm transformed each fork into a finished 'component' – fabricating connections which establish each fork's relationship to those around it. After being pre-assembled manually in the Big Shed,<sup>6</sup> the Tree Fork Truss was successfully erected on site.

Digital fabrication tools, in line with their mechanical predecessors, are typically employed to achieve exact 1:1 representations of a thoroughly crafted 3D model – making components which 'click' together. Though enabled by these same precise tools, the use of minimally processed timber establishes the Tree Fork Truss as a fundamentally different structure. Wood in this state remains a dynamic and deviant material, and the successful realization of a structure which approached the digital model could not have occurred without skillful manual operations - from careful felling to eventual assembly. The successful realization of the Tree Fork Truss is not positioned to propose a future of structures composed entirely of forks, but rather to show that these technologies and techniques might be employed more creatively. When used on materials in a raw state they might help to recapture some of the depth of knowledge lost to industrialization; and in doing so elicit exciting, unpredictable architectural forms derived directly from nature.

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4 The Vierendeel is a type of truss used in both bridges and buildings which is non-triangulated – recognizable by its four sided openings. Where a typical truss gains stability by triangulation, its members joined by non rigid 'pin' connections, the Vierendeel gains stability through rigid, 'moment' resisting connections. Within the Tree Fork Truss arrangement, the rigid triangular forms of the forks allow the development of a hybrid – a non-triangulated truss whose members are joined by 'pin' connections.

5 Francis Archer, Coco Van Egeraat, and Naotaka Minami of Arup provided structural analysis and evaluation throughout the Tree Fork Truss project.

6 The Big Shed is Hooke Park's large assembly building – home to the new robotic arm.

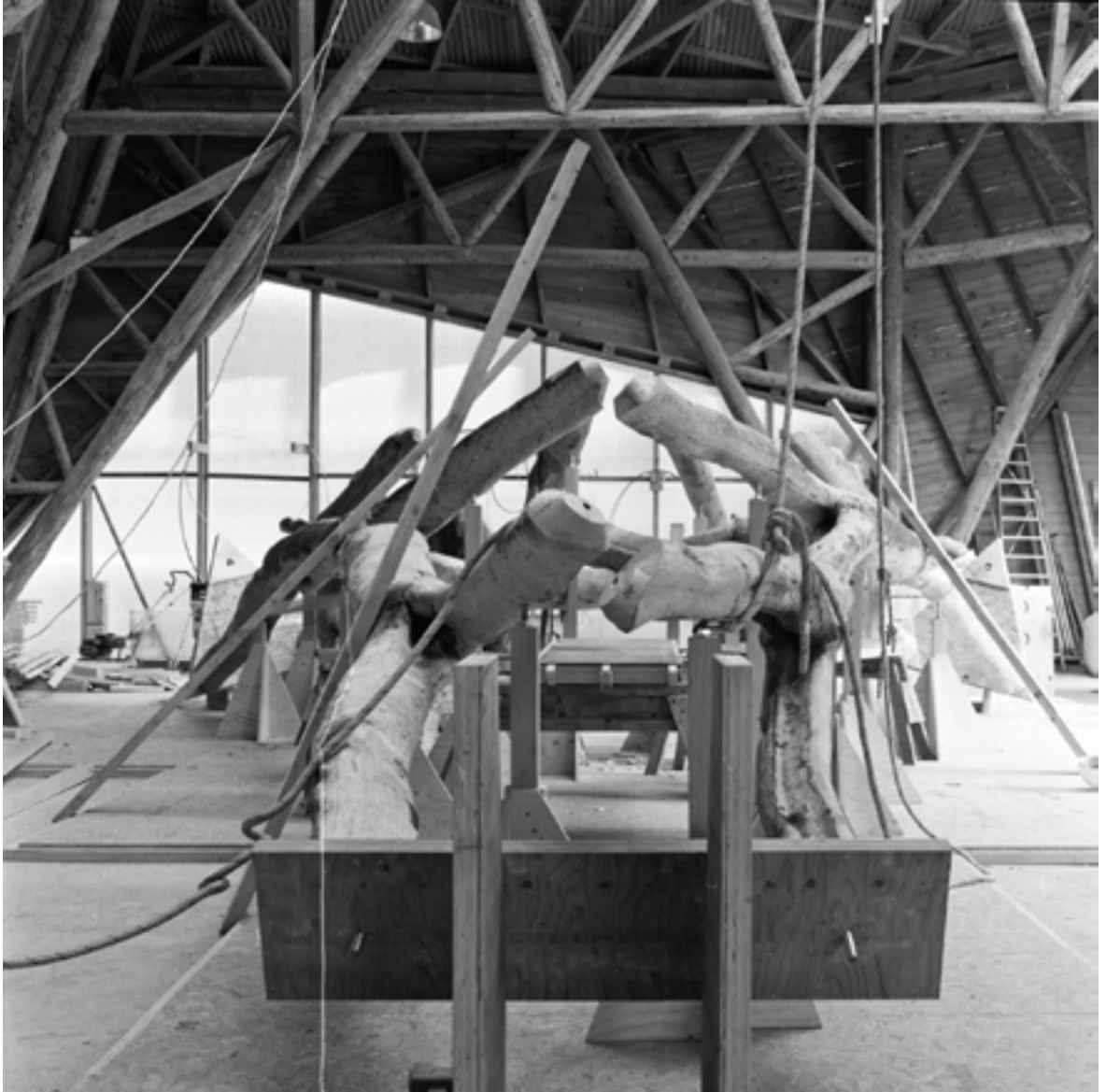


Fig. 1. Rear half of the Tree Fork Truss being assembled in the Big Shed

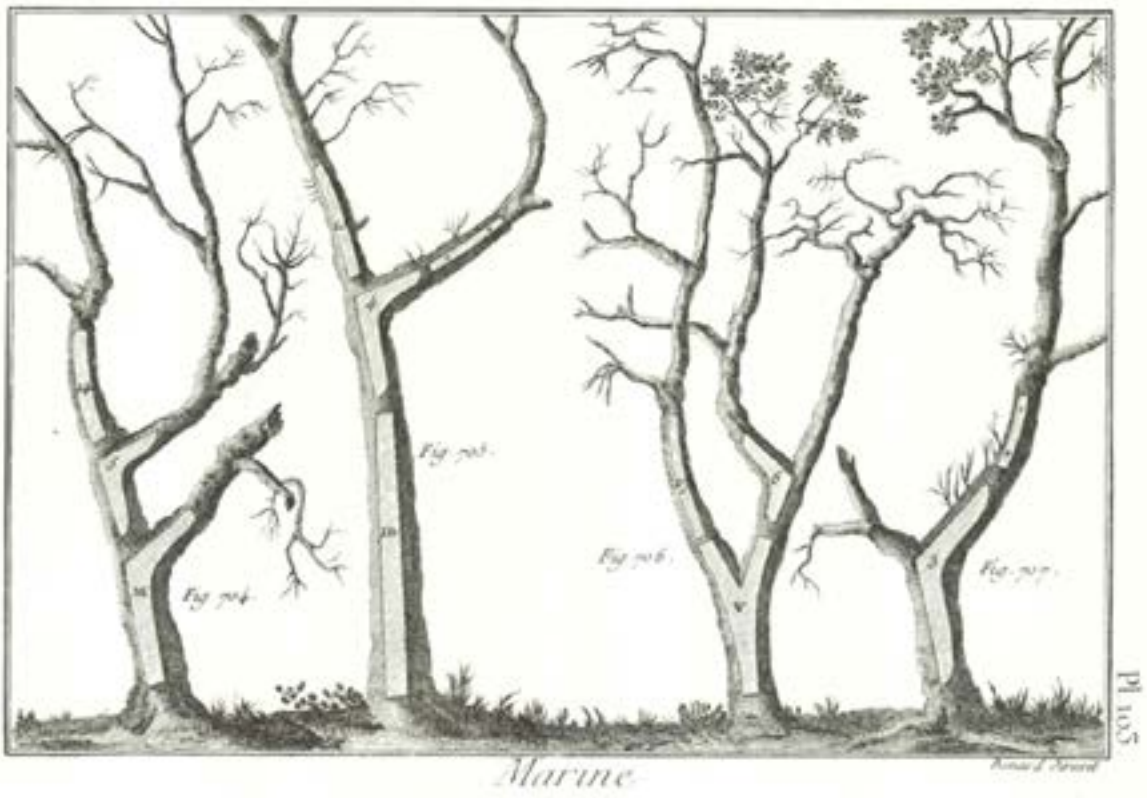


Fig. 2. This plate from the 18<sup>th</sup> Century text *Encyclopédie méthodique: Marine* illustrates a selection of the forms which traditional boat builders sought within the bends and joins of trees.

# Building with Wood

Timber construction is one of the oldest and most sustainable forms of building.<sup>7</sup> A naturally occurring material – forming over time without human intervention – wood retains properties of its development from its external geometric form down to microscopic properties. As Giuseppe Penone<sup>8</sup> explains: “the tree is a living being that fossilized its life in its form and that every part, every leaf, every single branch of it is necessarily linked to its survival, to its life; there is nothing random about a tree, anything in excess or shortage, its shape is exactly what it needs to live and for its survival.”<sup>9</sup> While trees might be classed generally into a handful of common forms, Penone makes clear that each tree remains unique. Emanuel Jannasch of Dalhousie School of Architecture describes this uniqueness of the internal memory of wood and other organic materials as their ‘embodied information.’<sup>10</sup>

The use of any material is fundamentally affected by the tools available at a given time. Authors Hani Buri and Yves Weinand suggest that the history of timber building can be divided into three phases. The ‘wooden,’ in which craftsmen build sensitively to the inherent forms and qualities of timber; the ‘industrial,’ in which machine tools allowed manufacturers to overcome the limitations and innate properties of timber by applying increased quantities of energy; and the ‘digital’ into which they group the use of new information-tool technologies to create complex new forms from standardized timber sections.<sup>11</sup>

The prevalence of wood in early construction can be attributed to the fact that it was readily available, is easily worked and can be transformed into a building material with minimal processing. Equipped with a limited array of hand tools, carpenters of this period developed joinery techniques which were sensitive to the inherent, variable information of wood. Carpenters “worked with the wood’s natural growth patterns, adapting the building’s design to fit as necessary. Each element was finished to connect smoothly with the neighbouring parts.”<sup>12</sup> A traditional example of particular relevance to the Design & Make project’s use of naturally formed hardwood tree forks is the use of curved timber sections in the fabrication of various components required to construct a wooden boat hull in this period. In need of a range of different pieces, traditional shipbuilders selected their materials based not only on the geometric form of a piece of wood but also an understanding of the strength of its grains. By aligning the grains of these branched members which had grown in response to specific loads they had carried while standing into their designs, boat builders were able to construct

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7 Kolarevic, Branko, editor. *Architecture in the Digital Age: Design and Manufacturing* (London: Spon Press, 2003), 135.

8 Trees appear commonly in the work of Giuseppe Penone in which he often compares natural and artificial processes.

9 Natalini, Arabella and Sergio Risaliti. *Giuseppe Penone: Perspective Vegetable* (Florence: Form, 2014), 49.

10 Jannasch, Emanuel. “Cultivating Complexity.” (Abstract outline sheet. Dalhousie School of Architecture, 2014)

11 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 56.

12 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 57.



Fig. 3. Counter to the sensitive use of wood by early craftsmen, this aerial photo shot in 1950 by William Garnett shows the change to building systems based on standardized materials under mechanization.



stronger vessels.<sup>13</sup>

Artist Giuseppe Penone who himself works primarily by traditional means with a hammer and chisel aptly describes the sensitivity exhibited by craftsmen of this era. “It is not possible to use materials without taking into consideration their characteristics. It is not possible to use materials only for their exterior shapes without understanding and respecting them. A blacksmith I once knew told me: “In order to produce a good object in wrought iron, you do not have to strike it with obtuse strength, but rather you must watch it, understand it, feed it with the fire and caress it with strokes of the hammer. Only in this way will you be able to extol its virtues.””<sup>14</sup> As a result, constructions of the wooden age were necessarily unique – the result of an interplay between tool, craftsman and wood’s embodied information.

In pursuit of increased production of repeatable forms, industrialization introduced machinery capable of striking with ‘obtuse strength.’ In this context, trees, once valued for their inherent properties eventually, came to be seen simply as potential ‘saw logs’ and hand made objects once characterized by their variability were replaced by mechanically produced objects characterized by their sameness. “The prerequisite for this development was the production of large quantities, as every readjustment of the machine slowed down the production process. The components were hence standardized and no longer adapted individually, becoming in effect interchangeable.”<sup>15</sup>

In converting wood from a naturally (and beneficially) unpredictable material to a predictable, homogenized one, the application of industrial scale energy resulted in a loss of informational richness. First, the material lost its embodied information – reduced to just ‘stuff’ in an attempt to attain the performance of any other industrial material from it. “Wood in its natural state was taken apart, broken down and then glued together again in order to cancel out its anisotropy and the inhomogeneity of its growth patterns.”<sup>16</sup> Second, the depth of knowledge of how to join pieces of timber, developed over centuries, was lost to a dependence on mechanical fasteners and adhesives which were easily produced and required little skill to implement - timber was simply cut to length and knocked together. “Construction techniques have shifted from using joinery that exploits the properties of the material to using adhesives and fasteners, with the intention of eliminating the “problem” of material behavior from the manufacturing process.”<sup>17</sup> That timber appeared now primarily as dimensioned sawn sections or sheet materials resulted in a fundamental impact on the forms that were constructed, with designs derived from the constraints of these standardized products. This phenomenon is seen most emphatically in the spread of the stick frame house so common to North America. As author Jason Griffiths describes: “this architecture can be boiled down to

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13 Stanton, Christian. “Digitally Mediated Use of Localized Material in Architecture” (Paper presented at the 14th Congress of the Iberoamerican Society of Digital Graphics, November 17-19 2010), 2.

14 Teitelbaum, Matthew, editor. *Giuseppe Penone: The Hidden Life Within* (London: Black Dog Publishing Limited, 2013), 81.

15 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 57.

16 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 57.

17 “Special Subject: Architecture Design—Craft and digital manufacturing” MIT Architecture, accessed December 20, 2015, <https://architecture.mit.edu/subject/spring-2014-4s13>

the pure geometry of dimensional lumber and board sizes: a cool rationale of 2” x 4” studs gridded by 12” centring and sheathed in 8’x4’ boards.”<sup>18</sup>

Over the past 30 years, the development of computer modeling and digitally controlled fabrication tools has offered architects a rediscovered sense of freedom and control. No longer dependent on the arrangement of standard components, these technologies have allowed designers to create individualized components – a variable information flow to electronically controlled production machines allowing for the customization of components without significant increases in cost.<sup>19</sup> In this context, timber has seen a resurgence as a high-tech material, its easy machinability making wood an ideal candidate for computer guided routers.<sup>20</sup> And yet, while these information rich technologies are employed to produce organic shapes, timber continues to be processed by industrial means first – processed by these new machines after having been standardized. In fact, as these digital tools have developed, so too have their mechanical predecessors: “driven by increases in efficiency and standardization, natural wood is making way more and more for homogenized plywood.”<sup>21</sup>

In addition to plywood and other forms of wood panels, glulam beams have become a primary means of building with wood in the ‘digital age’. “Thin layers of wood glued together under pressure is a wonderful material because it has the strength of steel, the malleability of concrete, the lightness of timber, and exceptional fabrication possibilities.”<sup>22</sup> As described, it is not the specific properties of timber itself that these architects and manufacturers pursue, but rather an efficient means to an end. This disinterest in the inherent characteristics of wood is quite well described by the title of a chapter within *Constructing Architecture: Materials Processes Structures*: “Wood: Indifferent, Synthetic, Abstract – Plastic.”<sup>23</sup> Generating both single- and doubly-curved components the trees used in these projects are reduced to ever smaller square sawn section before being glued back together and undergoing complex reductive machining processes – a process involving significant waste. Emmanuel Jannasch suggests that these ‘digital age’ constructions might be more accurately described as ‘hyper-industrial’ - “computer driven machines can impart ‘digital shapes’ to industrial wood-products at some material and energy cost, but attain little informational depth.”<sup>24</sup> While the range of non-standard curves generated in these projects might evoke the formal characteristics of trees – their eventual forms owe nothing to the inherent forms of the trees from which they have been processed.<sup>25</sup>

18 Griffiths, Jason. *Manifest Destiny. A Guide to the Essential Indifference of American Suburban Housing* (London: AA Publications, 2011), 60.

19 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 58.

20 Ibid.

21 Buri, “The Tectonics of Timber Architecture in the Digital Age,” 59.

22 Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*, 145.

23 Deplazes, Andrea, editor. *Constructing Architecture: Materials Processes Structures*, (Basel: Birkhauser Verlag AG, 2010), 77.

24 Jannasch, “Cultivating Complexity.”

25 While objecting to these processes’ treatment of trees ‘stuff’, a simple means to an end shape, the benefits of engineered wood products are well established. As Martin Self, Director of Hooke Park, describes: “By gluing veneers or laminas together, mechanical consistency and stability can be achieved which is only possible in unprocessed wood through intimate craftsman-like knowledge of the behaviour of a given species. Engineered products remove or even-out the ‘flaws’ in timber, such as knots, producing predictability.” (Self, Martin. “Hooke Park: Applications for Timber in its Natural Form.” (Conference Paper, Architectural Association School of Architecture, 2015), 1.)



Fig.4, 5. The Metz Pompidou is a spectacular contemporary wood structure. Yet each component is made by first reducing trees to squares sections of approximately two cm before having a complex form returned to it.



Fig. 6. [Left] Giuseppe Penone's *His Being in the Twenty-Second Year of Age in a Fantastic Hour*. The first work in which the artist found a tree within a sawn beam. Notice the misalignment of the tree within the beam.

Fig. 7. [Right] Emphasizing the homogenization enacted on timber by the indifference of the industrial sawmill, Penone continues this work still in a series entitled *Repeating the Forest*.

# Led by Material

The form of trees appears commonly as a theme in the work of Italian artist Giuseppe Penone. Working with age-old materials such as wood, bronze and marble, Penone's work reflects on the relationship between natural and artificial processes. In 1968, Penone completed *'Il suo essere nel ventiduesimo anno de eta in un'ora fantastica'* (*"His Being in the Twenty-Second Year of Age in a Fantastic Hour"*). Leaving the rectangular section of a mechanically produced wooden beam partially intact, Penone meticulously worked his way around each knot and perpendicular branch, working into the wood's growth rings and exposing a younger tree remaining inside as it was at his own age, 22. The decision to leave most or at least some of the original beam intact in these works rather than releasing the tree wholly is significant. In this act, Penone draws an analogy between the object as it is perceived as a common industrial unit and its unique, individual nature. We understand not only the artist's activity, but also a tree's layered growth processes and the indifference of the mill – its limbs cut squarely and its trunk running askew along the length of the beam.<sup>26</sup> Emphasizing the homogenization of industrial processes, Penone has continued this work in a series entitled *'Ripetere il bosco'* (*'Repeating the Forest'*). As he describes: "There is a work which I have continued to repeat over time — these are the trees that I find again in the body of the wood. It is an artwork that I started in 1968 and which I still continue to reproduce because the idea of the work is to discover the forest of trees contained in the wood [...] It is not truly repetition because every single tree is different and individual."<sup>27</sup>

Seeing the prevalent work of the 'digital age' of wooden building as a 'hyper-industrial' one as argued above, consider Giuseppe Penone working upon a doubly curved glulamined beam. Observing the beam, he finds himself wondering how it has been sawn so sensitively to the curvature of a tree. Yet, as he looks closer he becomes confused by the conflicting presence of precise parallel grain lines along with the tapered ones he is accustomed to. Beginning to carve into the wood he stops, unsure how he might follow the conflicting radial grain patterns. Pushing further, he is determined that a sapling must be found if he follows a particular knot deep enough. And yet, as he chisels gently along it, the knot falls out – seemingly disconnected from the core. Determined, Penone continues his work as usual. Eventually stepping back, he is surprised to see nothing but a pile of wood chips on the floor. If there remains a trace of the tree's 'embodied information' within the large sawn timber, nothing is left of it having been prepared for inclusion in a glulamined beam - most of its knots removed, and sawn to sections as small as a few cm. The final component's organic form owes nothing to the tree's own inherent form.

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26 Mollica, Zachary, "Associating Nature and Technology in Architecture," 4-5.

27 Teitelbaum, *Giuseppe Penone: The Hidden Life Within*, 93.







Fig. 8. Placed on a scanner after being sawn in half, this image gives some sense of multi-directional grain structure present within forks.



# Tree Fork Truss

While working with a common architectural unit to remind us of the unique nature of trees, Giuseppe Penone's work does not suggest any specific architectural approach – instead it is the continuance of a heroic, artistic practice.

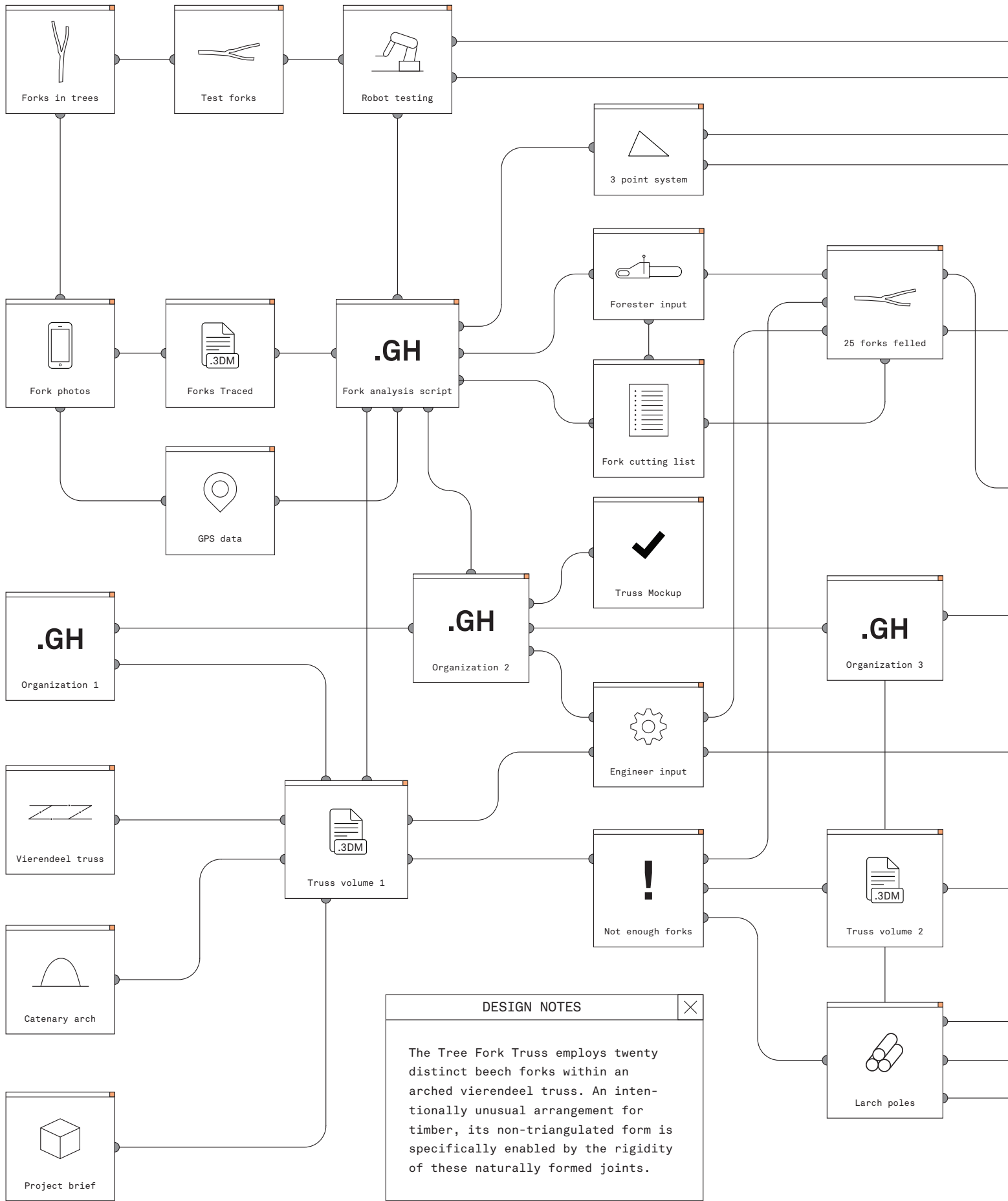
The Tree Fork Truss proposes an architecture which engages Giuseppe Penone's principle: "I don't want to change the material, I want to follow its lead."<sup>28</sup> Earlier criticism of digital wooden building is understood not as a rejection of these digital tools per se but rather their use. As Peter Buchanan states in criticizing contemporary 'high-tech' architectures: "none of the above comment should be mistaken for a rejection of the parametric software and modeling used to generate the forms of these buildings and then to execute them. These are powerfully useful tools crucial to the future of architecture when in the hands of the discriminating and when put to good purpose."<sup>29</sup> Instead, the Tree Fork Truss demonstrates the notion that before processing, trees and other organic materials already present what digital tools are so commonly employed in pursuit of – a non-standard series. Throughout this project, digital technologies -- rather than being used to introduce complexity to standardized materials -- are used in order to gain precise knowledge and control of a material which is inherently complex and non-standard.

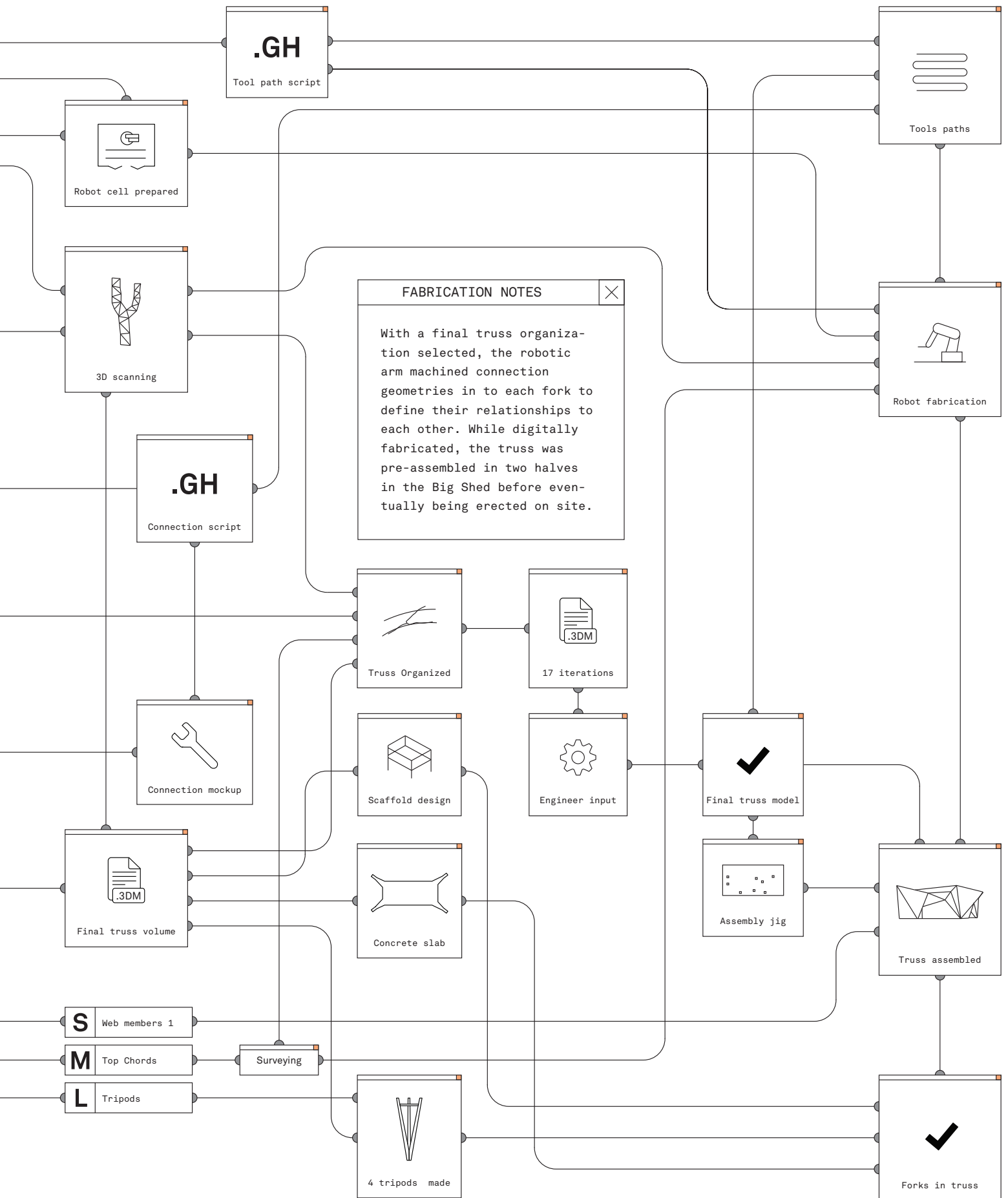
Using techniques such as 3D scanning, parametric control modeling, and robotic fabrication, the Tree Fork Truss attempts to utilize not only the external geometric shapes that trees present, but also to take advantage of the material efficiency and exceptional strength exhibited by a fork while standing – carrying incredible cantilevers with minimal material. While contemporary timber industries consider forks and other irregular forms a nuisance – fire wood at best – traditional craftsman understood the potential of these complex grain patterns and used them in sophisticated structural ways in order to produce stronger vessels. The Tree Fork Truss stands as a unique structure in contemporary wooden building. In it, twenty unique beech forks are organized into an arched Vierendeel structure – an arrangement enabled specifically by this rigid, naturally formed junction.

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28 Enright, "The Perfection of the Tree and Other Material Concerns"

29 Buchanan, Peter, "Empty gestures: Starchitecture's Swan Song," *Architectural Review*, (February 27, 2015. <http://www.architectural-review.com/rethink/viewpoints/empty-gestures-starchitectures-swan-song/8679010.fullarticle>)





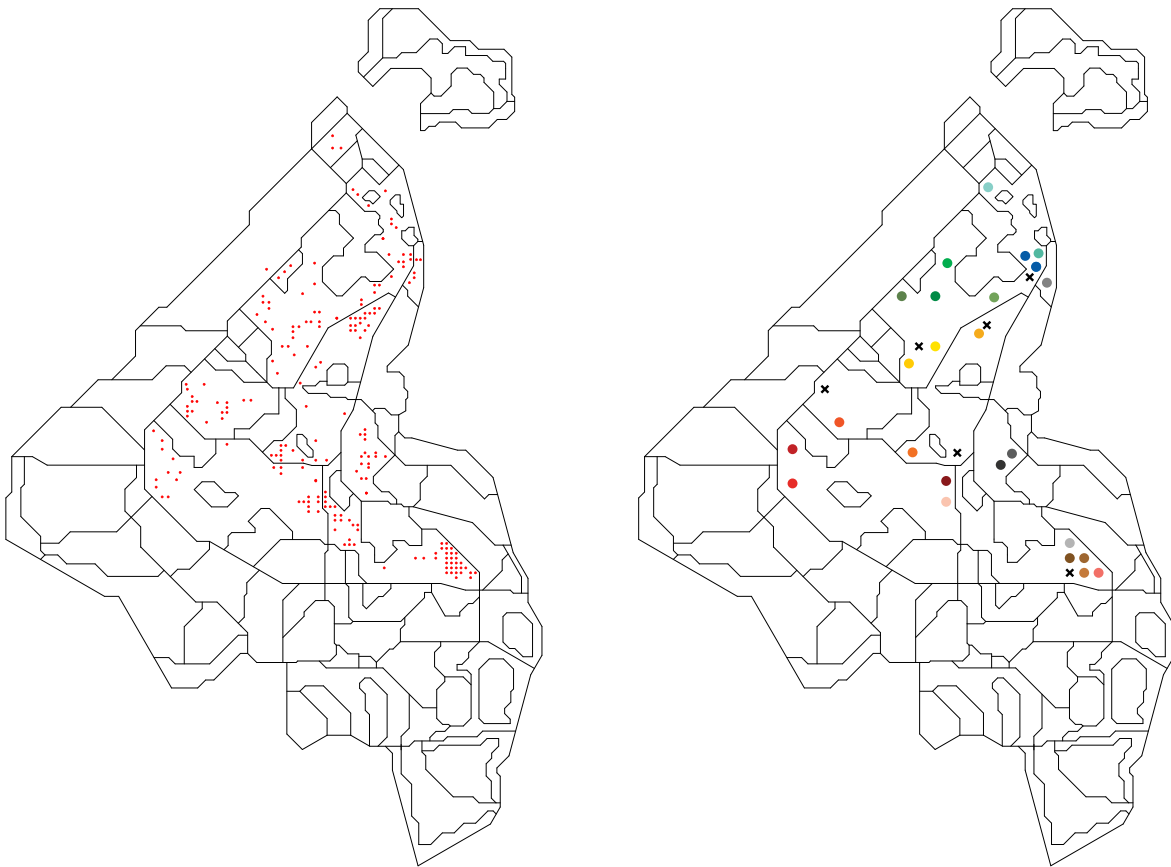


Fig. 9. Spread throughout Hooke Park beech compartments, the general survey documented 204 forks in standing trees. Based upon this survey, 31 trees were felled yielding 25 forks after 6 were damaged.

# Establishing a Dataset

Historically, shipbuilders traveled into the woods equipped with a set of templates describing the range of approximate forms that they required. A fork was surveyed from the ground, and if deemed suitable, felled. In pursuit of these predefined forms to be found within the timber, boat builders were constrained in the range of forks or other irregular timbers that they might work with – some being too open, some too narrow, and some too thin. The twenty forks which comprise the Fork Truss exhibit a wide range of different geometric forms. The integration of digitally controlled modeling and fabrication in the project allowing the use of a wider range of forks – deriving eventual form from their specific and unique character. In a number of areas such as the two ‘groins’ of the truss (where forks cross past each other) the presence of different forms was integral.<sup>30</sup>

For this Design & Make project, and those that it anticipates, the establishment of databases of various levels of precisions is a crucial step which allows for the consideration of actual forms from the early stages of design. Within the development of the Tree Fork Truss, two databases were created. A general survey of 204 beech trees throughout Hooke Park produced two-dimensional representations which, by gathering just enough information allowed for the analysis of the overall design to begin without felling any trees. With 25 forks extracted from the woods, a second more detailed database was made by 3D scanning each fork. This detailed scan provided an important opportunity to establish a permanent connection between the physical forks and their digital representations which would be significant throughout the process.

Observing forks from the forest floor while walking around was useful in providing a general understanding of how forks acted in trees and their range of shapes, but left us unable to evaluate which forks should be sought based on a precise knowledge of their angles and diameters. Even the Forester Christopher Sadd had difficulty accurately estimating the diameters of a fork six to ten meters in the air. In order to avoid felling trees unnecessarily, a workflow was developed for generating an approximate polyline representation in Rhino of each fork deemed a potential candidate.<sup>31</sup> As well as marking each documented tree physically, the approximate geolocation of each tree was extracted from the photos taken in order to ensure we could find it again.<sup>32</sup>

The location of the 204 forks surveyed were combined with the polyline drawing of

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30 As developed later in this paper, the successful population of the idealized truss volume not only manages to make use of distinct forks, but depends on it. Areas such as the ‘groin’ could not have been arranged with 20 identical components.

31 A photo was taken of each fork from the ground with an iOS app which allowed us to record the angle of incline which the photo was taken at within the photo’s metadata. Combined with a measurement of the distance from the trunk of each tree that this photo was taken from and knowledge of the iPhone camera’s FOV we were able to scale and correct the angle of a polyline traced on each photo in rhino quite accurately.

32 Smart phones are able to record the longitude, latitude and altitude that a photo is taken within the photo’s meta data. Exiftools, a command line application, has been used to a number of different ends throughout this project in order to efficiently extract this meta data.

each fork and GIS information for the area surrounding Hooke Park in a Grasshopper script in order to begin to evaluate them. Each of the polylines drawn in the same format – a 23 segment polyline - characteristics of their shape such as angle of opening and diameter could be tested simultaneously for all 204 forks. Referencing their location at the same time, this tool provided the ability to search for patterns within – for example, a compartment which seemed to contain the best forks. Applied at a larger scale, a survey of this kind is speculated to grow to include thousands of available tree forms which might also be used to evaluate and understand how variables such as topography and climate might affect the growth of ‘good’ forks or other timbers for these purposes.<sup>33</sup>

Based upon early evaluations of the Tree Fork Truss’s performance and a general understanding of the material stock, a minimum diameter was decided upon as a criterion from which a list of 40 forks to be felled was prepared. Starting from this idealized list, felling became an ongoing negotiation - revisiting each fork a number of times. Forks were first re-examined to observe any defects which might have been missed in the initial survey and then were finally approved by Forester, Christopher Sadd. In order to maintain the integrity of the fork through the significant impact of felling, great care was given to the direction of fall with the hope that each fork would fall flat on all three limbs simultaneously. In total, 31 trees were felled. In the process, six trees were broken including seven forks. Though a few of these forks might have been preserved but for bad luck, internal rot was exposed in the rest which would have prevented their use (if it had been discovered). The felling provided an initial structural test while serving as a reminder that more than geometric shape must be considered in the use of these complex pieces of tree.

After transporting these 25 forks to the yard of the Big Shed, a detailed 3D scan was developed of each in order to better understand their complex forms. Without a laser scanner or permanent scanning setup, photogrammetry techniques were tested and determined to produce precise and consistent results – the flexibility of this method working well for our purposes. Anticipating the eventual digital fabrication of these forks, it was not enough to simply extract a 3D mesh. A reference system was required to establish a permanent link between the physical and digital objects and allow the confident transfer of information from the digital environment back to the physical objects. A jig crafted by Workshop Manager Charlie Corry Wright allowed for three parallel holes to be drilled into each fork to the same depth such that the bottom of all three holes lay flat on the same geometric plane. These three points were then picked up in the 3D scan.

In order to work with irregular pieces of timber, traditional framing methods include the projection of straight centrelines and axes onto each piece. Measurements are then taken outwards from this arbitrarily introduced centre geometry ensuring that variations in the

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33 Although a data set of just 204 forks is by no means a thorough representation of all of Hooke’s beech trees, it was observed that compartments 11B and 08A provided the highest density of forks suitable for purposes such as this. The author has had discussions with a small start up in Nova Scotia run by Alastair Jarvis and Will Martin interested in developing a platform to perform large scale surveying of undermanaged woodlots using a range of drone and 3D scanning technologies. Platforms such as this would have a significant impact on the design of similarly motivated projects.



Fig. 10. Fork 12\_A03 surveyed while standing. The red line shows the 23 sided polyline which was traced onto each photo in order to work with an approximate form digitally before felling.

tree's form have no bearing on the overall organization. Although a mesh provides a precise representation of the forks, in order to work with the complex forms of trees digitally, it is necessary to generate an intelligible geometric representation that might be more easily worked with. As each of the forks considered for inclusion in the Fork Truss possessed three limbs, it was decided that each be represented by three individual curves. Given the curvature of many of the forks, straight lines projected from the fork's node to the extent of each limb would have provided an insufficient amount of detail and resulted in significant inaccuracies in both arrangement and eventual fabrication. Instead, it was decided to generate a smooth centreline curve throughout the mass of the fork.

There is significant research into the generation of centreline curves from complex point cloud meshes.<sup>34</sup> Within the scope of this project, it was determined that a less complicated method would be sufficient. A Grasshopper definition was made which intersects planes with the fork mesh at regular intervals, three curves are then drawn by interpolation through the centre point of each intersection.<sup>35</sup> The second database fully prepared, each fork was represented by seven separate Rhino geometries.<sup>36</sup>

This simplified method proved more than sufficient. In integrating digital technologies throughout the Tree Fork Truss workflow, a theme that reappeared consistently was that of having too much or too detailed information. Forks, and more generally, irregular timbers, present a near infinite range of complex forms (embodied information) which might be described geometrically down to the last twig. Further, their complex internal properties might be studied by a range of professionals to establish a definite knowledge of their characteristics. Counter to this, the Fork Truss engaged uncertainties. Gaining confidence and enough knowledge of these natural forms through a direct engagement with unique materials.

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34 Although the techniques applied specifically for this project are successful at our scale, experiments of 3D scanning entire forests might employ techniques such as those proposed by Zhixun Su et al in *Skeleton Extraction for Tree Models* in which the centrelines of complex trees are generated through mesh reduction algorithms. A searchable forest of geometries is imagined.

35 With this method, the node of each fork was difficult to accurately represent, but a slight inaccuracy in this area was considered acceptable as no robotic operations would be performed near the node in order to prevent cutting cross the grain arrangement so valued.

36 In Rhino, the full digital representation of each fork consisted of three centreline curves, one scan mesh, and its three reference points – labeled consistently from zero to six.





Fig. 11. Fork 12\_A03. Cut to a length of five meters in the woods, forks wanted to be kept as large as possible to ensure flexible use, while also kept manageable - weighing approximately 500kg at this length



Fig. 12. The mesh, centrelines, and reference points geometries for each of the twenty forks included in the final built Tree Fork Truss

# Organizing Inherent Forms

The design of a structure which makes use of inherent forms will likely follow one of two paths. The first involves allowing the components themselves to freely organize – directly informing the structure’s overall geometry. Early consideration was given to this idea<sup>37</sup> - the ability to self-determine their own organization seeming in line with their wild organic forms. And yet in these arrangements, a system could not be developed in which the forks played a crucial structural role in addition to acting as a form generator. The second option, demonstrated by the built truss, involves fitting the inherent forms within a system which has been designed with them in mind - developing a set of variable control modeling tools which would allow the rationalization of complex forms into a rather simple geometric organization. As Vincent Monier describes in an academic project related to the work undertaken here: “digital tools allow applying a systematic reasoning to a stock of eclectic resources in order to compose an intelligent structure.”<sup>38</sup>

As mentioned above, a primary motivation in the application of forks was to use them not only geometrically, but also structurally. To this end, the naturally formed timber joint was regarded as a potential ‘moment’ resisting connection – a property more common to steel construction and difficult to recreate artificially in timber. It was understood that this might enable an overall structural system in which additional mechanical connections were enabled to be simpler, ‘pin’ connections – that is not subject to bending forces. In the built Tree Fork Truss, this concept is realized.

Though a wide range of options were explored, most fall in to one of two categories: structures composed entirely of forks; and structures in which forks were spread throughout a system adjoined by straight timbers. In models which consisted primarily of other timber elements with forks between, it was commonly observed that the ‘moment’ resisting ability of the joint was underutilized – with forks still requiring substantial connections at the end of each limb and little force placed upon the joint. Eventually, the idea of utilizing the forks in an arched system relying on a Vierendeel style truss arrangement was raised. Connected directly to each other, the forks enabled the construction of non-triangulated trusses – an intentionally unusual choice for timber. With hopes to achieve a compression only arch, a catenary curve was generated in working with Arup to serve as the centre of the arched geometry. In its final form, the truss is composed of two inclined arched Vierendeel trusses with a triangulated bottom lower truss made up of additional members. The truss lands at four points, the front slightly wider than the rear, with four tripod legs supporting the robotically fabricated mid

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37 Although not elaborated in this paper, a number of early experiments were attempted in which the forks were allowed to self arranged using digital modeling programs such the Kangaroo plug-in for Grasshopper.

38 Monier, Vincent et al, “Use of Irregular Wood Components to Design Non-Standard Structures,” *Advanced Materials Research* Vols 671-674 (2013): 2337-2343. DOI: 10.4028/www.scientific.net/AMR.671-674.2337), 1.

section.<sup>39</sup>

Evaluating the fork's dimensions based on the 3D scans and centrelines that had been generated, a final version of the truss volume was drawn. Five triangles were oriented to the catenary and a series of curves projected between to define the volume. The first four triangles implying the truss' connection to the tripods, the fifth anticipated the truss' construction in two halves. Based on the quantity and scale of selected forks, it was determined that the truss would be made of twenty forks – six down each of the two outer chords and two along each of the four interior chords. The top chord was to be faceted, made up of eleven straight larch poles. A number of these decisions were informed by the limitations of working within a relatively small forest survey. While the Tree Fork Truss was based upon a rough survey of 204 forks from which 25 were extracted, eventual projects might refer to large databases compiling surveys of many woodlands.

While the volume of the truss was finalized, a significant period of time was invested in developing a technique for arranging forks within the ideal target curves. Based on a fork's three limbs<sup>40</sup> - to be referred to in this project as root, stem and branch from largest diameter to smallest - it was determined that a method for their placement should find three points of contact with a set of two target curves – bottom and top truss chords. This would ensure that where two forks were to be connected, their centrelines would align. A variable method was developed by which each fork would undergo three sequential transformations to be placed within the truss: (1) point on root moved to an assigned position on the lower target curve; (2) rotated three dimensionally such that its stem finds contact with this same curve; (3) a second rotation performed using these two points to define an axis allows the branch to find contact with the upper target curve.

A first script was capable of finding the optimal positioning of a single fork - selecting 'fitness' by minimizing the fork centreline's deviation from the catenary curves. This technique was applied laboriously to produce a few populated trusses. As only one fork was considered and placed at a time, before moving on to the next, previously placed forks were difficult to reconsider and there remained the significant chance that a fork placed early on might be better placed elsewhere in the truss. While areas such as the groins remained near impossible to solve. If the full potential of these fork geometries was to be harnessed, it was understood that an organizational strategy should be developed which might allow the simultaneous and dynamic organization of the entire truss – forks moved around the system globally (occupying different positions) as well as locally (moving within that position).

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39 The arched Vierendeel truss was originally imagined to land at three points. Entirely made of forks (without tripod legs) in this arrangement three lines of forks spiral towards each other using each other as a second truss chord. As a result of the spiraling arch, three typologies of fork shapes were required – one for each chord. Analyzing the fork database, it was realized that of these three, only one was commonly occurring. Further, approximately 50 forks at an average length of three meters would be required to populate the truss – and approval had only been given for the felling of 31. As a result, the truss was redrawn as two inclined Vierendeel trusses sharing a single top chord to be made of straight timbers. Further analysis of initial wireframe models suggested another revision. In order to increase stability, each of its four ends should terminate at a single point. The forks at each end were replaced, a middle section of the truss would be supported by four tetrahedral units made of straight timbers.

40 While branch junctions in which more than three limbs join are often observed, within the scope of this first project, only those with three were considered for inclusion.

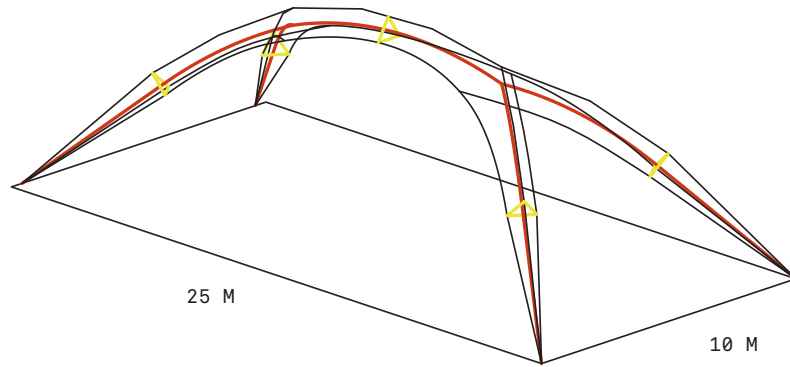


Fig. 13. Final volume of the truss. In red, the catenary arch it is based on. In yellow the 5 triangles between which it is drawn. And in black, the final target curves which forks will be fit to.

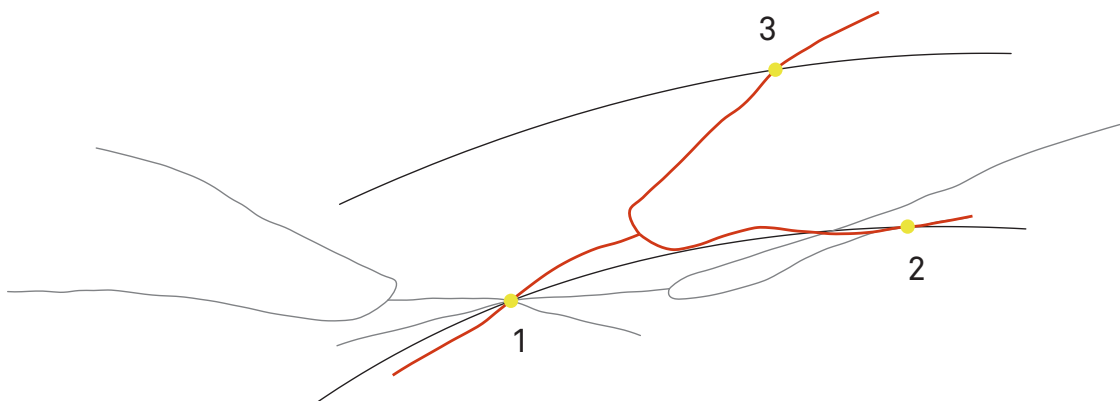


Fig. 14. Logic for placing a fork into the truss. Its three limbs made to find contact with one of two target curves by undergoing three transformations: a move, a rotation, and a second rotation.

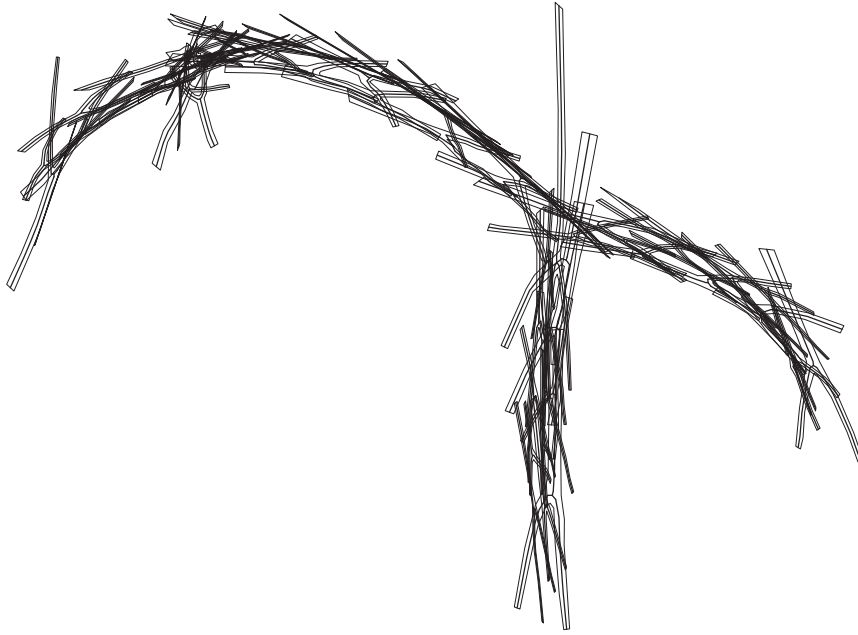


Fig. 15. An early truss iteration, this diagram describes how the various organization scripts populated target curves with forks - their whole length oriented in to position before being trimmed.

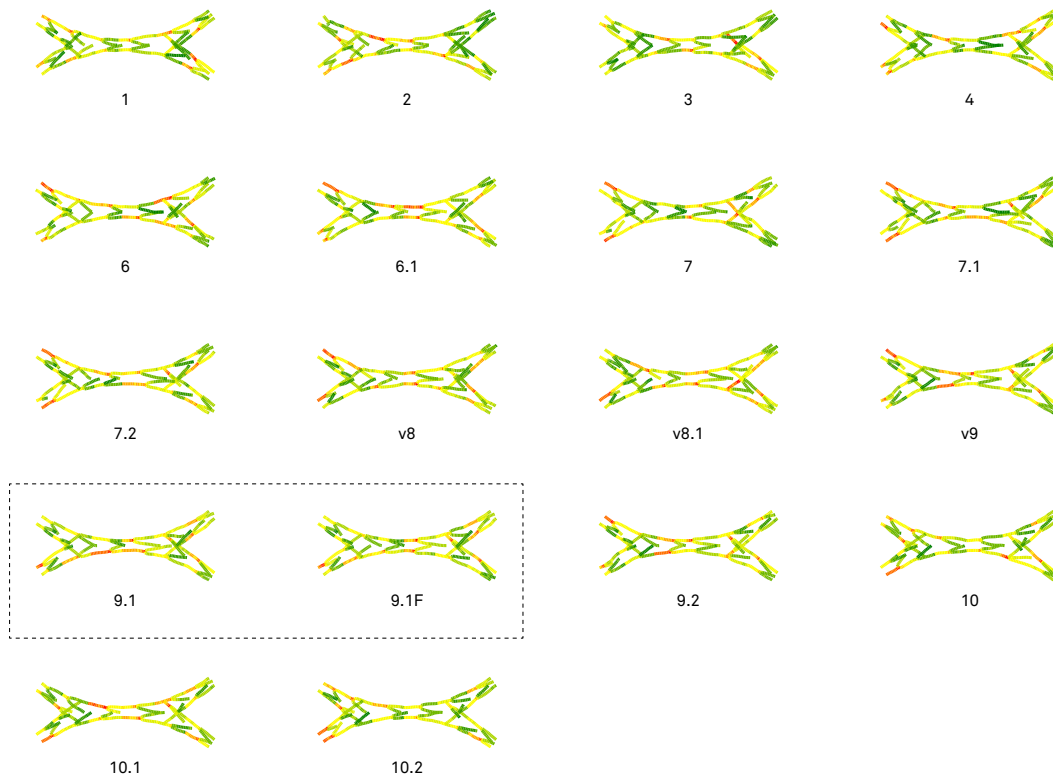


Fig. 16. Seventeen final iterations of the truss output from the organization script. Showing local diameters by colour, a main factor in selecting 9.1 from the grid with Arup was a balanced distribution of forks.

With Grasshopper, an organization script capable of harnessing these geometries was realized. While much of the running of the script would become automated, driven by the evolutionary algorithms implemented within Grasshopper's Galapagos<sup>41</sup>, the script retains the ability to be manually adjusted. In this system, each fork may be individually manipulated, with its various relationships to others updating automatically. The organization of forks by Galapagos was driven by the optimization of three primary parameters: minimizing deviation from target curves – encouraging a pure compression arch; ensuring a minimum 300 mm between connections along the top chord; preventing clash between the forks in the groin area while ensuring a close enough placement to connect. This final script was run over the course of a week to produce seventeen unique arrangements of the 25 forks. In discussions with Arup<sup>42</sup>, 9.1 was selected as the best solution. Further developed, fabrication would start from version 9.1E (revisions included manually replacing a few forks in which defects had been noticed at the last moment, and allowing their positioning to further optimize).

It was observed throughout the production of these seventeen iterations that Galapagos' algorithms struggled to have much success on their own – requiring a brute force manipulation of its running by an operator. A main source of this struggle seemed to be the diverse and unrelated range of forms presented by the forks – something this project celebrates. When moving a slider from one-to-two within Grasshopper to select a new fork, Galapagos expects a progression which might be similarly related to that experienced between two-to-three and so on. In the case of found geometry, this predictable relationship between consecutive forks geometries does not exist.<sup>43</sup> Moreover the organization scripting made no attempt to address defects within the pieces. Although some of these issues might be addressed by more experienced programmers (the students responsible began this work with none) or more computing power, it is speculated that as with working with these forms physically, working with them digitally will require the intuition of an operator and not just algorithmic 'optimization' – the potential variables too vast to define.

A particular strength of the design approach taken – indirectly designing an intelligent structure around forks' geometry rather than deriving a specific form from them - is that it avoids an over-dependence in the system on any one specific piece while still making use of the inherent form of each. As mentioned earlier, seven forks were lost in the felling process.<sup>44</sup> While a larger database of curved timber geometries might remove this problem, there stands

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41 Galapagos is a component built into the Grasshopper interface for Rhino which allows the implementation of evolutionary optimization algorithms within a definition. Through these algorithms, Galapagos attempts to 'optimize' a given problem by adjusting variable while measuring a 'fitness' parameter provided to it by the operator. That these functions are provided as an easy to use component presents inexperienced programmers the potential to solve complex problems.

42 Built in to the organization script was the ability to output a straight line model representing each of the forks for finite elements analysis. Outputting lines to layers based on local diameters, each fork was more accurately described and Arup was able to more quickly evaluate many iterations.

43 Experiments which attempted to number the forks by some order of similarity failed to change this situation. As well, the sheer order of possible solutions to this organization of just 20 forks was immense. Dependent on the level of precision its parameters were set to, the organization contained approximately  $2e21$  potential variations. Able to run between 50,000 and 100,000 iterations over the course of a day – there was not time perform an exhaustive search in the attempt to arrive at a single solution optimized to our parameters.

44 Transport and fabrication operations on a found material also present this risk of breakage. Only a handful of minor errors occurred during the machining processes of the Tree Fork Truss – no forks were replaced.

a chance of damage to a component whose exact equal does not exist. A particularly good example of the need for this flexibility in working with inherent forms was displayed part way through fabrication of the Tree Fork Truss. After the fabrication of fifteen fork members and six top chords, truss iteration 9.1E was revised to 9.1F (in which a top chord was replaced) – the variable Grasshopper definition maintaining the global shape and automatically adjusting the unprocessed fork's precise positions to suit.



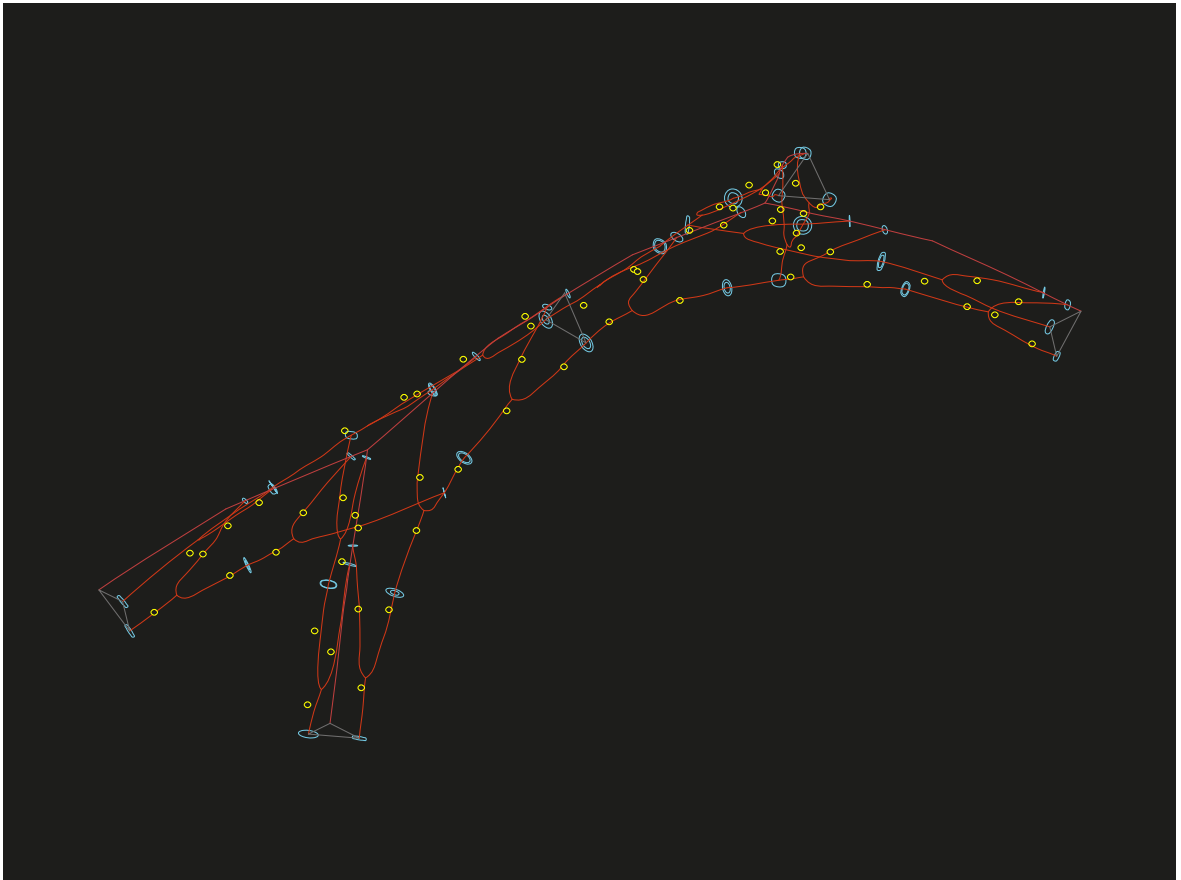


Fig. 17. Final truss geometry exported from organization script. All connection geometries are derived from this Rhino model.



Fig. 18. The robotic arm machining a bearing surface on to a forkB stem. While limited to a milling head for the scope of this project, future endeavours will likely use multiple tool heads.

# Materialising Information

Hooke Park's new 6-axis robotic arm provided the means of transferring the geometric information generated in the fork organization back to the physical forks – defining their relationship to each other in the fabrication of connections. Although the truss is designed as a pure compression arch, the irregularities of its final form due to its unique components required all connections be capable of handling both tension and compression forces. To this end, three families of connections were established: the end-to-end bearing faces between two forks; a mortise and tenon connection between each fork's branch and its top chord; and the flat pockets to which web members were connected.

With iteration 9.1E confirmed as the Tree Fork Truss to be built, a static Rhino model was output from the organization script to inform fabrication processes. Shown in Fig. 17, each fork's geometries were output in their oriented position with the addition of three circles identifying local diameters at the point of significant connections. From a set of vectors and planes surrounding each connection, the various surfaces and holes were derived using a Grasshopper tool developed in parallel to the organization script. Based on the specific geometry of each fork, twenty unique sets of connection geometries were generated resulting in three families of similar rather than exactly the same connections.

The robotic arm performs its work unaware of what is in front of it, simply guided by tool paths the operator has defined. Because of this, the placement of each fork in the cell was a critical step – its physical location needing to be precisely referenced in the digital environment. Using the three reference points which had been drilled into each of the forks and picked up in each 3D scan, a support trolley was fabricated. With two fixed points and one floating point, the same as the reference point marking jig, the fork could be placed in front of the robot and its position confidently modeled within a digital representation of the cell.

As Hooke Park's first project to make use of the robotic arm, fabrication of these large forks was constrained by a few parameters. Given the size of each component in relation to the arm's reach, and considering that the arm is fixed, a number of connection geometries were not able to be wholly finished through digital fabrication. In these cases, a strategy was developed whereby the robot would provide a guide hole which was to be finished by hand. Where the robot's milling cut is capable of cutting precisely into timber, the use of a long custom fabricated auger bits guided by the eye is prone to deflection by the specific grain patterns. With careful planning of what the robot was milling, these manual processes did not have critical bearing on accuracy of the system. The processing of what can be manually processed raises important questions as the assembly process will discuss, of how hybrid combinations of digital and manual techniques might be applied in favour of wholly digital workflows in the context of organic materials - allowing for digital precision while maintain-

ing the necessity for adaptation presented by a deviant material such as timber.

Typically, within glulam timber structures, “the joints usually employ mechanical fasteners such as gusset plates and dowels, the principle of which is similar to structural steelwork. True wood joints are hardly ever used in frame construction.”<sup>45</sup> While the fork truss is not constructed without metal fixings (its scale demands them), it has been achieved without a single custom fabricated piece of metal work - each connection using commonly available lengths of small diameter pipe, threaded steel bar, nuts and washers. The robot’s precise execution of variably defined connections allows complex angles and joints to be resolved within the fork’s body with milling operations performed only in localized areas. In this way, the precise operation of the robot allows for machining to be reduced to a minimum, and allowing the maintenance of each fork’s natural form through fabrication. Further, based on the Engineer’s analysis, each connection and its hardware could be specified locally rather than applied globally. “Standardization inevitably begets oversizing and wasted material.”<sup>46</sup> The branch to top chord connection, a unique mortise and tenon, is seen as a first exploration of the potential for timber to timber joints within a system of this kind.

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45 Deplazes, editor, *Constructing Architecture*, 98.

46 Carpo, *The Alphabet and the Algorithm*, 104.



Fig. 19. The mortise and tenon connection designed for the Tree Fork Truss. While involving basic mechanical fasteners, this joint implies the potential to revisit complex wood to wood jointing with digital tools



Fig. 20. Suspended in its approximate orientation, each fork was lifted in to place by the telehandler. Each was then brought to rest on their three vertical supports.

# Assembling by Hand

At an average length of over three meters and weighing a third of a ton each, the twenty forks were too large and heavy to pull into their correct alignment by simply bolting together. And while digital processing and fabrication tools were used throughout, timber still represents a dynamic and unstable material, presenting the possibility of small errors and inconsistencies built up throughout the forks' processing which are difficult to account for – owing to such factors as the drying of green timber.<sup>47</sup> In order to address these two issues, a system for precisely assembling and fastening the two halves of the Tree Fork Truss manually was developed. The success of this process in allowing for the precise assembly of the two truss halves – each approximately 8 m x 6 m – relied on two developments. First, the design of a large assembly jig which would allow the positioning of ten forks with respect to each other without fastening, and second, the implementation of a half finished connection system. By these two methods, small errors were picked up, and intuitively addressed. The continued importance of the presence of manual craftsmanship within a digital workflow for handling natural varied materials was observed.

Given its size, and proximity to the robotic arm, the Big Shed was determined as the best location for assembly of the Tree Fork Truss. Although setting out directly from the floor by drawing at 1:1 was considered, a jig was conceived which would allow the consecutive assembly of both halves with CNC fabricated components. Eighteen sheets of OSB (oriented strand board) were machined and assembled on top of an approximate stud frame on the Big Shed floor. Throughout, this large gridded deck would allow for the quick and clear addition of various notations and marks. The last procedure performed by the robot on each fork had been to mill a second set of three reference holes – each drilled such that they would be vertically oriented once the fork was properly positioned above the jig deck. Corresponding to these points, three square pockets were cut into the deck for each of the twenty forks. A simple vertical support rose from each of these pockets, with a bolt at its top leveled precisely to the required position of the reference hole. As well, the three end triangles of each truss half – where they join to each other and the tripods – were simulated by large stands CNC cut from thick plywood and placed precisely in slots within the deck.

With the jig fully constructed, forks were lifted into place one at a time by the telehandler and temporarily braced. As more were added, measurements were constantly taken off of an updated 3D model in an attempt to catch any inaccuracies which had occurred in processing. As the forks were not 3D scanned after coming out of the robot cell, it could be difficult to determine where an error might be (5 mm in each of three spots, or 15 mm in one?). With

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<sup>47</sup> The effects of drying upon straight round wood and sawn timbers are well understood. While there was not time for it within the scope of this project, a thorough documentation of what happens to these fundamentally three dimensional pieces of timber throughout the process of drying presents a potentially rich field of study aligned to this project.

ten forks positioned and approximately fitting, the robot-fabricated top chords were lifted in to place. With all of the major pieces held together as a loose system, the assembly team moved around the truss with hammers, straps and a Rhino model, adjusting every piece to as close to its intended position as could be achieved. Reflecting on the number and variety of unusual dimensions and projected lines which were required throughout this assembly, it would have been impossible to generate a meaningful set of drawings for the assembly of the truss – working in reference to a 3D model providing absolute flexibility.

With all of the forks and top chords properly positioned, the process of making connections began. In order to account for the possibility of slight deviations from the original model, half finished connections set out by the robot – holes having been milled in one of the two forks which were to be connected. Once satisfied with the position and using auger bits up to 1300 mm long fabricated by Workshop Manager Charlie Corry Wright, these bolt holes would be run through the second fork in exactly the position they were held. Though in some cases quite difficult simply due to their length, the flexibility this system enabled was important to the success of the truss.

Assembly of the first half was difficult – taking nearly five weeks to remove it from the shed. Starting as the robotic fabrication began, each fork and top chord was added one at a time as they were finished - a few of them having to be removed temporarily in order to address minor milling errors. In the case of the second half, all ten forks and all top chords were ready as assembly began. Due to an increase in the precision of the robotic processing, not one of the forks had to be removed once located. With a good process established during the first half, the second was completed in just two weeks.

With assembly in the Big Shed complete, the two halves of the truss and tripod legs were moved to site where scaffolding had been arranged at each of the five locations parts would be joined. Over the course of just one day, the two halves of the truss were craned in to place - held together with chain hoists, the crane was able to come off before any of the remaining connections had been made. The last connection to be made was between the two fork truss halves. Indicating the accumulation of a few small deviations throughout all of our processes, with the aid of an extra chain hoist, the whole system fit together snugly. A result of the accuracy achieved in the pre-assembly of the truss within the Big Shed, its assembly on site was completed in just five days.

With its scaffolding removed, the fork truss was left self supporting – the rigid naturally formed joints working together to allow a non-triangulated truss to stand stably. Spanning 25 m from front to back, 10 m side to side and rising to 8.5 m at its zenith, the Tree Fork Truss surpasses the span of any previous Design & Make projects. The completion of the Tree Fork Truss within the time available had prevented any large scale physical test of the whole structural arrangement or even its parts. Aside from a two-thirds scale mock-up of two forks and a top chord which could not be tested effectively for structural performance, a





Fig. 21. The truss was pre-assembled in two halves of ten forks each. Here, the ten forks of the front half are loosely positioned together on top of the Assembly Jig before the top chords are added.



Fig. 22. Designed and fabricated with digital precision, a number of forks required some encouragement to align properly. Here, points are tied back to the structure of the Big Shed with ratchet straps.



Fig. 23. In a number of cases, forks pass by each other with little room to spare. Once assembled, most traces of robotic fabrication are concealed.

1:20 model is the largest scale at which the concept was physically tested. Given the number of interconnected steps involved in this process, the success achieved came as at least a slight surprise to all involved. As Make Tutor, Charley Brentnall, remarked to me as the assembly of the second half of the truss was finished: “I really didn’t think this would all work.”

Precise digital modeling and fabrication notwithstanding, unprocessed timber represents a dynamic and irregular material. Early in the design process it was recognized that this would be a reality of working with the inherent forms of trees and was taken into account. The overall volume of the truss was conceived to allow a certain level of flexibility to account for this variation – that absolute precision of each moment throughout was not essential to its success. As long as the three triangles which define the extents of each truss half were precisely located, what happened in between them was far less a concern. Enabled by this latitude, as small errors were observed in the assembly process, decisions and adjustments were made on the fly in keeping with the artisanal tradition. That the various pieces of the Tree Fork Truss came together easily demonstrates that the accuracy of the end triangles was achieved - the exact relationship of the whole form to the Rhino model from which it has been set out however remains unknown.



Fig. 24. Front half of the Tree Fork Truss being craned in to position.

# Conclusion

Over the past 30 years, digital design and fabrication tools have been used to materialise complex free surfaces by generating non-standard structural components from standardized materials. In the case of wooden building, these technologies have largely been applied to engineered wood products (e.g. glulam) resulting in what this paper has identified as a ‘hyper-industrial’ kind of building - energy intensive processes which reduce a natural material to ‘stuff’ before returning to an artificial complexity through laminating and machining processes.

As our first structural building material, timber occupies a significant position in our cultural and material history. With an increased awareness of sustainability in contemporary architecture, wood will continue to be an essential building material – its environmental benefits are well known. And yet, the high level of energy involved in the fabrication of non-standard components from natural material not only compromises wood’s inherent strength by cutting into its grain, the waste generated, along with the transportation of these components from centralized plants, is environmentally questionable. Digital technologies have been used in the Tree Fork Truss project to convert these naturally formed pieces of timber into complex and valuable building components while using a minimal amount of energy.

In regard to the use of digital technologies, Mario Carpo writes: “A meaningful building of the digital age is not just any building that was designed and built using digital tools: it is one that could not have been either designed or built without them”<sup>48</sup>. Although some configuration of naturally occurring forks might have been achieved without the use of technology, the intelligence and efficiency achieved throughout these processes could not have happened without them. Making structural use of twenty naturally developed beech forks within a relatively simple architectural form - one defined by just eleven curves - Hooke Park’s Tree Fork Truss suggests a new orientation for ‘digital age’ wooden constructions. This is an orientation which views these technologies as a means to encourage a return to a craftsman-like understanding of the specific properties of materials - their variation and so called ‘flaws’ embraced as exciting opportunities, and made use of rather than seen as something to overcome. “Contemporary digital technologies are in many ways closer to some technologies that preceded the mechanical age than they are to the mechanical age we are now abandoning.”<sup>49</sup> Yet, working with predictable and stable materials, digital fabrication techniques are commonly employed as a means to construct an exact 1:1 copy of a precisely constructed digital model with various pieces ‘clicking’ together on site without the need for ‘craftsmanship’. If

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48 Carpo, Mario, editor, *The Digital Turn in Architecture 1992–2012 AD Reader*, (Chichester: John Wiley & Sons, 2013), 8.

49 Carpo, *The Alphabet and the Algorithm*, 118.

Mario Carpo's statement is to be meaningfully fulfilled, this author believes that something of the unpredictable nature of how the craftsman worked - directly discovering and learning from material - must be reintroduced. The interaction of precise digital technologies with a fundamentally dynamic and deviant material – prone to change – presents this opportunity. Though aiming for the realization of a Rhino model while constructing the Tree Fork Truss, the use of this found material inevitably prevents its sameness.

In contrast to the common architectural search for organic forms and analogies to nature in which: “the non-standard aspect of those realizations is considered as an a priori characterizing the resulting building,”<sup>50</sup> the Tree Fork Truss inevitably results in a form which evokes the qualities of nature by making use of inherent forms. Twenty distinct forks suspended in mid-air deny the simple geometric drawing which lays beneath – each deviating in their own way. The Tree Fork Truss demonstrates the exciting potential of architectural forms generated by a unique interaction of natural materials, traditional craftsmanship and innovative new technologies.

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50 Monier et al, “Use of Irregular Wood Components to Design Non-Standard Structures,” 1.



Fig. 25. The Tree Fork Truss







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# Images

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