ASSEMBLY AND TECTONICS: UTILISING LOCALISED TIMBER IN AN INTELLIGENT WAY AS TO CREATE A LOW ENERGY BESPOKE ARCHITECTURE

A dissertation submitted to Technological University Dublin in part fulfilment of the requirements for award of

Masters in Architecture

by

Sean Nolan BSc. Arch

January 2023

Technological University Dublin
Bolton Street,
Dublin 1

Head of School: Conor Norton
Supervisors: Dr. Marcin Wójcik and Dr. Sarah Sheridan (Design Studio)
Dr. Kevin Donovan (Dissertation)]

ABSTRACT

This research project analyses how utilising timber elements that are on a site can be rearranged by specified requirements to manifest an architectural structure that is unique to these requirements and does so in a sustainable way. This is achieved first by analysing what material is available and digitally cataloguing the timber elements into a database. These specific timber elements are digitally assembled to create a desired structure. This intelligent use of timber available on site reduces the energy required to achieve the design of a structure. This methodology was examined though a design project that took the form of a data centre in Finglas Co. Dublin. The research was then focused through the design of a bridge that demonstrated utilising forked branches as the building material. The research indicated that the structural integrity of the bridge is realised when proposing the breakdown of the bridge elements into sub-assemblies that are further embedded in one another. These design projects convey an architecture that utilises timber's natural form and is evident in the quality of spaces these structures generate. This is reassured through the fabrication of the connection joint at a scale of 1:1. This ability to effectively connect one branch to another proves how the branches in the bridge design come together indicating the possibility of such a structure. Evidentially, by utilising timber from the site in an intelligent way we can create a sustainable, low energy bespoke architecture.

Figure 1.01: Huntstown Bridge | Nolan | 2023

DECLARATION

I hereby certify that the material submitted in this dissertation toward the award of Masters in Architecture is entirely my own work and has not been submitted for assessment other than part-fulfment of the award named above.

Signature of candidate: Sean Nolan
Date: 13th January 2023

ACKNOWLEDGEMENTS

I would like to thank the all staff at TUD, in particular Dr Marcin Wojcik for his guidance and time, as well as Dr Kevin Donovan and Dr Sarah Sheridan, for their support in supervising this dissertation.

To my classmates and friends, thank you for being the reason I love doing what I do. I will never forget our adventures in Linenhall and around the world.

Also thanks my house mates Cormac Dockry and Cormac O'Mahoney who, due to our friendship, has given me the perspective of what architecture means to me.

To my family for their support, encouragement and always believing in me. Thank you for making me the person I am. I can always count on you.

Finally, I would like to thank my partner Mairead, who got me through everything. She was always there for me and together is there nothing we can't do. I am forever grateful.

INTRODUCTION

Author Julian Vincent argues in his work ‘Survival of the Cheapest’ (2002) how “nature treats materials as expensive and designs with apparent care and attention to detail. This results in durable materials and cheap structures that are easy to recycle under ambient conditions”. Last year concrete was only second to water as the most used material in the world and as an industry contributes about 8% of the global greenhouses gases (Rosen, 2021). In the age of climate action an alternative approach to construction must be explored. An approach that learns from structures in nature and can produce them in a less energy demanding way. Figure 2.03 highlights the current construction practices that being carried out today. The Oxford definition for ‘intelligence’ is “the ability to learn, understand and think in a logical way about things” (Oxford Learners Dictionaries, 2022). Vincent identifies in his essay how, in the construction industry, materials are used in an unintelligent way “as if the supply were infinite” (2002).

The return of wood for construction can be seen in the industry with it being practical, economic and ecological (Build, 2019). Coinciding with a push for new strategies of timber construction, modern advances in technology have allowed us to manipulate wood in new ways. Some of these frameworks were outlined in my position paper ‘Utilising timber’s natural complexity and form’ (Nolan, 2022). The position paper researched timber as a construction material and examined built precedents where they utilised timber’s natural complexity (Nolan, 2022). After studying similar work in the research area of ‘utilising timber in its natural form’, an insightful method taken away from the position paper was the strategy of 3d scanning a site and utilising its site information in an intelligent way (Wang, 2017). The research by Sattaveesa Sahu and Yingzi Wang in ‘Hooke Park Biomass Boiler House’ is driven by an architecture that learns from nature and has less of an impact to the environment. One that is inherently more sustainable, and has less of an impact than standard means of construction.

Figure 2.01: Plant altering its form to get sunlight | Nolan | 2021

Figure 2.02: Natural-form timber elements for Ship Building | Marine | 1798

Next Page - Figure 2.03: Huntstown Quarry batch mixing | Nolan | 2022


VOLVO

LITERATURE

HOOKE PARK

Hooke Park is a 150 hectare woodland in the west of England, where for 30 years, experimentation has been undertaken by different disciplines from the Architectural Association in London, which include multiple research projects (Self, 2017). Martin Self, a researcher involved in some of Hooke park's research projects describes how a major resource is the forest itself, which includes a mix of broad-leaf and conifer species, as well as the multiple workshop facilities (Self, 2017). Studying the results of the projects in Hooke park outlined in 'Advancing Wood architecture' by Menges et al, the authors aim to investigate alternative means of construction in timber. In relation to aiding my own research project, the methods examined with timber's irregular form act as a mine of existing knowledge. This is knowledge that allowed my own research project to be focused. This is achieved by the opportunities brought about with timber's natural properties, complexity and form that were explored in projects like the 'Woodchip Barn' in Hooke Park (Self, 2017).

Figure 3.01: Hooke Park Woodchip barn | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2017

Figure 3.02: Exploded axonometric diagram | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016

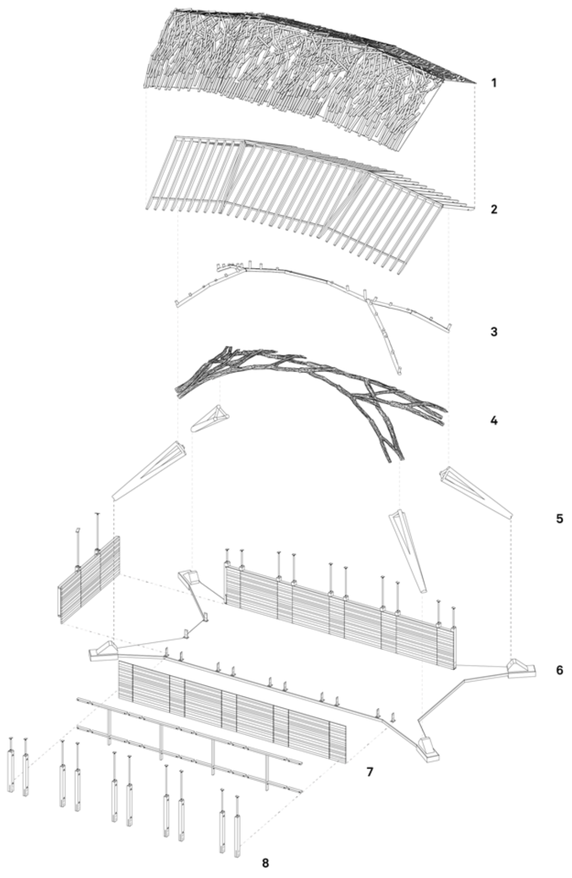


Figure 3.03: Joint Fabrication | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016

APPLICATIONS FOR TIMBER IN ITS NATURAL FORM

This leads us to the paper 'Applications for Timber in its Natural Form' which was written by Martin Self and outlines a research agenda that takes advantage of the specific local characteristics of timber. This research agenda includes digitally cataloguing trees and applying big data strategies (Self, 2017). This is in order to make individual shapes like forked branches or other timber elements, that are contained in a large database. This is then paired with digital manufacturing through "vision and sensor robotic machining" (Self, 2017). Curved timber pieces, like the ones shown in figure 2.02, were used in ship building in the seventeenth century (Self, 2017). The English demand for naval boats resulted in trees being surveyed and nurtured to maximise availability (Self, 2017). In 2017 a similar approach was taken, that used the natural form and complexity of timber in Hooke Park, but with modern technology (Nolan, 2022). Self-navigating drones were mounted with 3D scanners to catalogue every tree in the woodlands and added to a database (Self, 2017). Here in figure 3.05 the 'Woodchip Barn' was created with the structural frame consisting of forked timber elements identified in the catalogue of material which act as the main load bearing elements (Self, 2017).

Figure 3.04: Forked Branch | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016

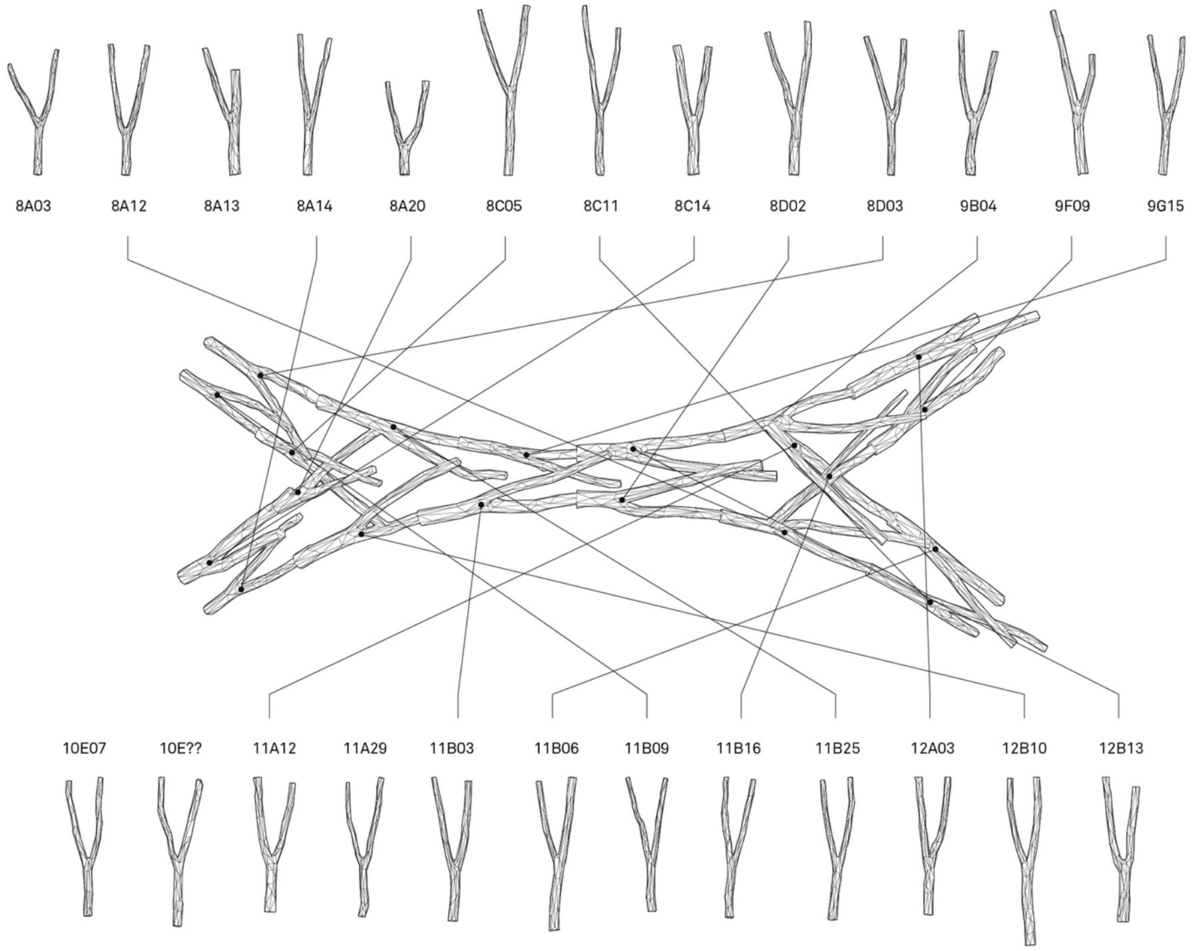


Figure 3.05: Forked Branchs coming together from the Database | Mollica | 2017

Figure 3.06: Biomass Boiler House | Sattaveesa Sahu & Yingzi Wang | 2015

HOOKE PARK BIOMASS BOILER HOUSE

Staying in Hooke Park, we look at other research such as that by Sattaveesa Sahu and Yingzi Wang. Together they developed on existing 3D scanning technology, by using specific trees from the forest in the research project "Hooke Park Biomass Boiler House" (Nolan, 2022). Their brief for this project was to design and construct a building that would house a biomass boiler, a buffer bank, and a woodchip bunker for the district heating system of Hooke Park campus (Wang, 2017). The approach creates new opportunities to exploit natural timber forms in architecture and increases the economic potential of locally grown timber (Wang, 2017). Within Hooke Park, there was an area in the forest where, being on a sloping hill, the base of the trees had curved trunks or a 'basal sweep' (Wang, 2017). In the paper Wang argues a case according to evidence how "digital script routines were written to automate the process of interactively test fitting all the tree curves and optimizing the wall geometry with respect to different criteria. This approach meant that the computer could rapidly test and refine many variations for the wall". The resulting building proved how much more accessible 3D scanning is, while also eliminating waste in construction. The project also shows how, 'less desirable' curved timber can come together into a cohesive system in its natural form.

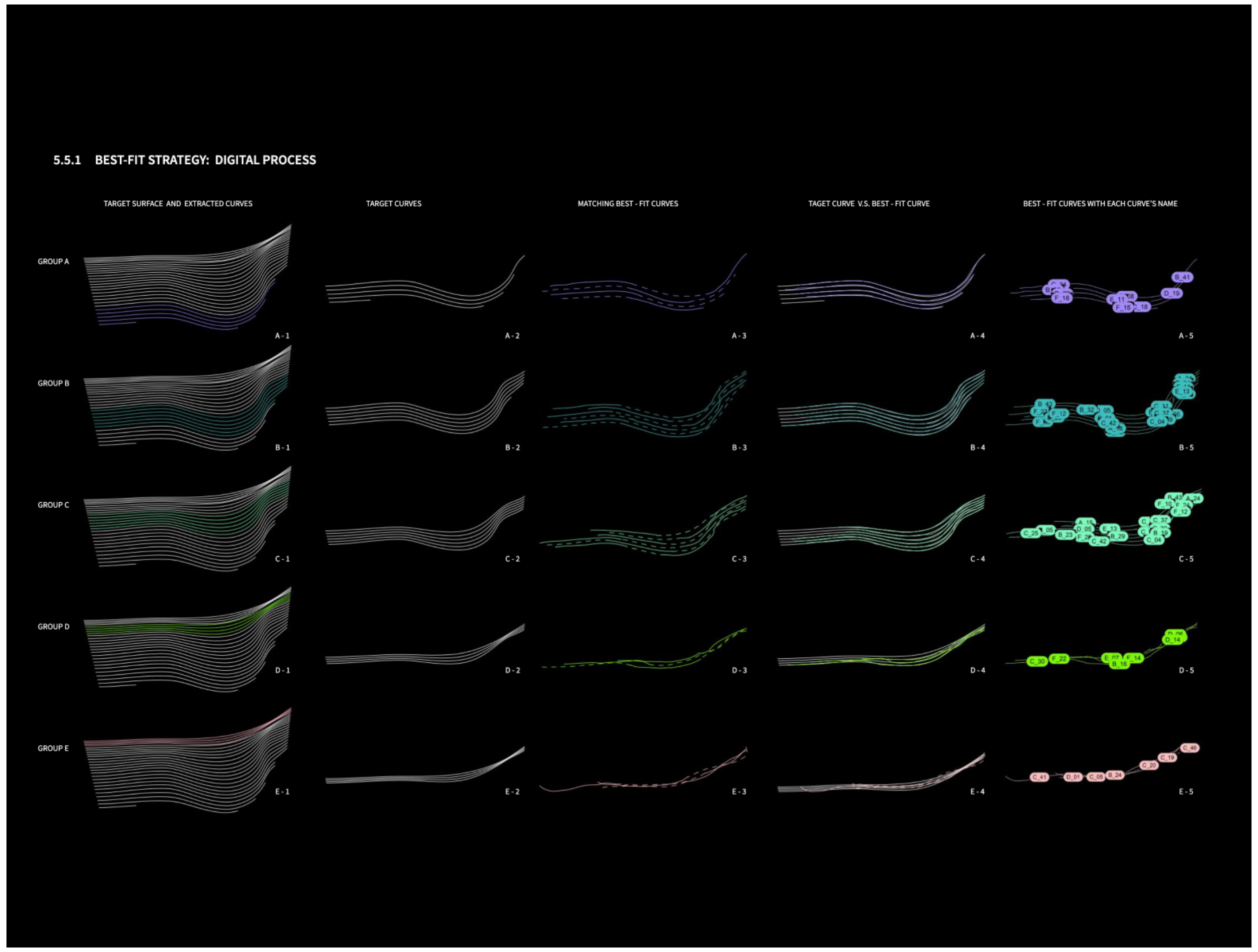
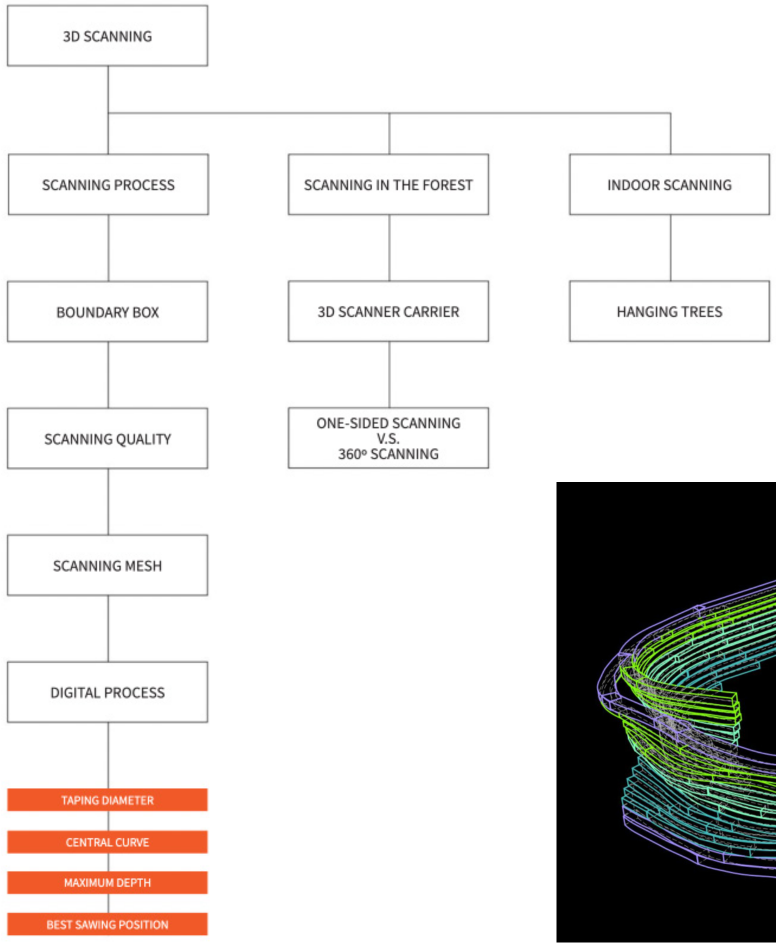


Figure 3.07: Best-Fit Strategy: Digital Process | Sattaveesa Sahu & Yingzi Wang | 2015

Figure 3.08: 3D Scanning Strategy | Sattaveesa Sahu & Yingzi Wang | 2015



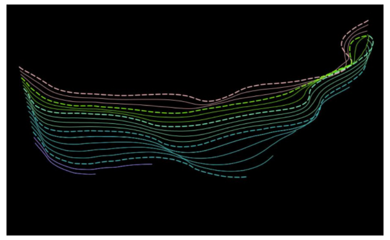


Figure 3.9: Groups being assigned to section line | Sattaveesa Sahu & Yingzi Wang | 2015

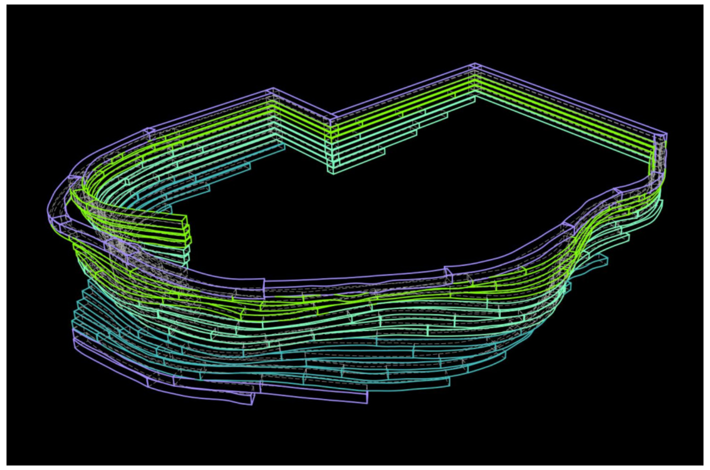


Figure 3.10: Combined Strategy: Digital Log Wall | Sattaveesa Sahu & Yingzi Wang | 2015

CONCEPTUAL JOINING

This book acts as documentation of the research work that emerged from the project with the same title that was carried out at the UAAV (University of Applied Arts Vienna) (Allner et al, 2022). A team of researchers investigated "the specific characteristics of wood as well as historic, existing and potential processing techniques for that material with the aim of deriving guiding principles for the design and materialization of architectural scenarios" (Allner et al, 2022). It was these 'potential processing techniques' where I extensively studied their reasoned judgements in order to adopt an appropriate framework for moving forward with my own research project. This was in the form of the connection joints that the UAAV had experimented on, and being more specific, the fabrication techniques. The book makes it clear in areas where they feel more research can be achieved and lay out frameworks for others to follow up on.

Figure 3.11: Full scale prototype - assembly | Lukas Allner | 2021

Figure 3.12: Nut and Bolted Connection | UAA Vienna | 2021

Figure 4.01: Huntstown Quarry Batch Mixing | Nolan | 2022

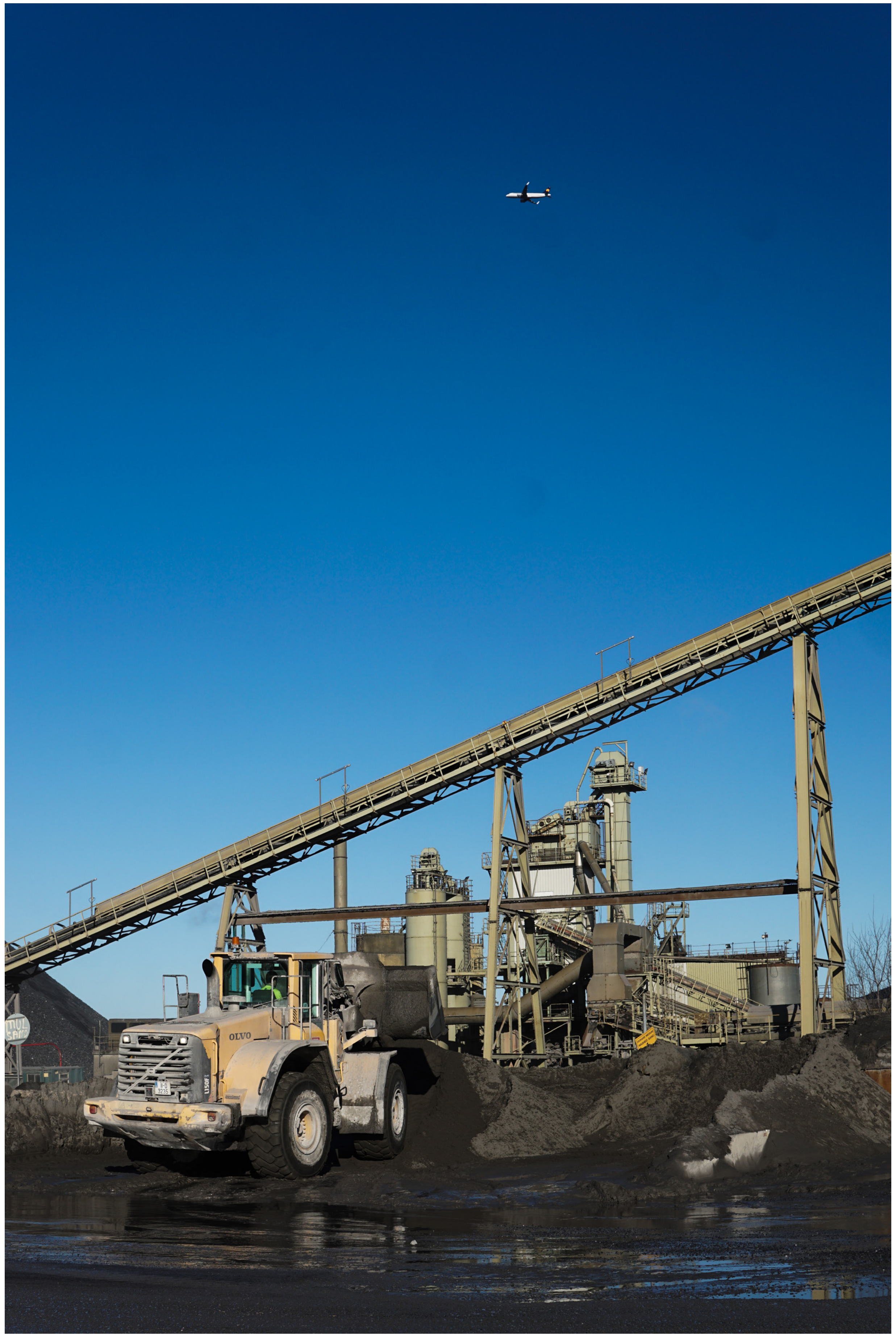
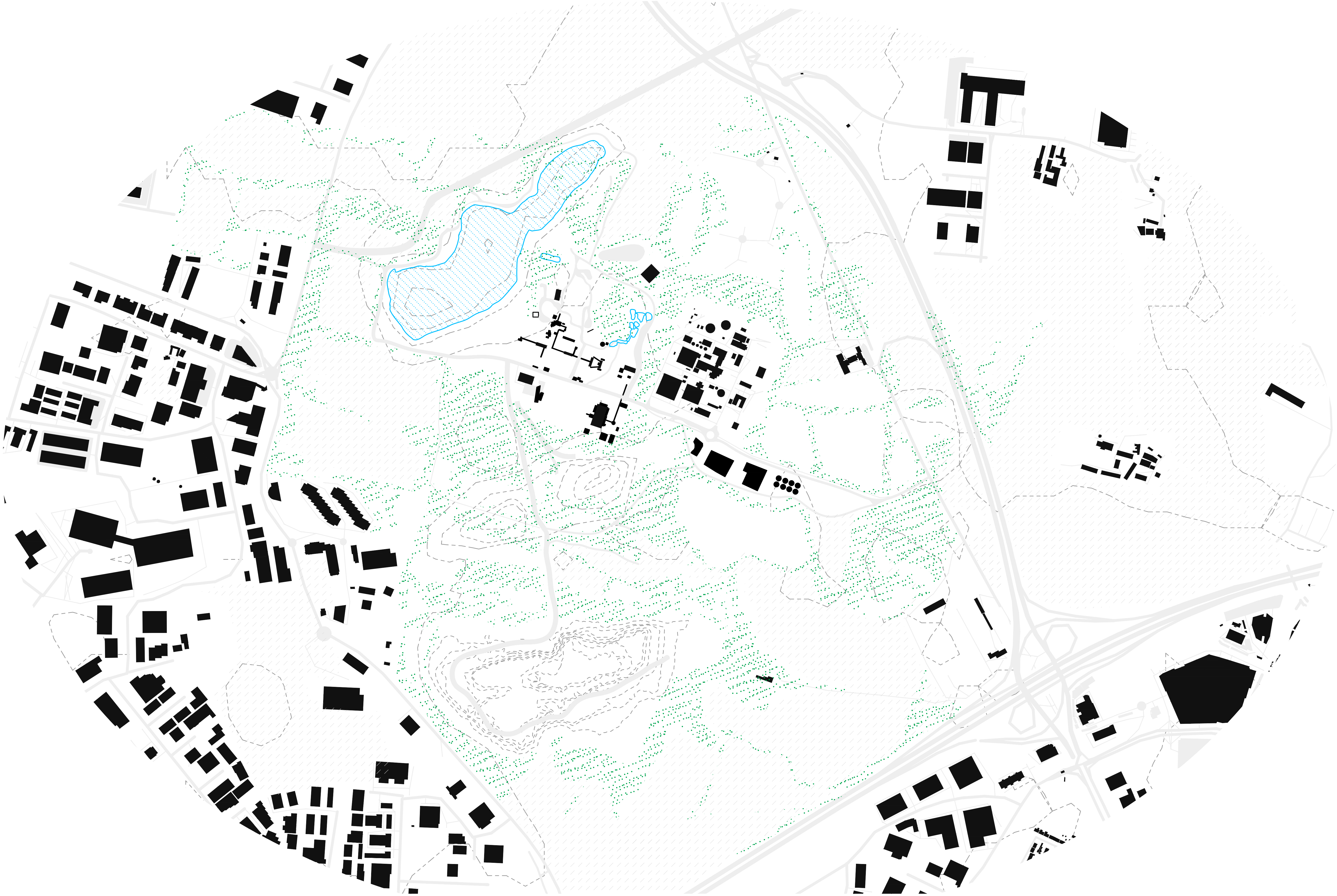


Figure 4.02: Huntstown Quarry Aggregate Factory | Nolan | 2022

SITE AND CONTEXT

Huntstown Quarry in Finglas, Co. Dublin is located just off the m50 and is a heavy industry area. The site is best characterised by its contents which include 4 quarries, an aggregate plant, a power plant, two biodigesters, as well as a proposed new data centre. This site was chosen on the speculation that it will become a post-industrial site. The time frame of the design project is set in the near future. This allowed a degree of flexibility, as well as design freedom. I undertook traditional site analysis, like looking at the context, topography and geology of the site, as well as its history. I modelled how the site would be reforested over time and with what species. Quarries usually have 3D scan information, but I was not able to obtain any scans for the trees on site so using grasshopper I generated a fictional catalogue of timber and used scanned trees from a site also located in Dublin. Digitally specifying branches in the Lidar scan identifies the use of material as intelligent, as you can automate a program to search through this database instead of a single individual searching through a catalogue by hand. An additional ambition here is the ability to utilise less desirable cuts of timber, like the crown of a tree.

Figure 4.03: Huntstown Aggregate Factory | Nolan | 2022



1:2000

Figure 4.04: Huntstown Area | Nolan | 2022

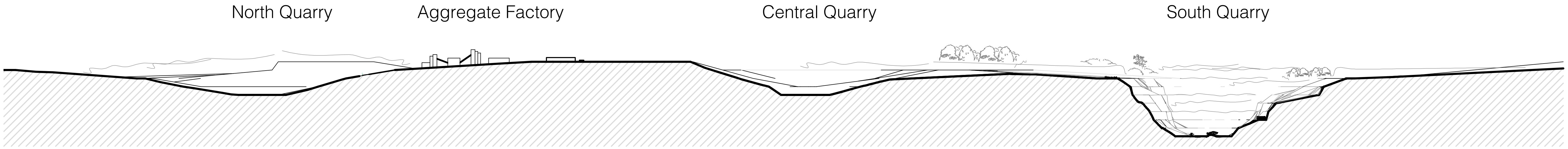
Silver Birch
- Hardwood
- Small diameter (0.5m)
- Used for plywood and engineered I-beams
- Needs preservatives
- Good for breaking up soil and releasing nitrogen
- Can withstand saturated soils

Scots Pine
- Diverse soft wood
- Ability to survive
- Slightly durable but needs preservative
- Reliable and sustainable timber

Irish Oak
- Hard wood
- Interlocking grain
- Less need for preservatives
- Acidic timber
- Easily certifiable

Sitka Spruce
- Soft Wood
- Native to North America
- Low strength
- Fast growing
- Less Durable
- Numerous knots

White Willow
- Strong but light hard wood
- Medium size diameter (1m)
- Good in water and badly drained areas
- Fast growing but short life-spans



1:5000

Figure 4.05: Inventory for Re-wilding Huntstown | Nolan | 2023

Figure 4.06: Longitudinal section through Huntstown Quarry | Nolan | 2023

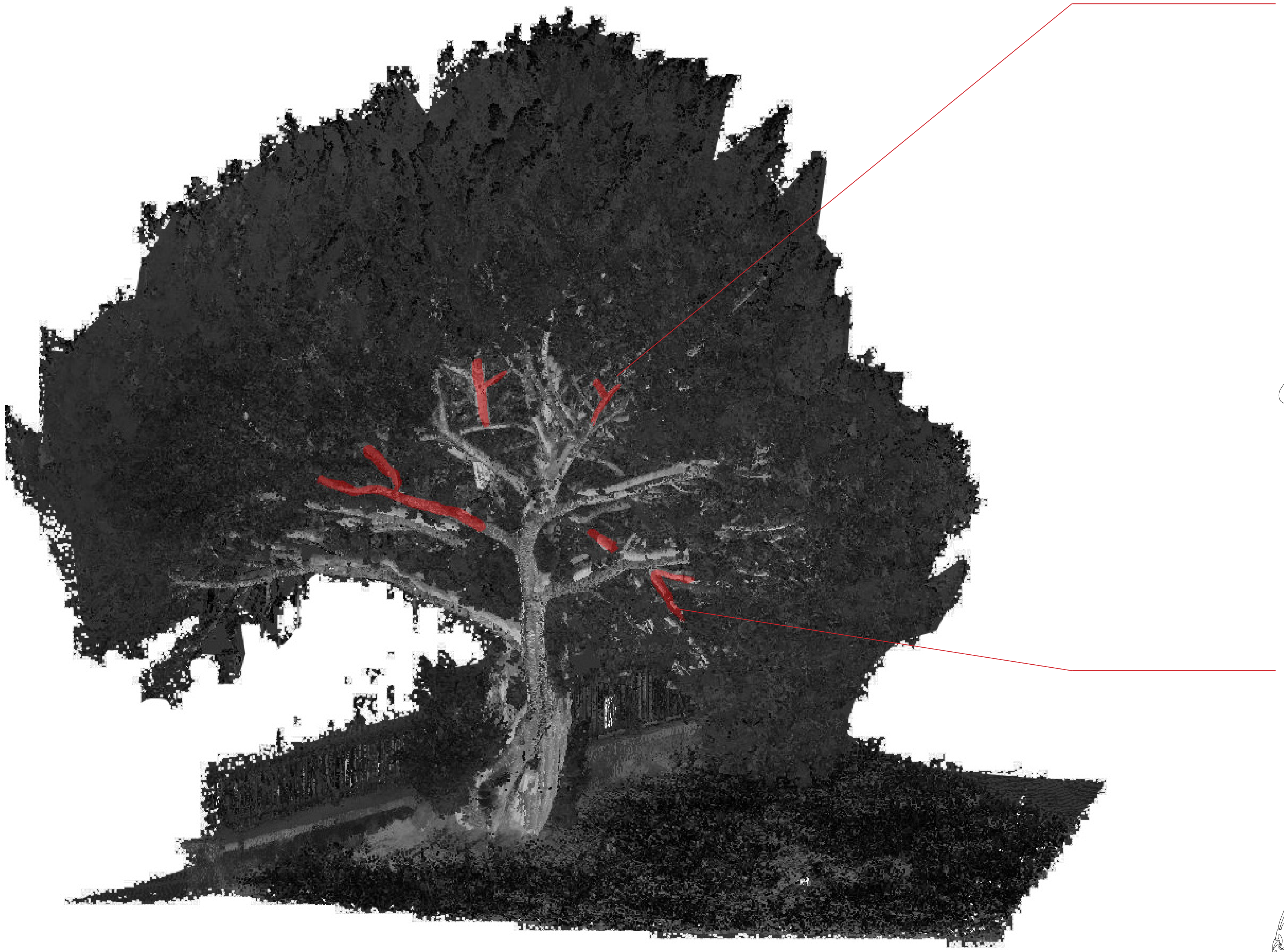


Figure 4.07: 3D Scan Artefact | Nolan | 2022

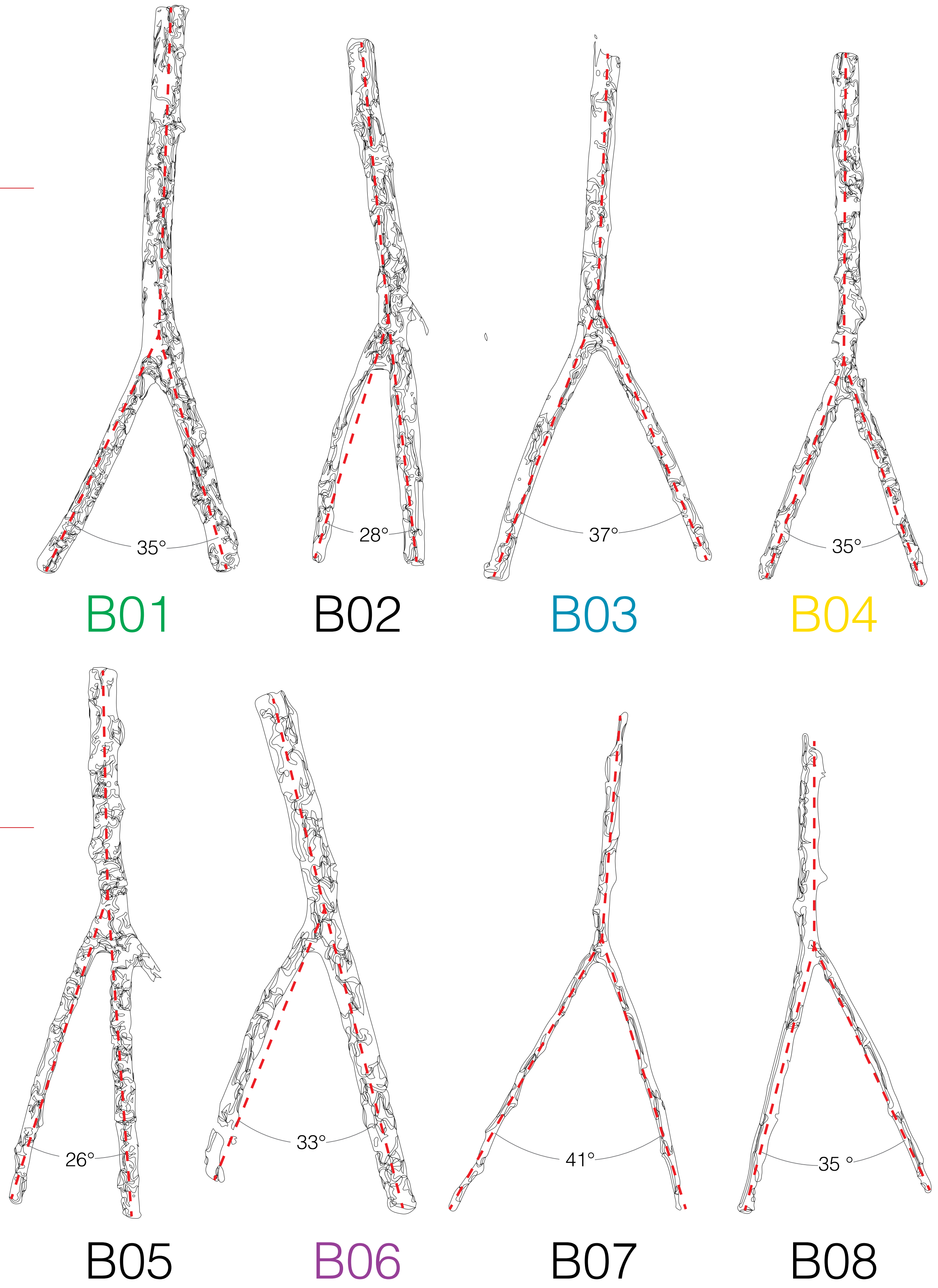


Figure 4.08: 3D Scan Catalogue | Nolan | 2022

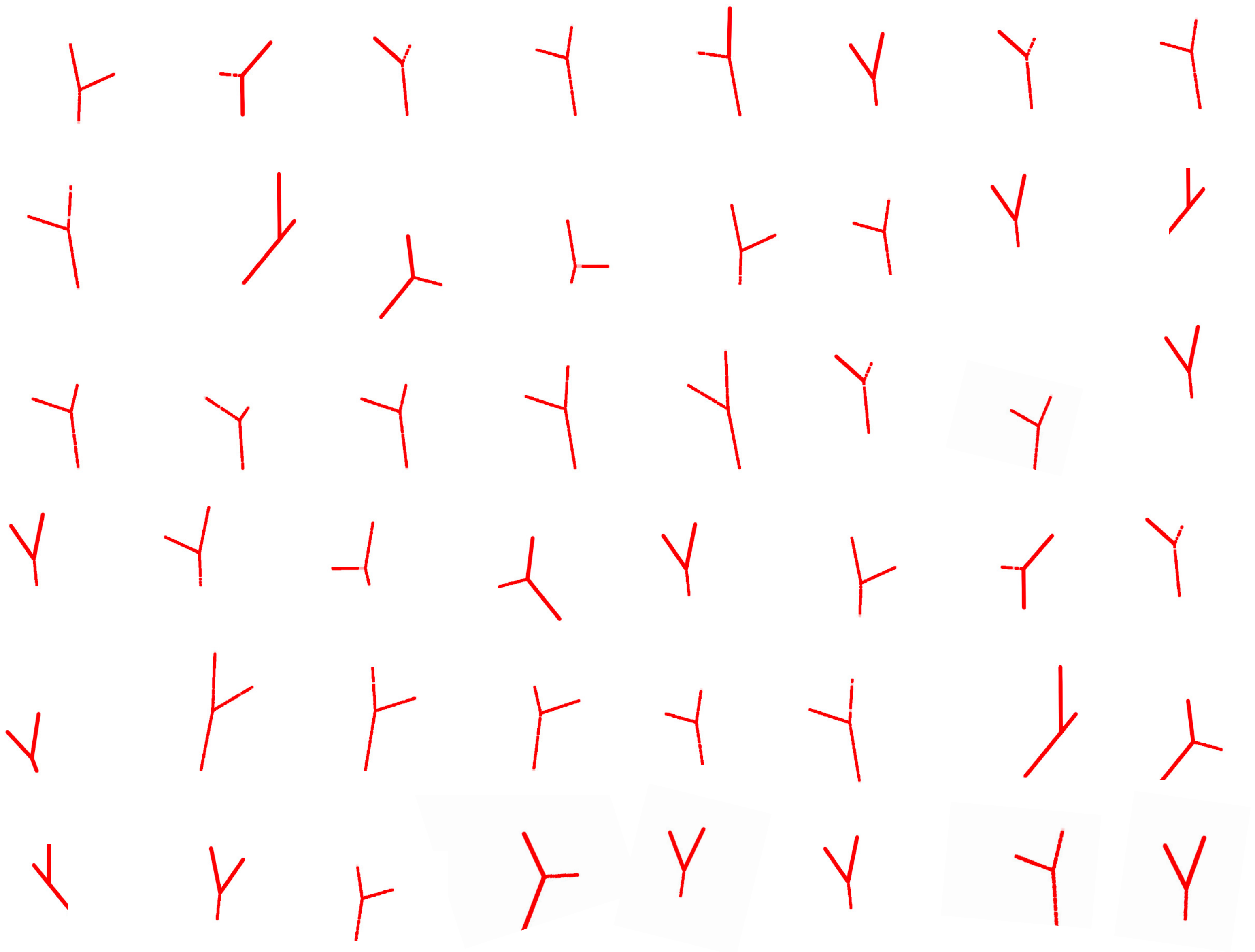
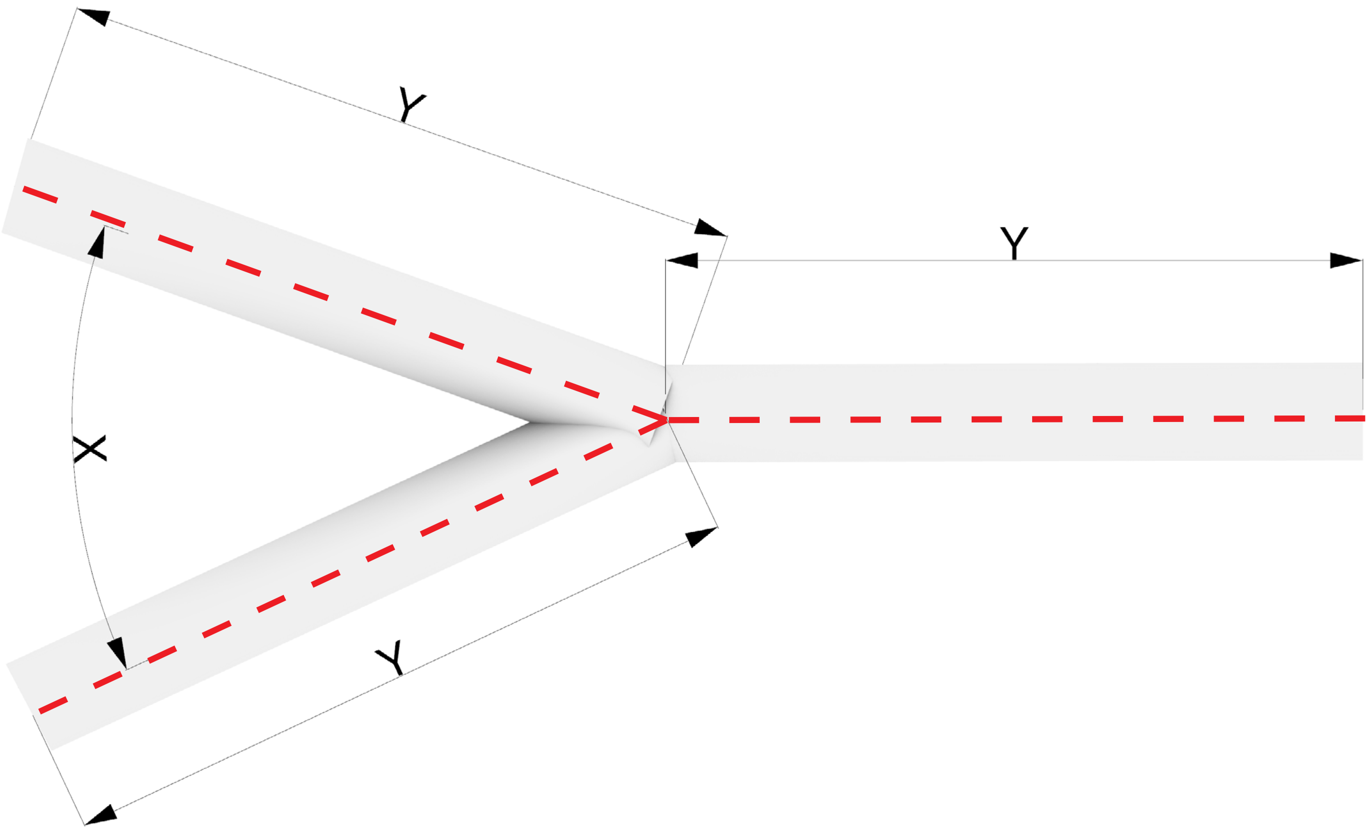


Figure 4.09: Digital database of simplified branch geometries | Nolan | 2023



X = 35° (Average crotch angle of sample set)
Y = 500mm (Uniform Length)

Figure 4.10: Analysing the database to produce a proto-part | Nolan | 2023

PROTO-PART

By intelligently selecting specific branches from the database, we can arrange the materials into hierarchies. Author Ishani Desai follows a similar procedure in 'Designing structures with tree forks: Mechanical characterization and generalized computational design approach' (Desai, 2020). In his paper he arranges a data list of branches into a chart determined by the crotch angle of each branch. The crotch angle is formed by the parting of two branches (Merriam Webster, 2022). The values of each branch present a bell curve with different species of trees usually having a high number of branches with a typical average crotch angle. Instead of using the fictional database of materials for my own analysis, I collected 30 forked branches from alder trees that I had access to. Of the branches that I collected the average crotch angle was 35°. This indicated that the proto-part would have a crotch angle of 35°. The different branches were at varying scales, but the larger branches could be cut to a certain dimension. The length of each element in the fork would measure 0.5m for the proto-part. Reducing the database to a single average part allows for efficient and optimised assembling of this part.

Tree Name	Common Name/Characteristics	Match to location tree type	# of species at location (Total = 14k)	Aver. Angle	Max. Angle	Min. Angle
Betula platyphylla	Birch	Birch	173	60	86	35
Cornus controversa	Dogwood, med-size, deciduous	Dogwood	71	60	88	40
Liquidambar formosana	Sweet gum, deciduous	Ash	1052	64	99	25
Lithocarpus edulis	Stone-oak	Oak	730	54	86	32
Myrica rubra	small-med-size, fruit tree	Crabapple	208	60	85	30
Liriodendron tulipifera	Poplar, large, deciduous	Maple	7	56	83	25

Figure 4.11: Tree fork average, minimum, and maximum angles | Ishani Desai | 2020

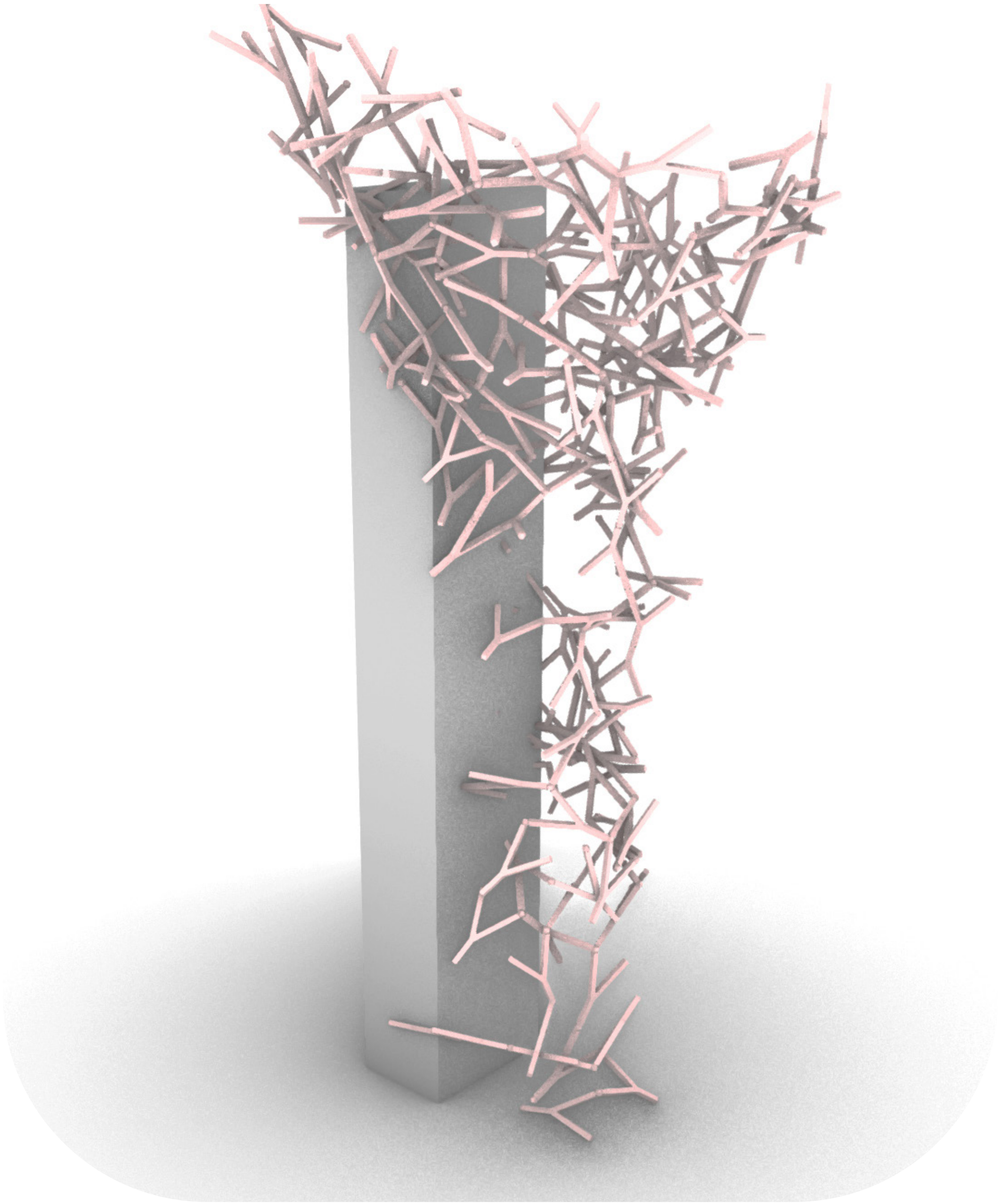


Figure 4.12: Protopart assembled to create structures under certain instruction | Nolan | 2022

ASSEMBLY

The assembly of this proto-part results in various structures. This assembly was carried out through two methods. The first was discrete digital assembly as a method of rapid prototyping using the grasshopper plugin 'Wasp'. Wasp creator Andrea Rossi describes this Rhino plugin as

> a method for hierarchical discrete modelling of objects as aggregations of modular parts, with focus on the generation of architectural objects. By conceptualizing the discrete nature of the final objects already within the software, it becomes possible to model heterogenous artefacts composed of basic parts, which are reversibly joined into a complete aggregation (Andrea Rossi & Oliver Tessmann, 2019).

This allowed rapid prototyping of different types of structures. In conjunction with digital modelling, I was physically modelling structures with scaled forked branches. This allowed me to test how the different structures acted when I applied external forces, such as weight and movement.

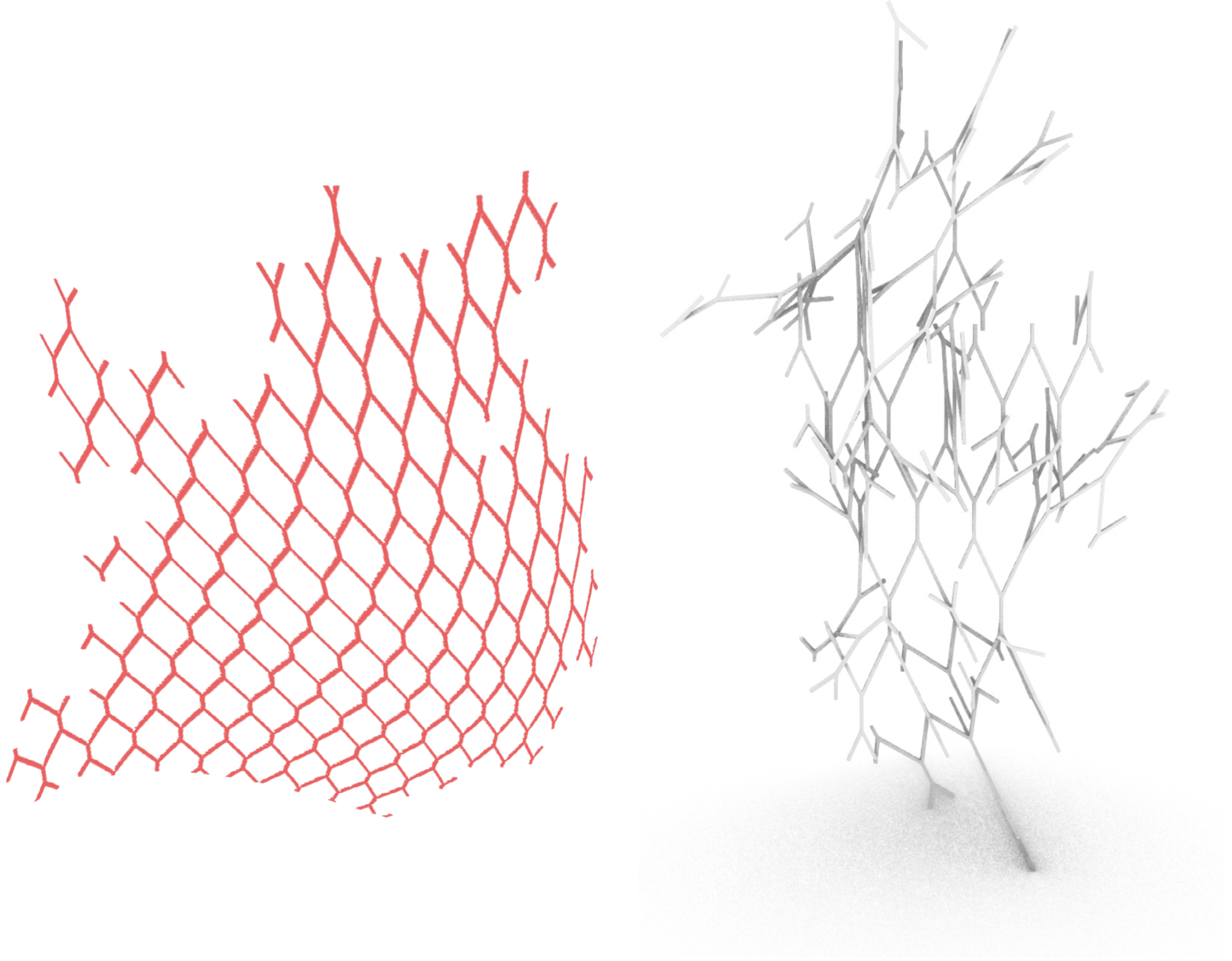


Figure 4.13: Digital Prototyping | Nolan | 2022

Figure 4.14: Physical Prototyping | Nolan | 2022

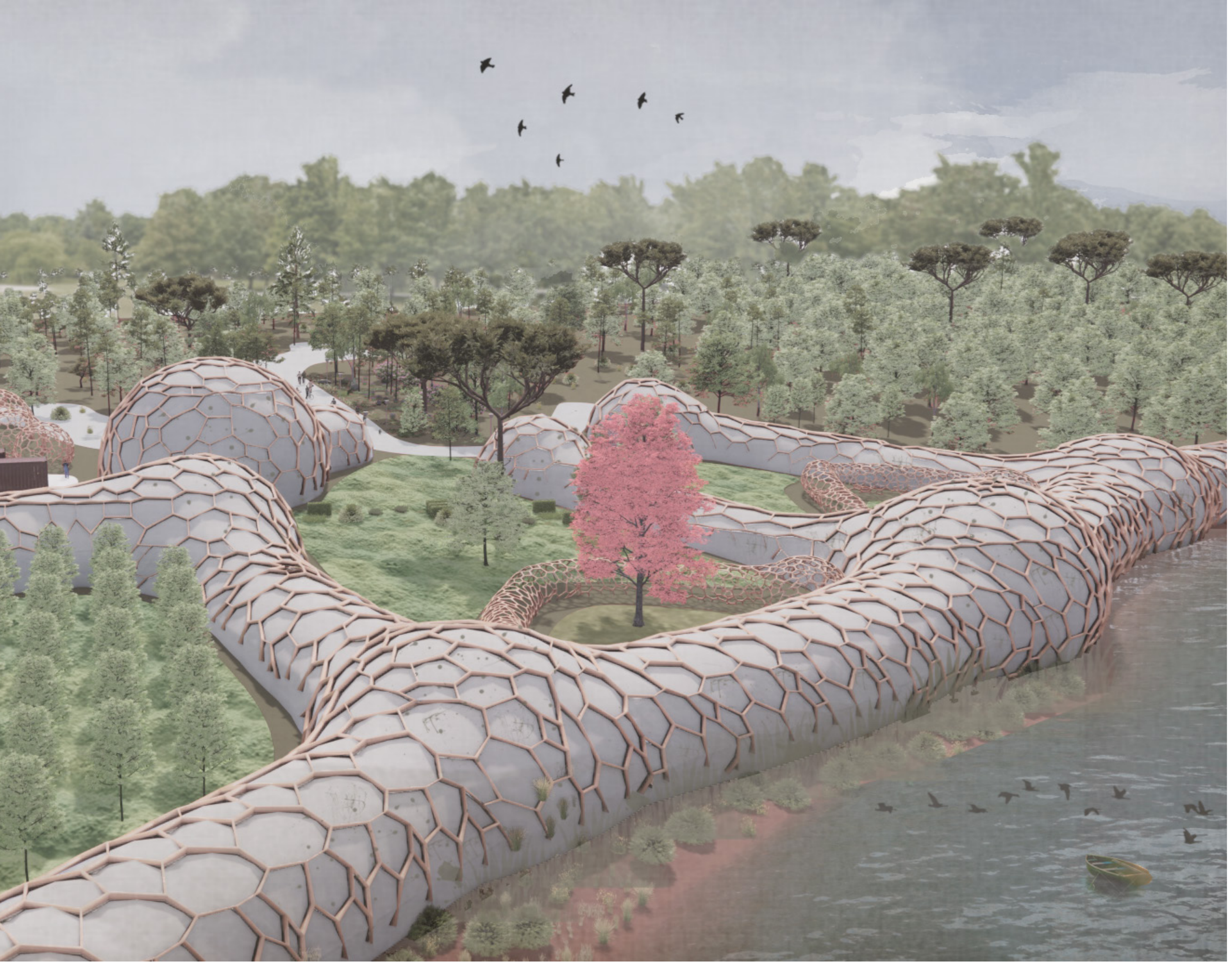


Figure 4.15: Aerial View of Data centre | Nolan | 2022

HUNTSTOWN DATA CENTRE

A research design project acted as vehicle to test these assemblies as a conceived and viable project to experiment with and develop further. The first structure to test these methods was a data centre. There are current plans to build a new data centre on one of the only remaining green field sites in the Huntstown area. The ambition of my design was to act as a more sustainable approach to the proposed data centre on site. This would be made possible by designing the new data centre from materials of the site in the form of forked branches from the trees. The design for the data centre was located on an exhausted quarry on the north side of the site. Water from the quarry lake would be used to cool the building which would be constructed from existing timber on site. The structure was produced using the Wasp script for prototyping with the proto-part. The design demonstrated how the aggregated assemblies of forked branches could create an architecture which was of the site. The design also showed a project that utilised timber in its natural form. After taking some critical distance from the project over the Summer, I decided to focus on the tectonics of the research. This direction would consist of focusing on a smaller intervention, with the primary use of this developed methodology to research a scaffold like structure. This allowed the research to reframe from the technical program of a data centre and other aspects like waterproofing.

Figure 4.16: Data centre Entrance | Nolan | 2022

Figure 4.17: Server Racks | Nolan | 2022

01 SUMMARY

The design of the data centre demonstrated how unprocessed timber can be used as the main building material in a design project. The methodology outlined is intelligent, in the sense that it analyses what material is available and digitally assembles this specified material to meet a certain requirement or structure. This framework sets up precedent as to what is achievable for a built form. By utilising unprocessed timber available on site this framework critically reduces the energy required to achieve a building of this nature.

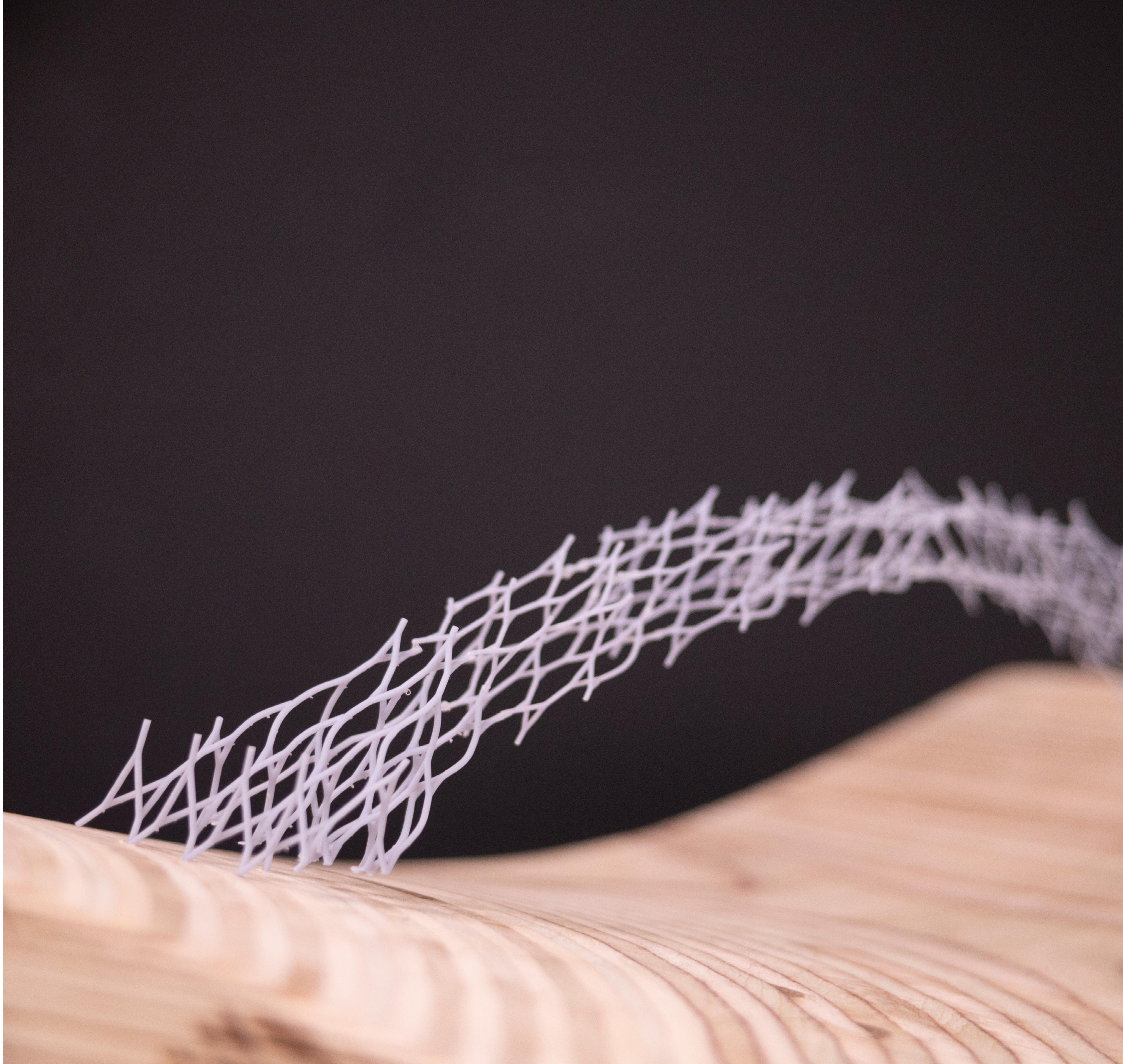
Figure 4.18: Huntstown Data centre | Nolan | 2022

HUNTSTOWN BRIDGE

INTRODUCTION

The second research design project came in the form of a bridge that was also located in the northern quarry. The bridges' structure comprised of forked branches assembled to create a structural system that spanned over a narrow area of the quarry. The ambition of the bridge was to demonstrate a design project that utilises the material existing on site and to focus on the tectonics. This structure would have architectural value and act as demonstrator for the possibility of what is achievable through this methodology. The bridge would be for climbers to cross and for wildlife to inhabit. A model of the bridge sitting on the topography would be a visual way of communicating the value of the design process and methodology as a means of construction in a more sustainable way.

Figure 5.01: Model of Huntstown Bridge | Nolan | 2023



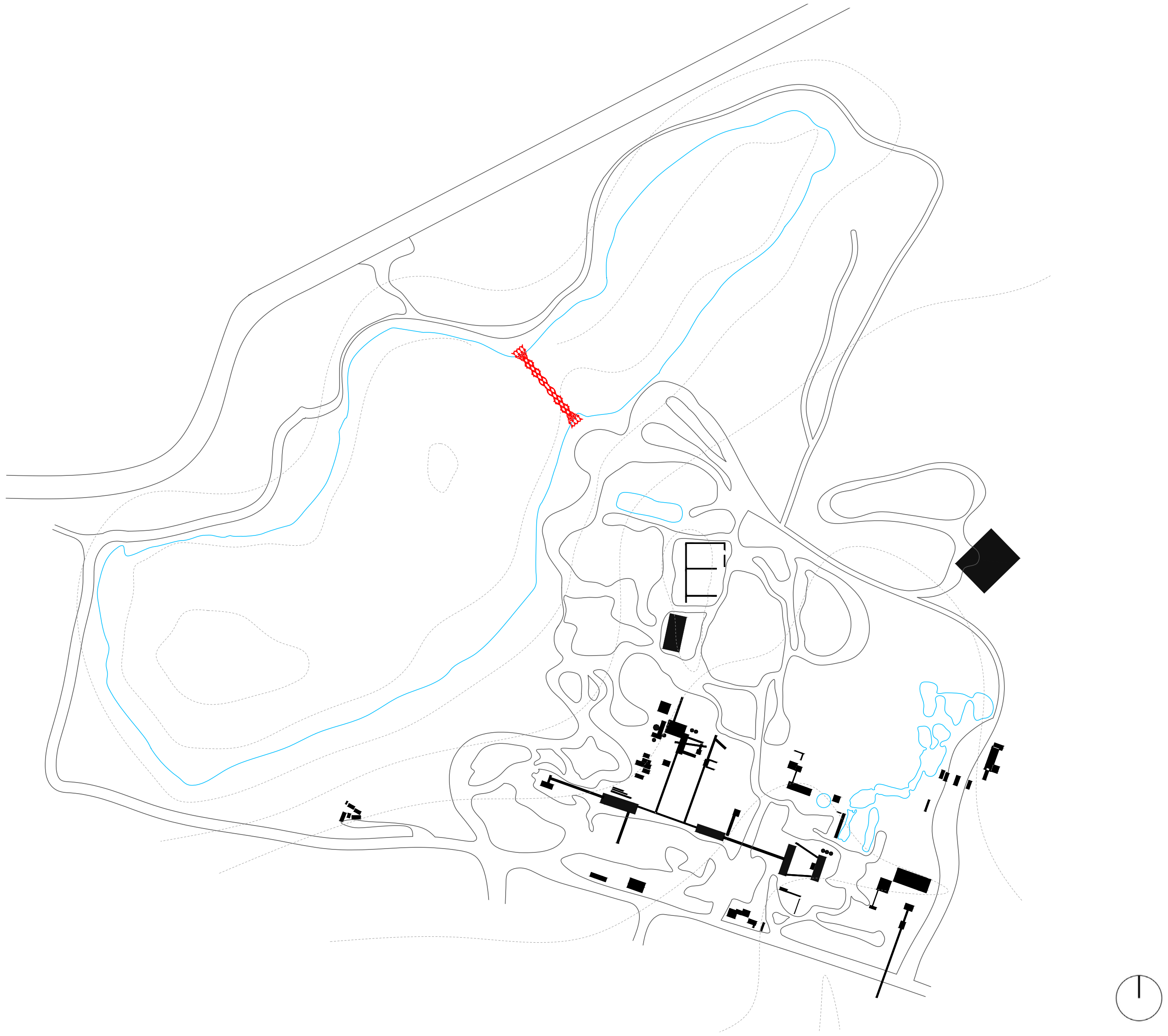


Figure 5.02: Northern Quarry Lake and Aggregate Factory | Nolan | 2023

The northern quarry was selected as the location because it narrowed in the middle and established a route from a new road being proposed to the north of the site, and to the construction aggregate factory. The time-frame of the bridge is also situated in the near future, when the factory is closed and rewilded. After further analysis and mapping of the north quarry it was decided that the bridge would span between the banks of the lake and would measure approximately 75m. Michael Piker, developer of plug-in Kangaroo for grasshopper, describes this computer program as "a live physics engine for interactive simulation, form-finding, optimization and constraint solving" (Piker, 2017). Kangaroo was used to aid the research and the structural integrity of the design project. Many form finding experiments were carried out using Kangaroo and resulted in surfaces that were in compression and no tension. These single minimal surfaces visualised the span of a shell structure from one bank of the lake to the other. The minimal surface acted as the field which the assembly of a the proto-part concentrated about. The Wasp plug-in has the ability to generate an aggregation of parts and applies a set of rules that you determine in a specified field (Andrea Rossi & Oliver Tessmann, 2019). This surface was then tested with Wasp and the assembly method outlined in chapter 4. This assembly was a field driven aggregation. When Wasp generated an assembly strictly of the proto-part, there were excess branches that were not contributing to the structural integrity of the bridge. A second observation found that using the single minimal surface required the proto-part to act in a 2D planar formation, which also lacked structural integrity. This finding highlighted how the assembly of the proto-part should be a 3D arrangement. In order to amend the first issue, the proto-parts first needed to be arranged in a sub-assembly. While on the second observation, the single minimal surface needed to be increased from one to two guiding surfaces with a relationship between them. This causes the bridge to act more like a truss than a shell structure.

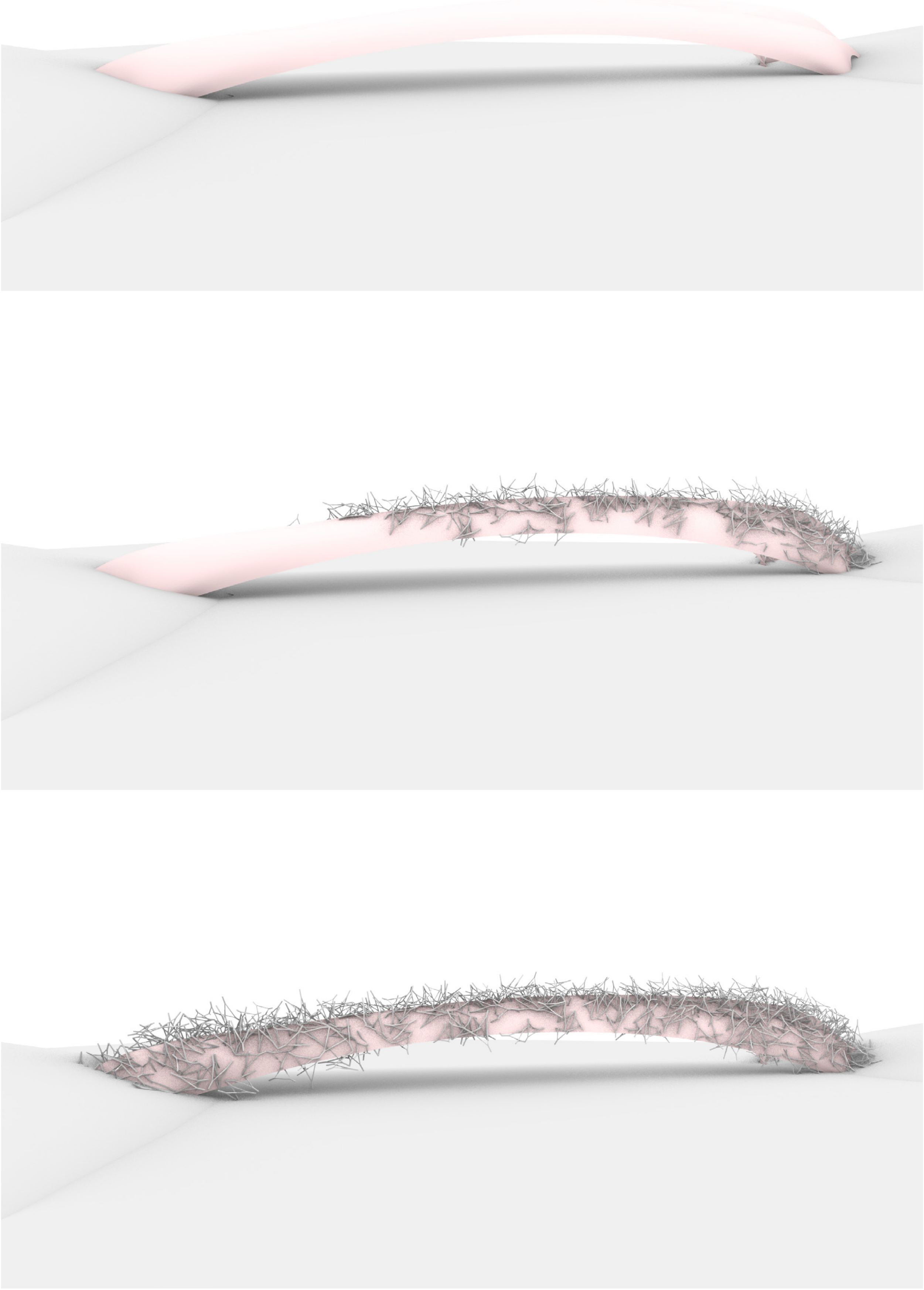


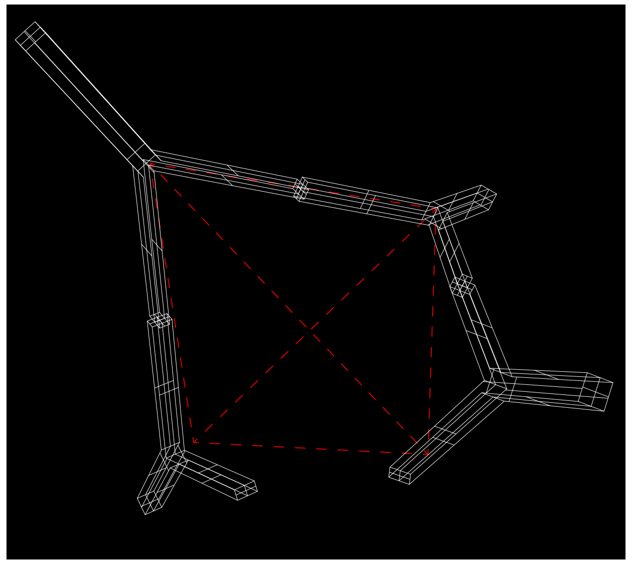
Figure 5.03: Initial Digital Assembly of the bridge where there was no structural integrity | Nolan | 2023

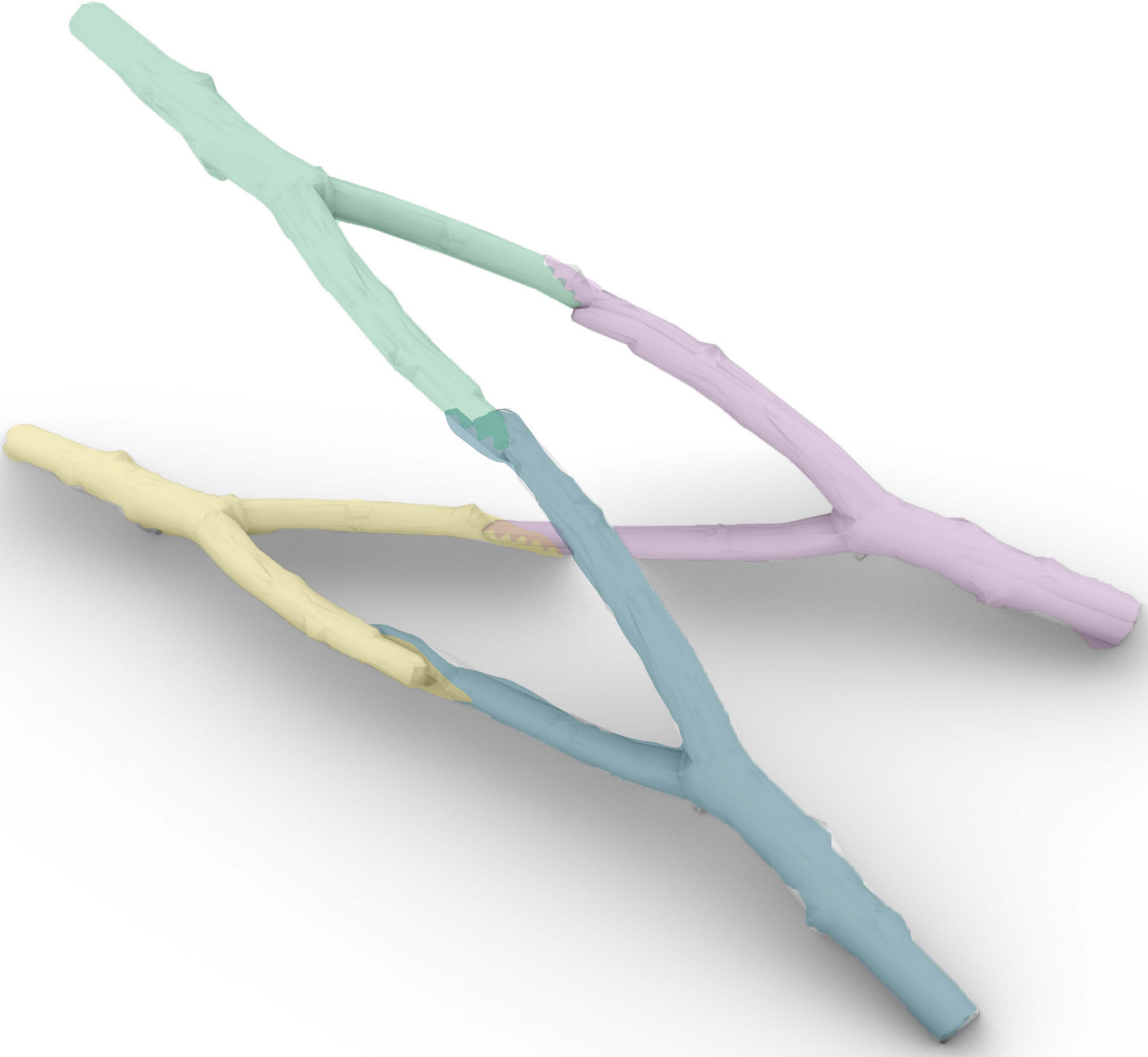
TETRAHEDRAL GEOMETRY

During prototyping with small scale physical branches, one geometric formation that arose was the tetrahedral. A tetrahedron is a 4-sided pyramid and structurally is described as a tetrahedral geometry. This sub-assembly is structurally strong when it works with other tetrahedra combined. Examples of this structure can be found in lightweight kites. When four forked branches are connected, they form a tetrahedral and have four connection points allowing for one sub-assembly to be connected to the next. When one tetrahedral meets another, at the connection point, the bottom of the branch meets the other at 180° and is in the same plane. In the proto-part, when the crotch angle is 35° each opposing branch meet in the same centre axis of rotation. When each branch is rotated 5° anti-clockwise it forms a complete tetrahedral. These sub-assemblies act like cells in the bridge structure and allow a synthesised structure to come together.

Figure 5.04: Four Forked Branches Coming together to form a Tetraherdral Geometry | Nolan | 2023

Figure 5.05: Working Drawing when Resolving the angle at which each branch meets | Nolan | 2023





The bridge acts a as hypothesis for how the structure might work with the use of the tetrahedral geometry. The use of the sub-assemblies creates a structurally strong span over the lake. Developing on the minimal surface, when this surface is given a depth, it transforms from being 2D and becomes 3D. This is more appropriate when in combination with the tetrahedral sub-assembly. The guiding surfaces establish a structure that is nearly all in compression in the curve, or two arches, while allowing less tension. This also allows the forked branches to resolve forces in 3D and not just be restricted to planar forces as to take advantage of timber's natural properties. The assembly of tetrahedra acts more like a Vierendeel truss than a shell structure. When the branches form a shell structure it is based on assembling the individual branches which increases the complexity and variety of connection types.

Figure 5.06: Tetraherdral Geometry With Each Branch Being Identified from the Catalogue of Material | Nolan | 2023

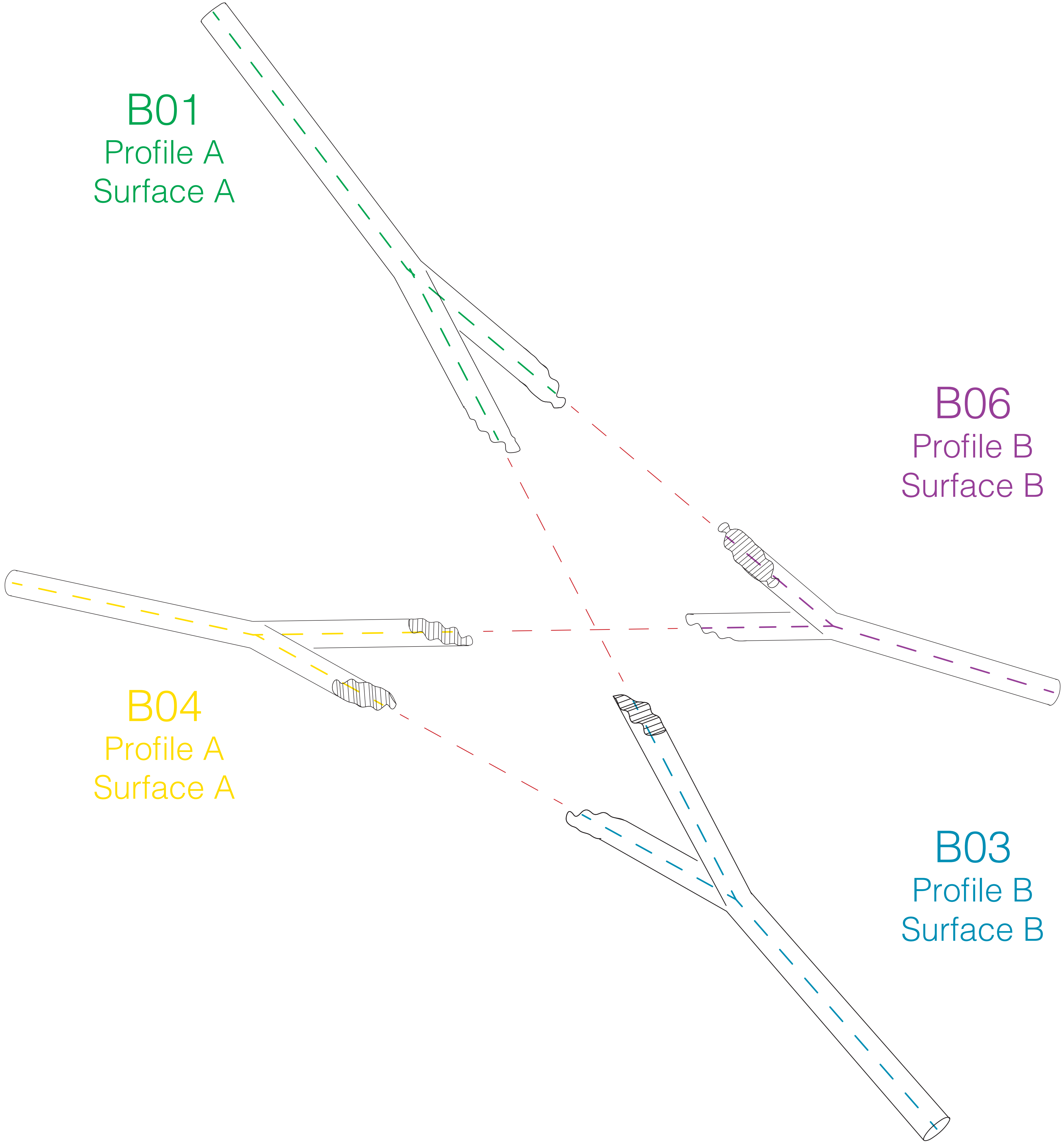


Figure 5.07: 3D Scan Catalogue | Nolan | 2023

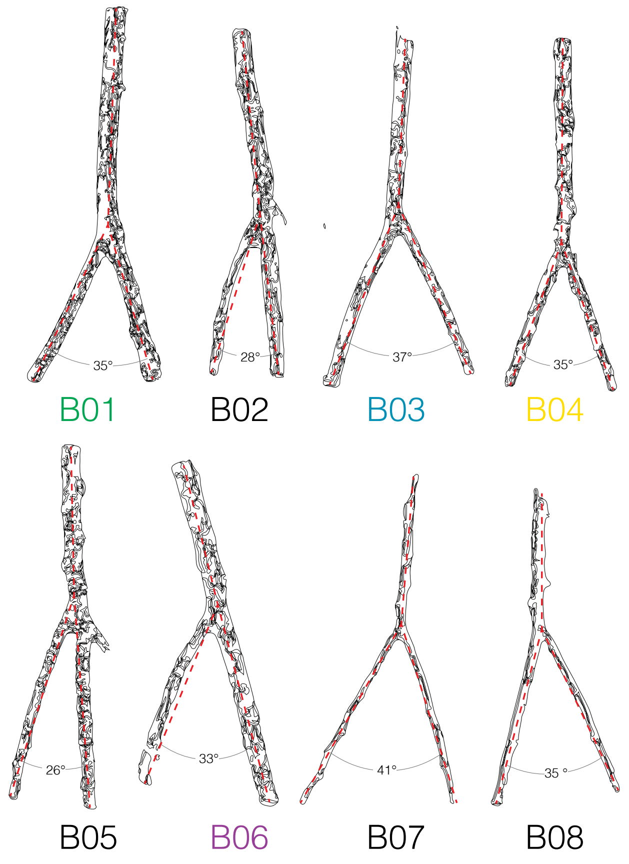


Figure 5.08: Render of tetrahedra working together at the start of the bridge | Nolan | 2023

The tetrahedral sub-assemblies were in turn organised to be in specific structural locations across the bridge. In the structural zones, the determining factor was the crotch angle of the proto-part. As outlined in figure 4.10, some branches were outside the average angle of 35°. As a result, these outlier branches formed different types of tetrahedral geometries.

Figure 5.09: Diagram of tetrahedra connecting together and aligning to the render of the bridge below | Nolan | 2023

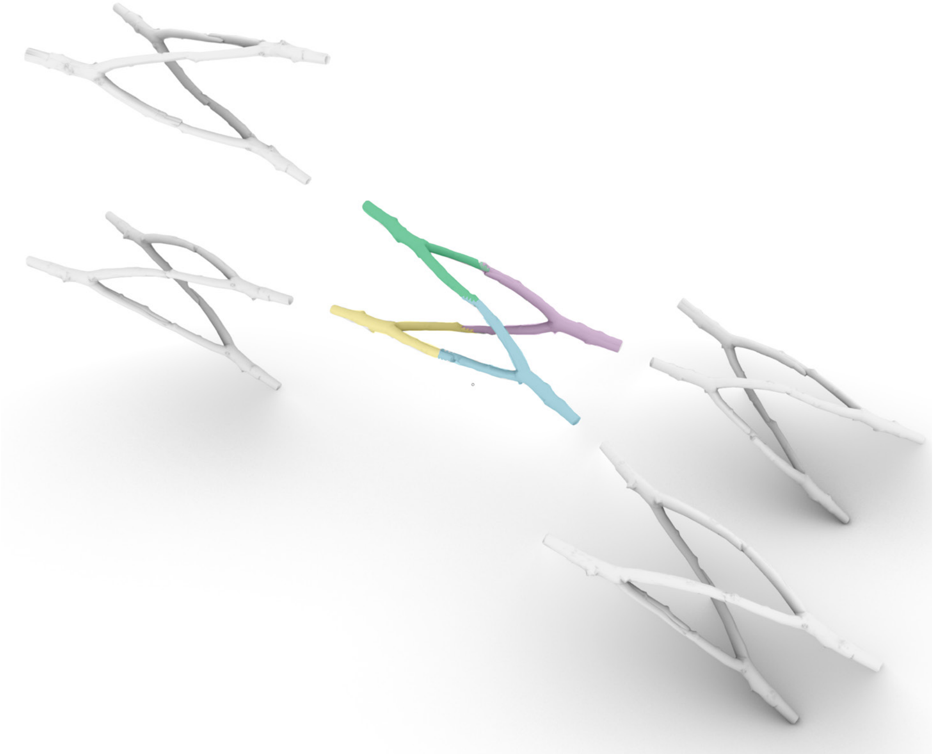


Figure 5.10: Diagram demonstrating the possibility to connect one tetrahedral geometry to another | Nolan | 2023

This caused sub-assemblies to differ in proportions, or to meet one sub-assembly at a different angle to another. These instances were incorporated into the design and allowed the bridge to taper as it spanned, resulting in the overall arc shape. A similar method was used at the banks of the lake. Branches that had a larger diameter were closer to the bank resulting in lighter weight branches being utilised in the centre of the bridge, at the greatest downward forces. The branch system is mirrored at the vertex of the bridge. This is to allow a similar path of forces to travel to the other bank.

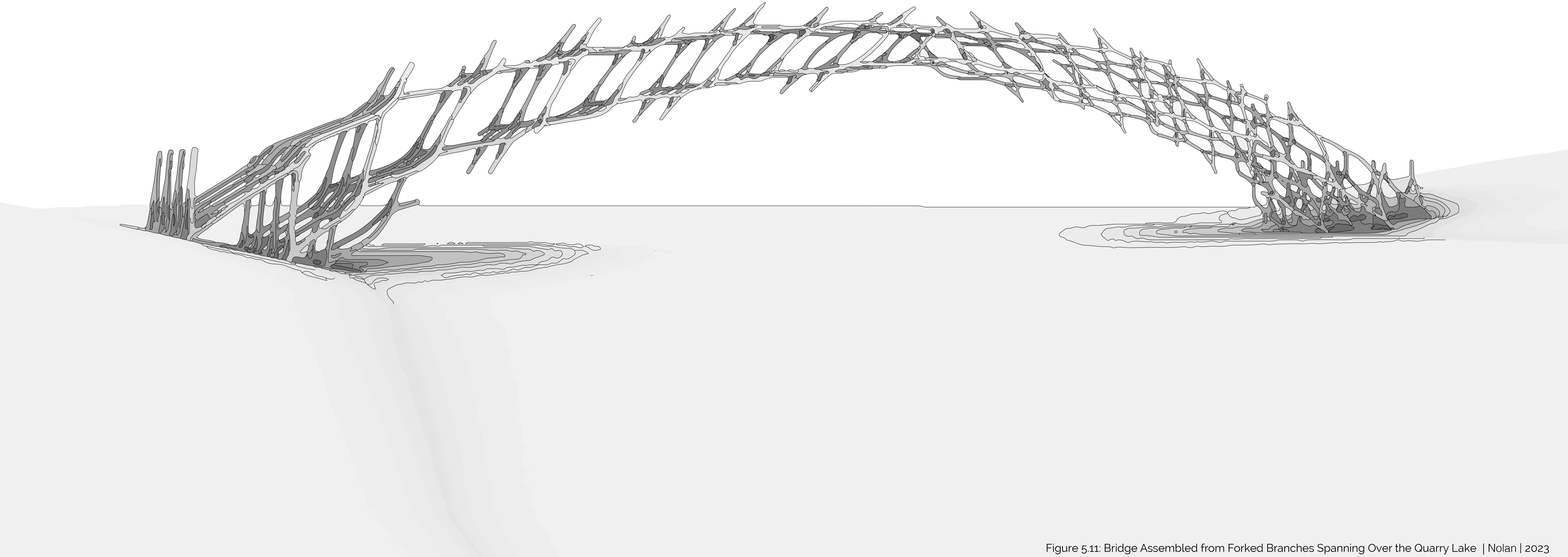


Figure 5.11: Bridge Assembled from Forked Branches Spanning Over the Quarry Lake | Nolan | 2023

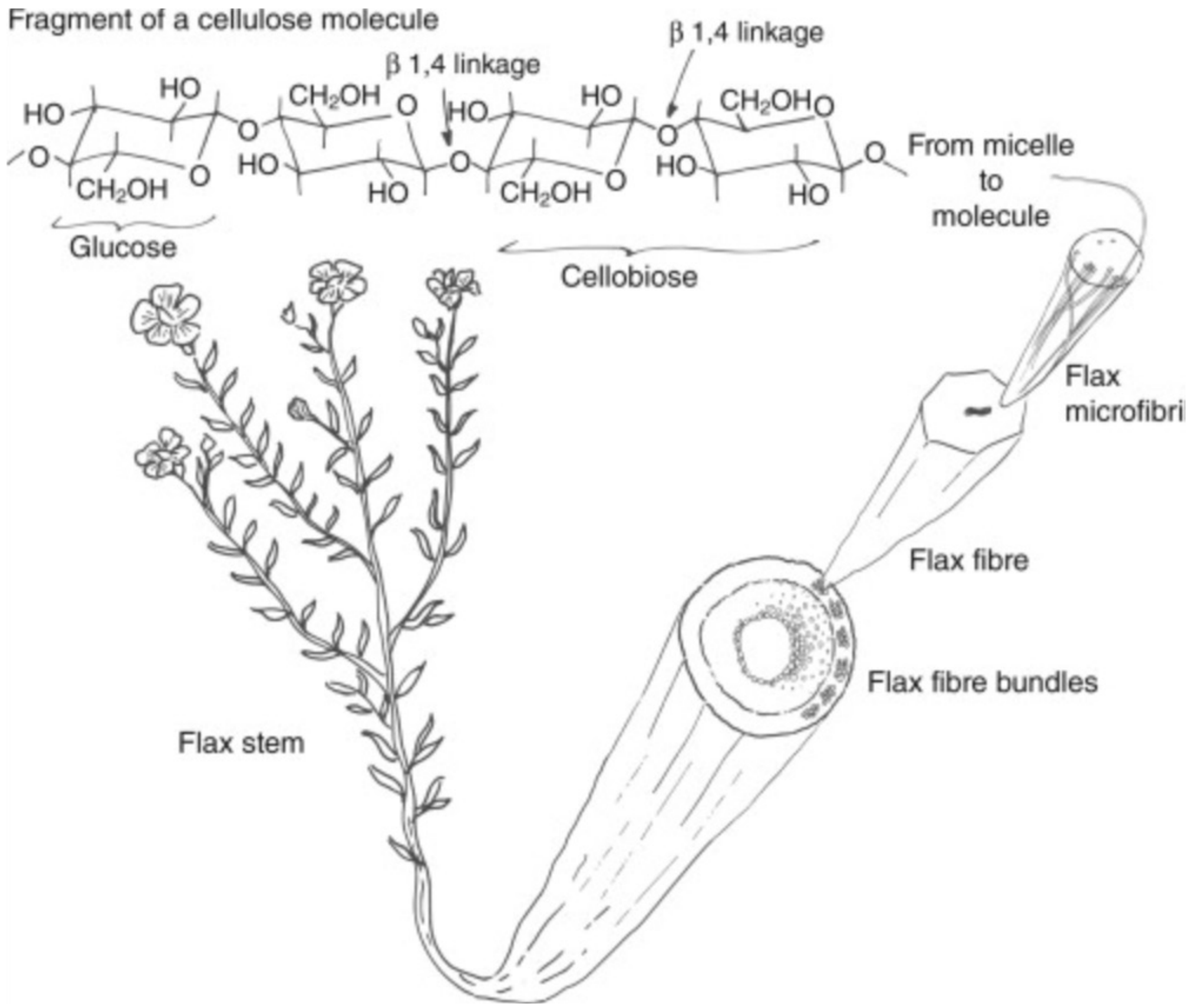


Figure 5.12: Fragment of a cellose molecule | Mussig, Haag | 2015

STRUCTURE

After a discussion with structural engineer Chris Bakkala, the structural stability of the bridge design was increased. An observation was made how a Vierendeel truss is "an open-web truss with vertical members but without diagonals and with rigid joints" (Merriam-Webster, 2022). To eliminate the bending moments at these rigid joints a diagonal tension member was proposed. This would consist of flax rope made from the flax plant that would be grown on the site. Flax follows a hierarchical system as seen in figure 5.12. The plant contains flax bundles which consist of flax fibres that have several cell wall layers (K. Haag, 2015). These cells in turn constitute cellulose that make micro-fibrils, another sub-assembly. The use of flax as a structural rope is aided by the fact that the "flax fibre industry is a mature industry and the different process steps are well adapted to the production of high-quality fibres" (Donald, 2001).

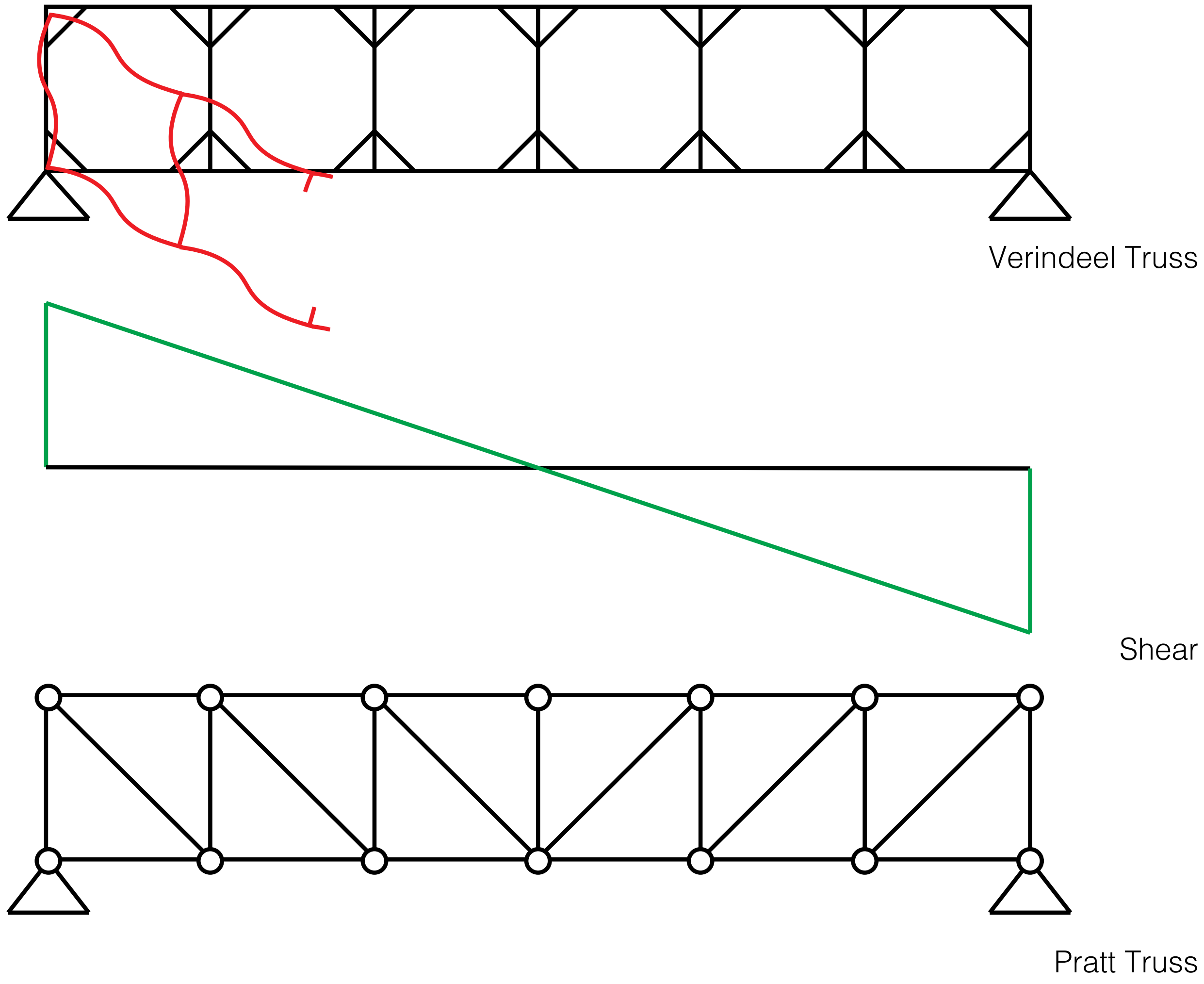
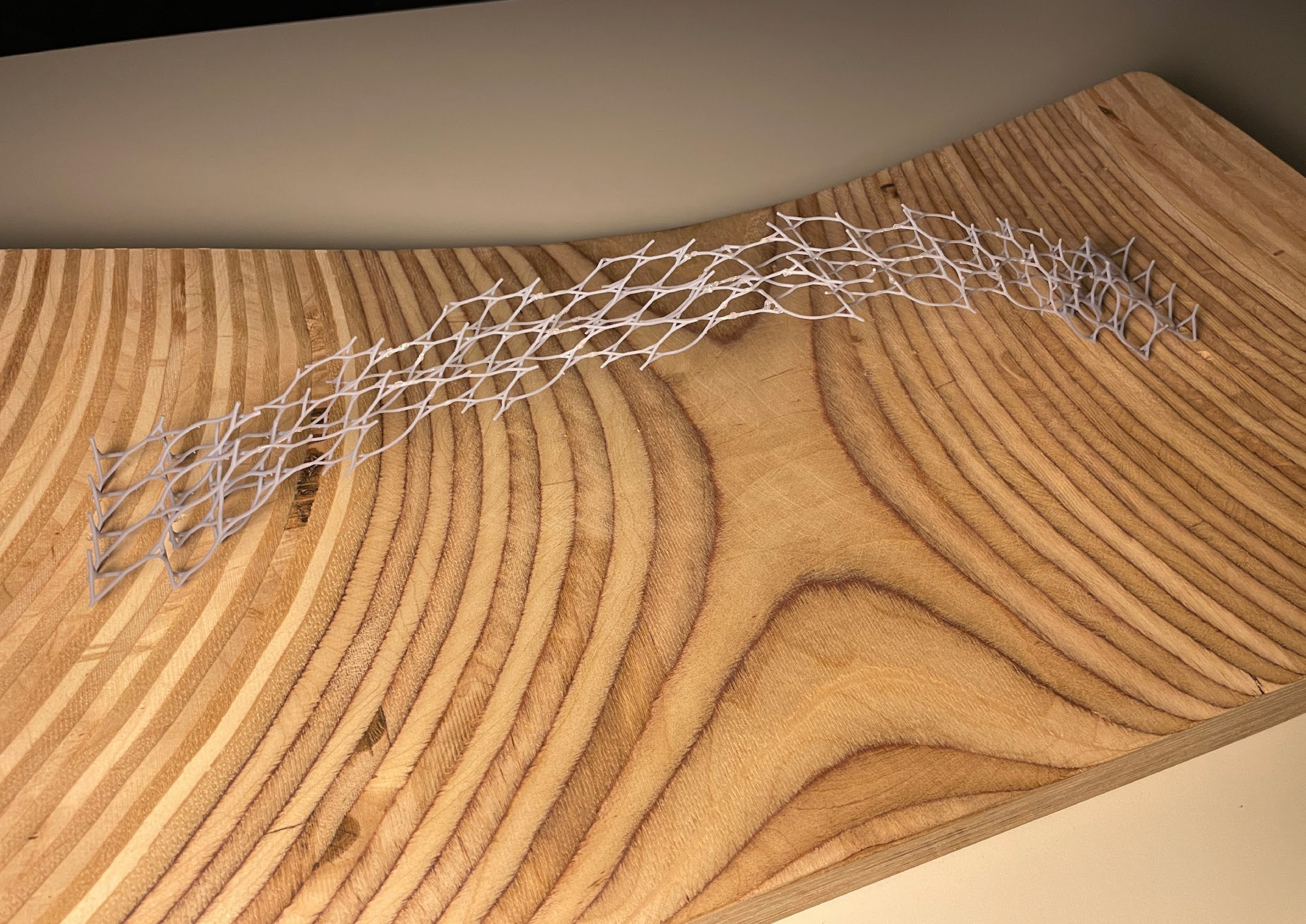
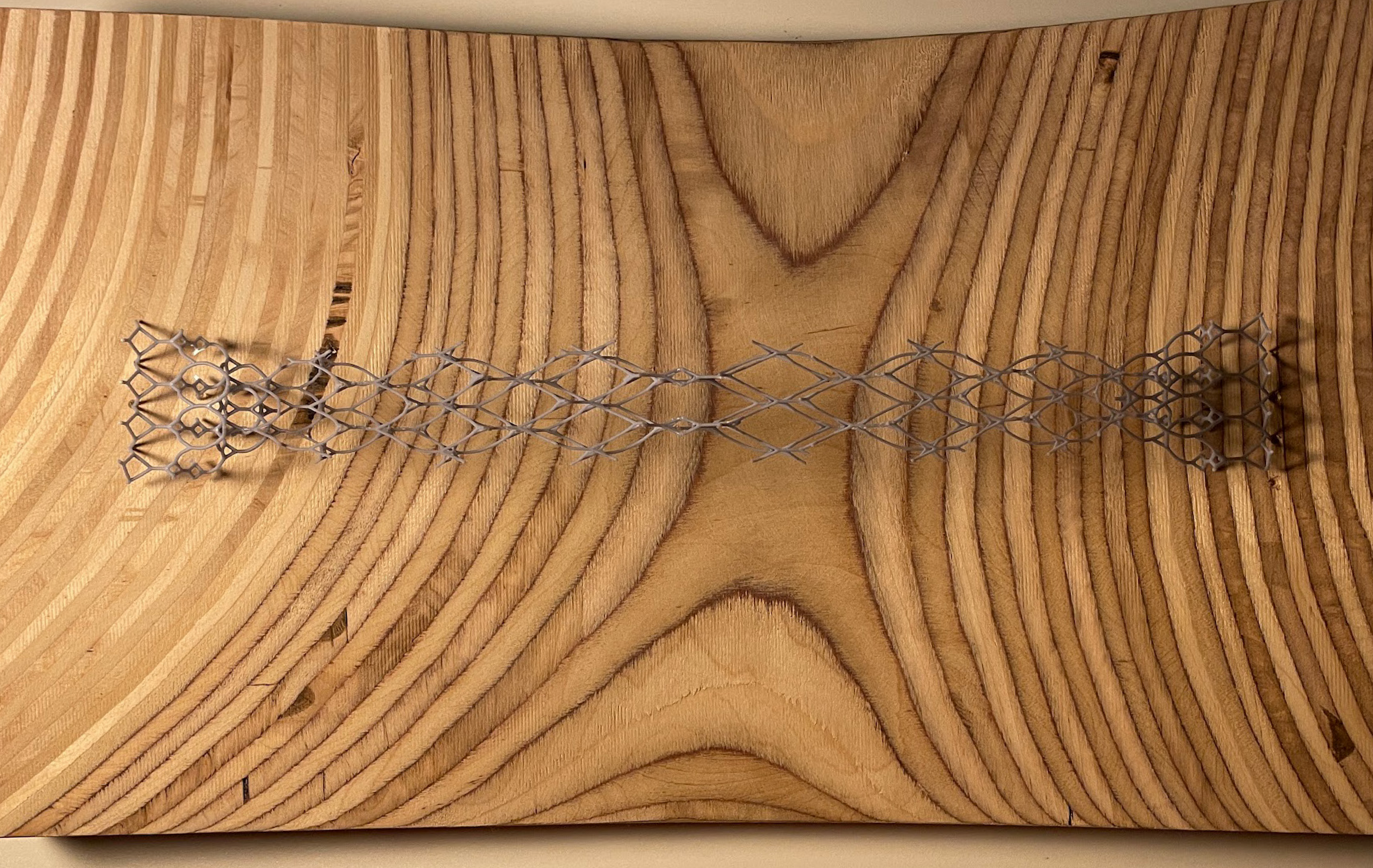


Figure 5.13: Structural Diagram | Nolan | 2023

Figure 5.14: The Barrow Bridge, Co. Waterford design by Architect Sir Benjamin Baker | Waterford Co. Museum | 1906

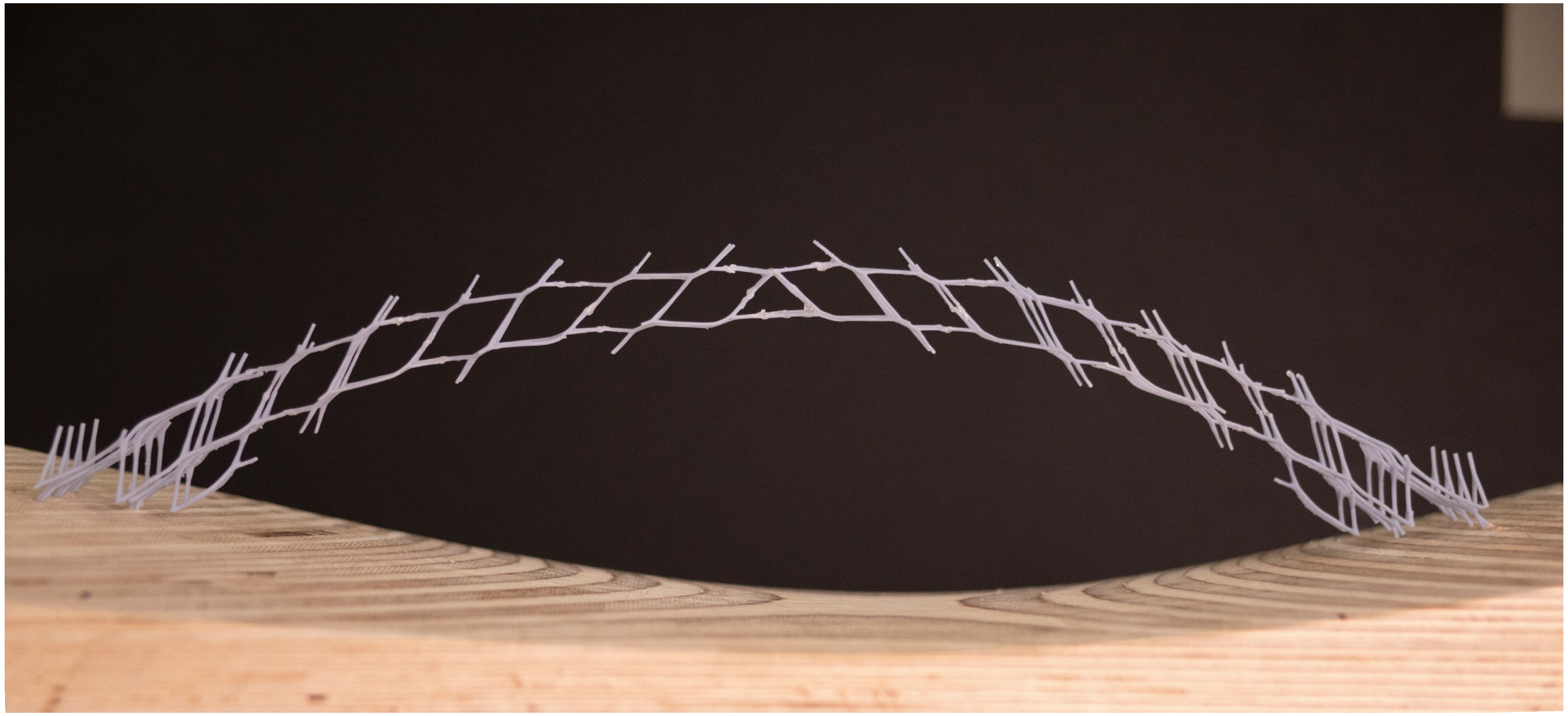
Next page - Figure 5.15: 3D printed model of bridge sitting on topography model | Nolan | 2023





02 SUMMARY

In summary, the design of the bridge demonstrates how a structure that utilises forked branches as the building material for its construction is possible. The structural integrity of the bridge is achievable when proposing the breakdown of the bridge elements into sub-assemblies that are further embedded in one another. Each sub-assembly has its own attributes that, consequently, allow the bridge to achieve a greater overall structural stability when spanning over the lake.



Previous page - Figure 5.16: Aerial view of 3D printed model of bridge | Nolan | 2023
Above - Figure 5.17: Side view of model of Huntstwon Bridge | Nolan | 2022
Next page - Figure 6.01: Catalogue of material for tetrahedra | Nolan | 2023

CONNECTION JOINT

INTRODUCTION

The focus of the project then turns to the connection joint. This connection joint is where one branch meets another in all assemblies for the bridge. Throughout the research above, there were many different aspects to where the research could go. An important thread through the different semester projects was how the branches must be connected somehow. The design of this connection between the branches will create the structure and in turn be highly sustainable. How the branches connect is essential to making the above design projects viable. The ambition here is that a full-scale connection joint will show the architectural presence of this construction method as well as resolve the branches connecting. This will then be used to synthesis the previous schemes and demonstrate architectural value and complexity. It is also the ambition that these joints are reproducible in several different situations and for others to follow this methodology and have the same results.

Figure 6.02: Forked Branch Having the Connection Joint Cut into it by the CNC Machine | Nolan | 2023

Figure 6.03: Jig for CNC Machine In Order To Hold Branch In Position | Nolan | 2022

TESTING THE JOINTS

A series of prototypes and test designs were set up for the connection joint. The joint was designed to utilise the advantages of a CNC machine available to me in the university. This machine is a 3-axis machine with CNC being an abbreviation for 'Computer Numerical Control' (Fast Radius, 2021). As a precedent, a series of existing frameworks was written about by Lukas Allner, Christoph Kaltenbrunner, Daniela Krohnert and Philip Reinsberg in the book 'Conceptual Joining' (2022). The research team utilises a 7-axis machine in the fabrication of timber joints, but these machines are generally more expensive and not as easy to access. The design of my branch joint had to accommodate the limitations of the CNC machine. One example being the work area of the machine being restricted to 1200mm by 600mm. A jig was created to hold the branch in position when located on the bed of the machine. This consisted of a flat piece of MDF timber with slots cut into it. Cable ties then held the branch in position with these slots. An alternation was made after the first test cut, with waste wood screwed to the jig to buttress the branch from any lateral movement. Another feature unique to the CNC machine occurs when the branch is laid on the machine bed, the drill can only work on one side of the piece at a time and hence becomes a requirement in the design.

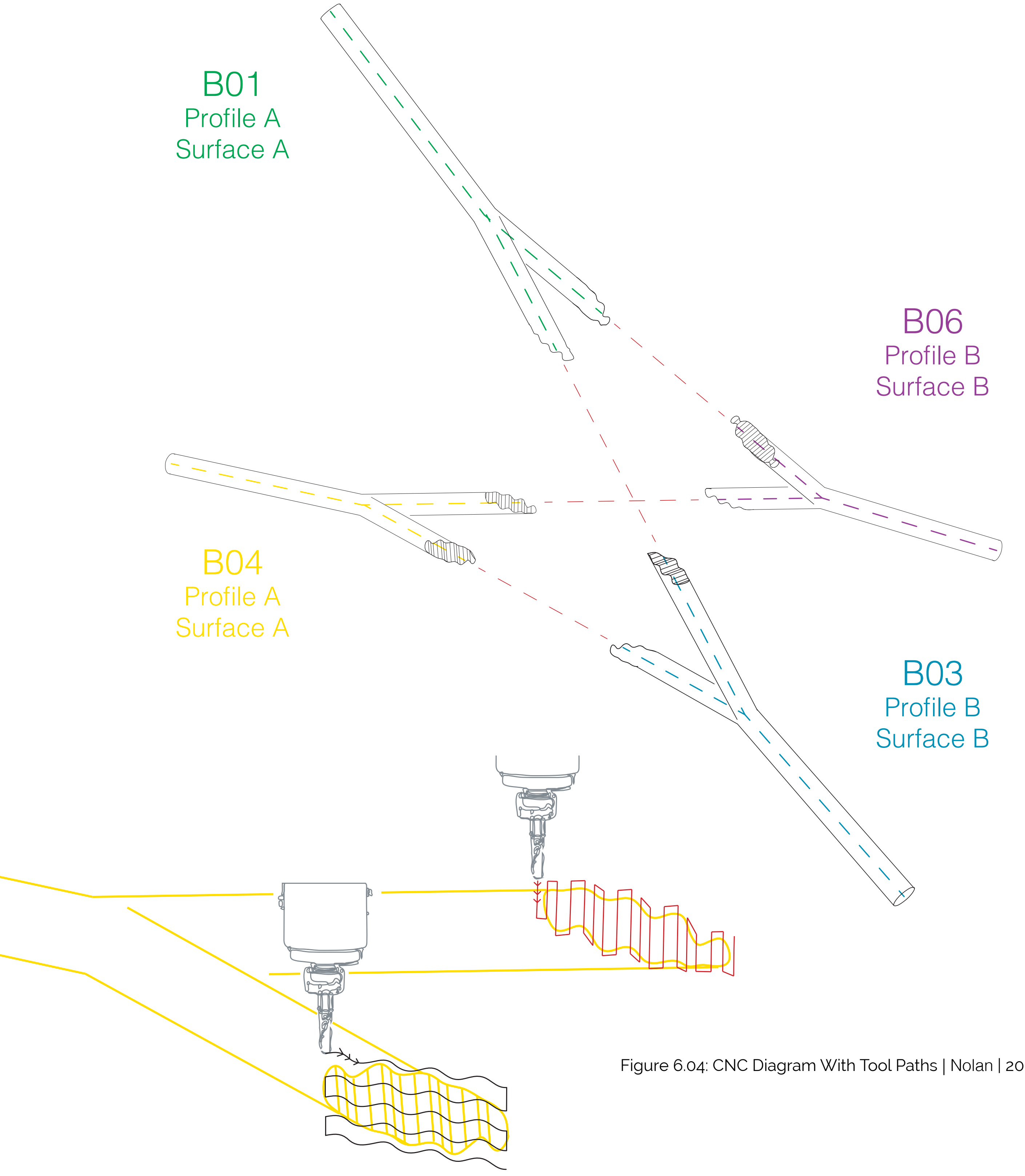
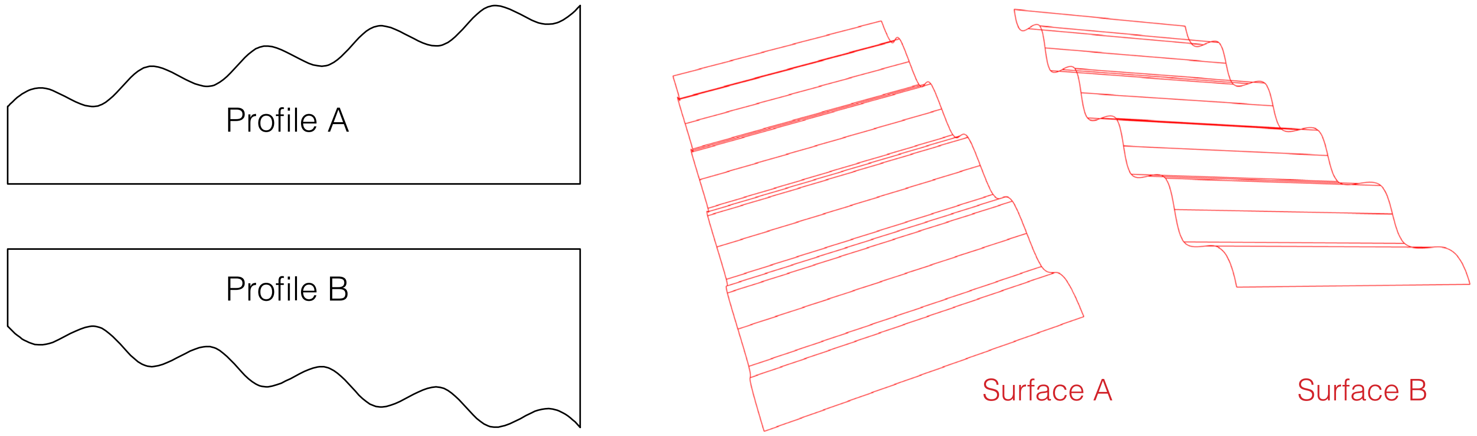


Figure 6.04: CNC Diagram With Tool Paths | Nolan | 2023



As the two ends of the branches are planar, the drill bit was capable of cutting a scarf joint into the branch. This cut evolved to form a wave in the joint as opposed to completely flat like a typical lap joint. As a result, the branch can be positioned higher or lower on the wave. This was the first accommodation in the design for resolving the differing crotch angles of the branches. The two branches can also be latterly positioned before being fixed together. The connection joint was tested multiple times to find an optimised wave pattern to cut into the branch.

Figure 6.05: Modified Scarf Joint Tested At 1:1 Scale | Nolan | 2022

Figure 6.06: Branch B04 Surface Cut | Nolan | 2022

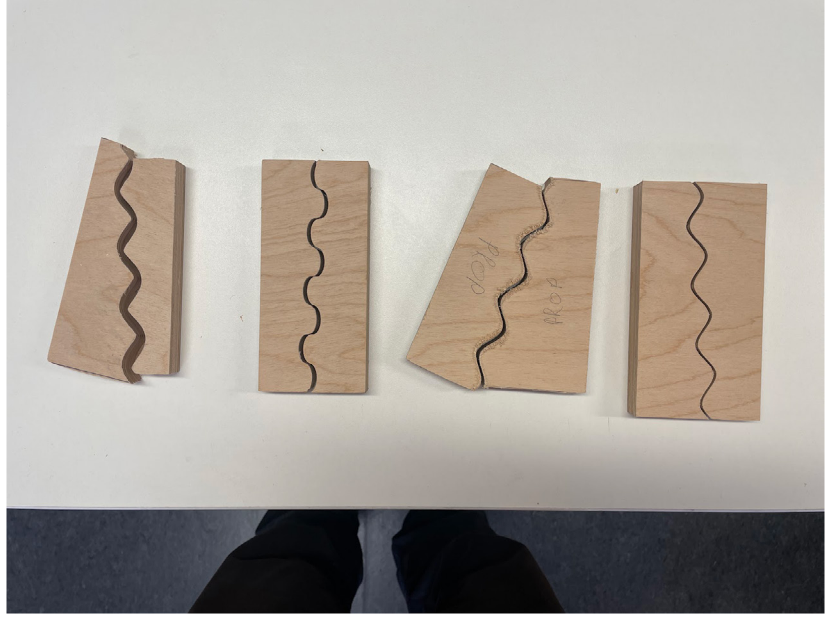


Figure 6.07: Testing Of The Different Waves That Would Be Could Into Each Branch | Nolan | 2022

Figure 6.08: Initial Test of the Final Wave That Was Cut Into the Branch at a Scale Of 1:1 | Nolan | 2022

Figure 6.09: Branch B03 Being Cut On The CNC Machine | Nolan | 2022

Figure 6.10: Assembly of the 4 branches to create the Tetrahedral Geometry | Nolan | 2015

Each branch was put on the jig and the pattern cut into them using the CNC machine. The joint would then be fastened together using the flax rope to act like a sleeve around the joint. This was a more sustainable approach, as opposed to using screws or bolts like the methods proposed in 'Conceptual joining'. This has the added benefit of not damaging the structural integrity of the bridge, like a screw splitting the branch for example. To demonstrate the process, four forked branches for were cut on the CNC machine and fixed together to form a complete tetrahedral geometry.

Figure 6.11: The start of the Flax Binding | Nolan | 2022

Figure 6.12: The Flax acts like a sleeve around the two branches | Nolan | 2022

Figure 6.13: View from above of the Modified Scarf Joint bound with Flax Rope | Nolan | 2022

Figure 6.14: Tetrahedron Standing Vertical | Nolan | 2022

Figure 6.15: Possibility to connect to other Tetrahedra | Nolan | 2022

CONNECTION JOINT

03 SUMMARY

To conclude on the connection joints, the evidence provided in the testing and fabrication of the joint demonstrates the ability to connect two branches in an efficient way. This ability to effectively connect one branch to another through fabrication proves how the branches in the bridge come together indicating the possibility of such a structure. The fabricated tetrahedra show how the structure is possible when in compression forces. This is achieved when cutting the scarf pattern into the branch on the CNC machine and bound together using flax rope.

Figure 6.16: Forked Branches connected together | Nolan | 2023

DISSEMINATION

To disseminate the findings of the research, the project will be exhibited in a gallery in Technological University Dublin. The ambition of the dissemination is to construct a table that will embody the methodologies discussed in this essay. The construction of this table has begun as of the writing of this dissertation. The legs of the table will be assembled from forked branches of alder wood and will be constructed using the framework indicated by the above methods. The top of the table will act like a display cabinet with a tempered glass top. Beneath this display there will be a selection of models and diagrams including the 1:200 bridge sitting on a topography model. This will be accompanied by key A0 drawings of the project that hang on threads from the ceiling. The website will aid in disseminating the work after the exhibition. The website can be found by following the QR scan on the right. Figure 7.01 shows the grasshopper script that was developed to carry out some of the digital prototyping. This script will be available on the website. The table will continue its journey with the university architecture society and be used at the next social event as a DJ table.

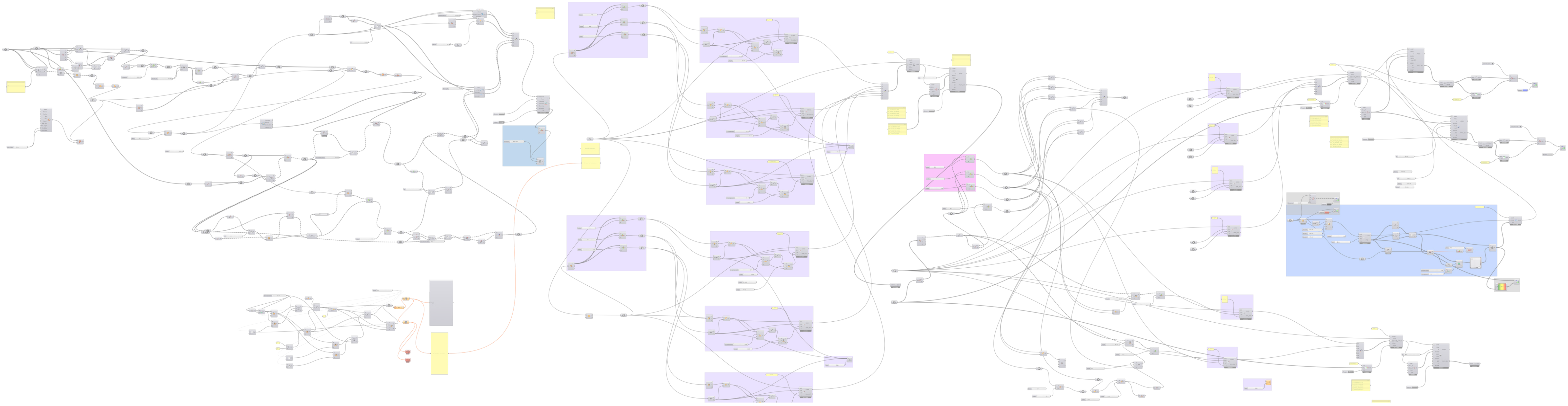


Figure 7.01: Grasshopper script for total project compiled and formed into one workspace | Nolan | 2023

DRAWINGS

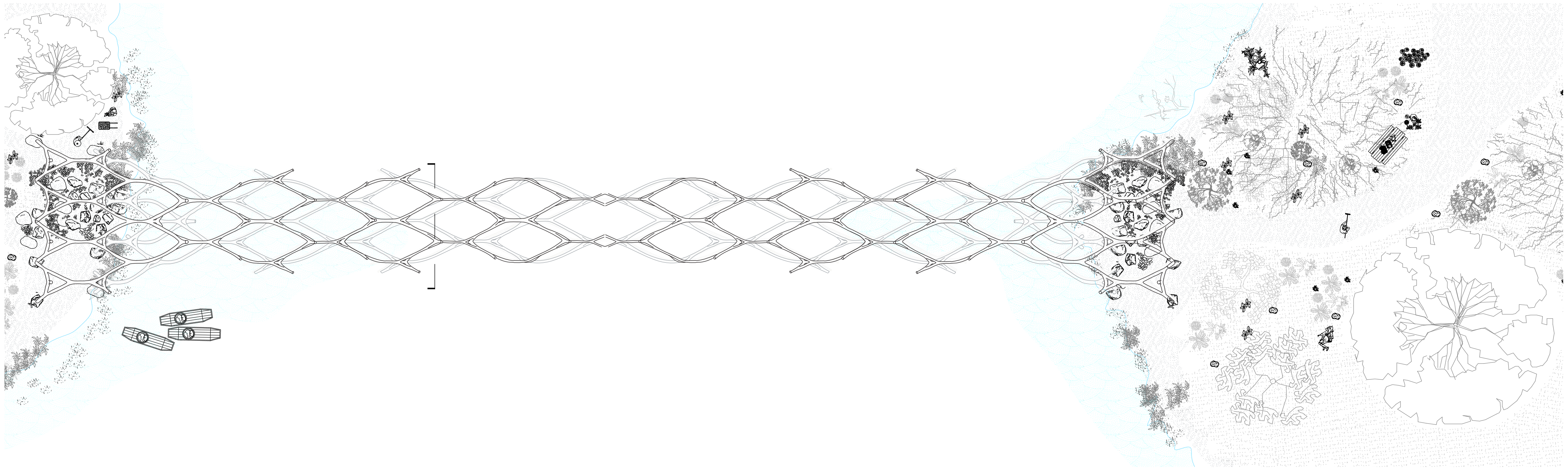


Figure 8.01: Plan of timber bridge spanning over quarry lake | Nolan | 2023

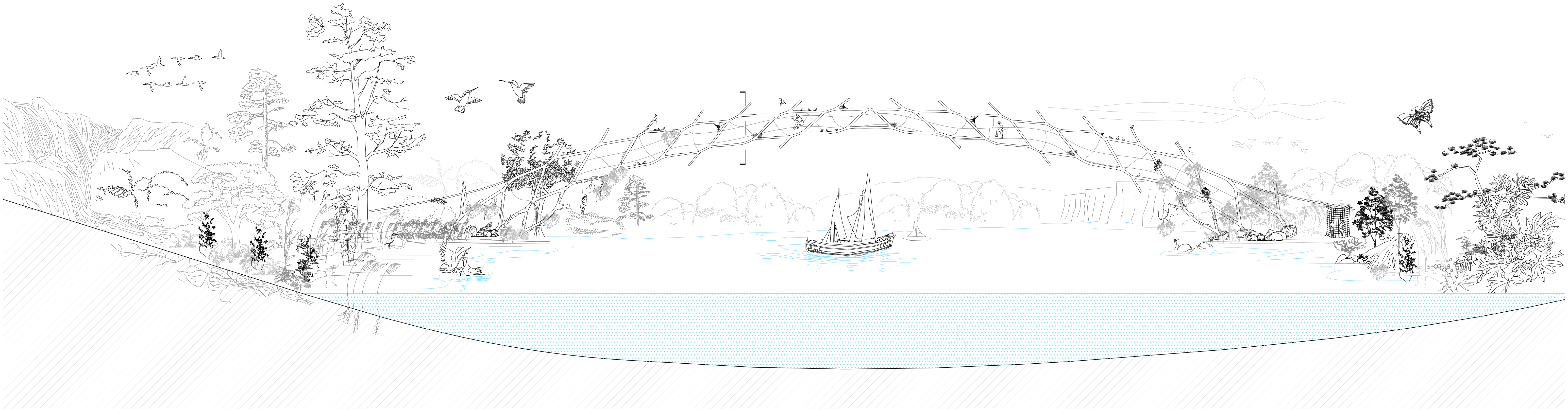


Figure 8.02: Bridge in elevation over the quarry lake | Nolan | 2023

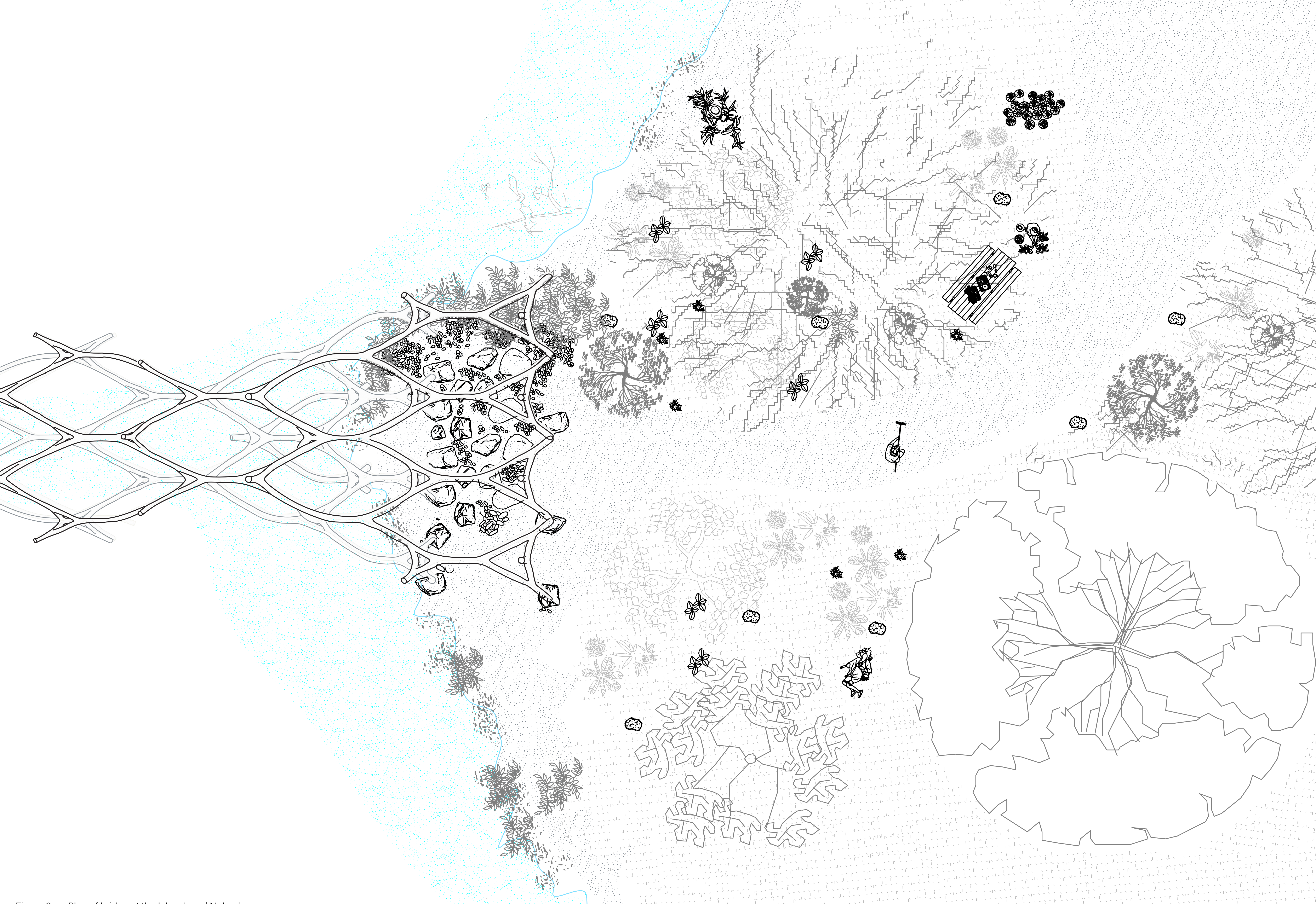
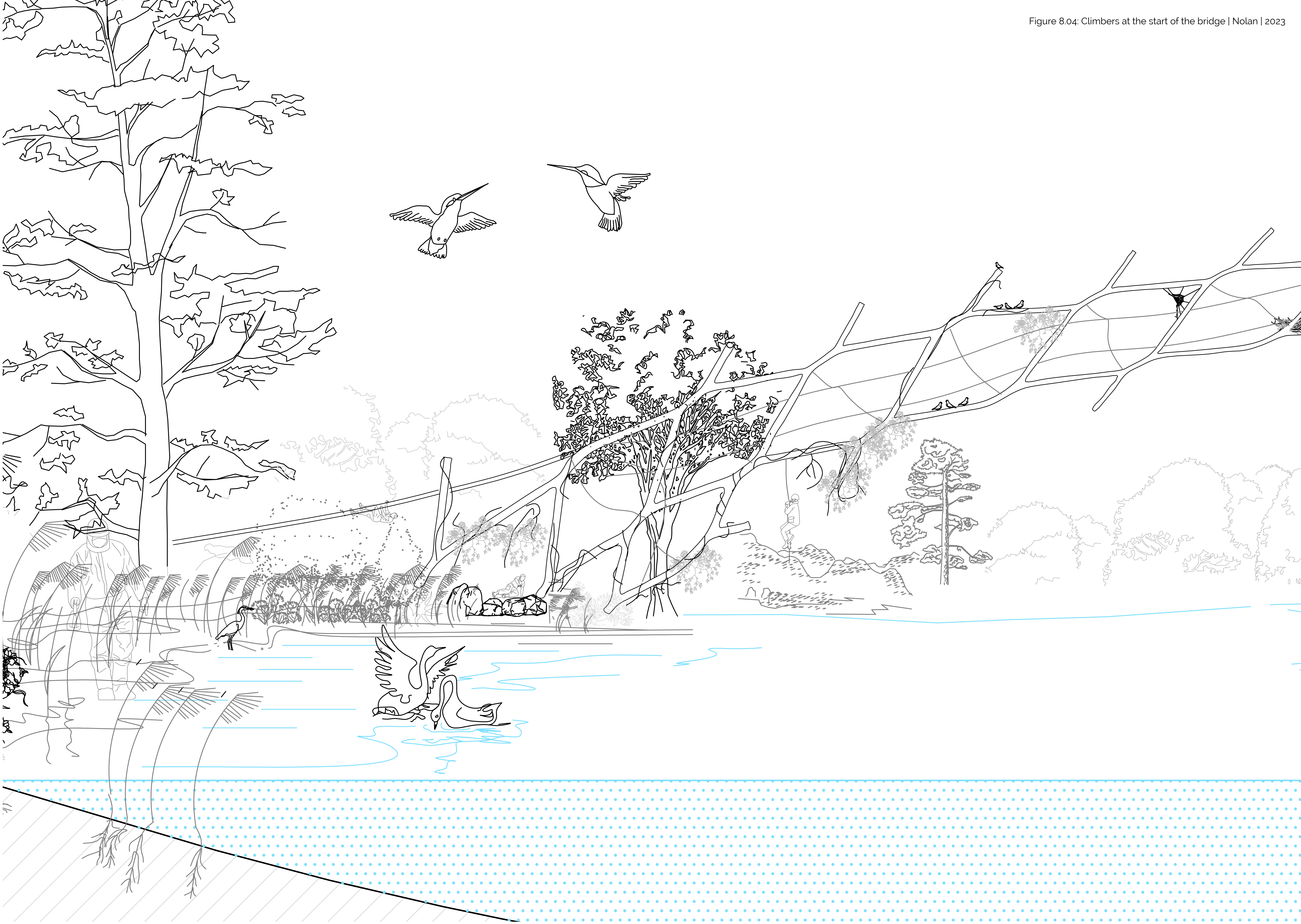


Figure 8.03: Plan of bridge at the lake shore | Nolan | 2023

Figure 8.04: Climbers at the start of the bridge | Nolan | 2023



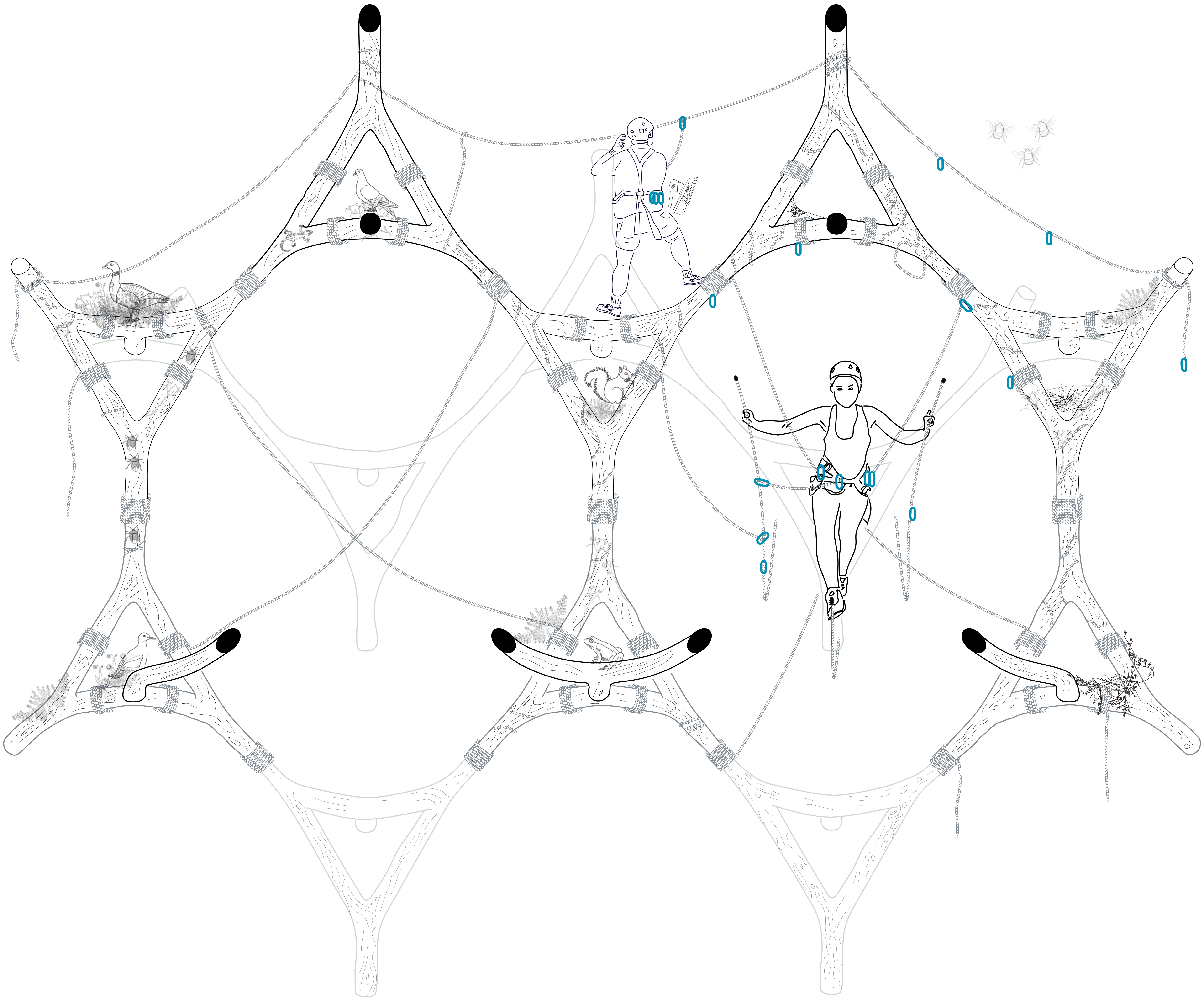
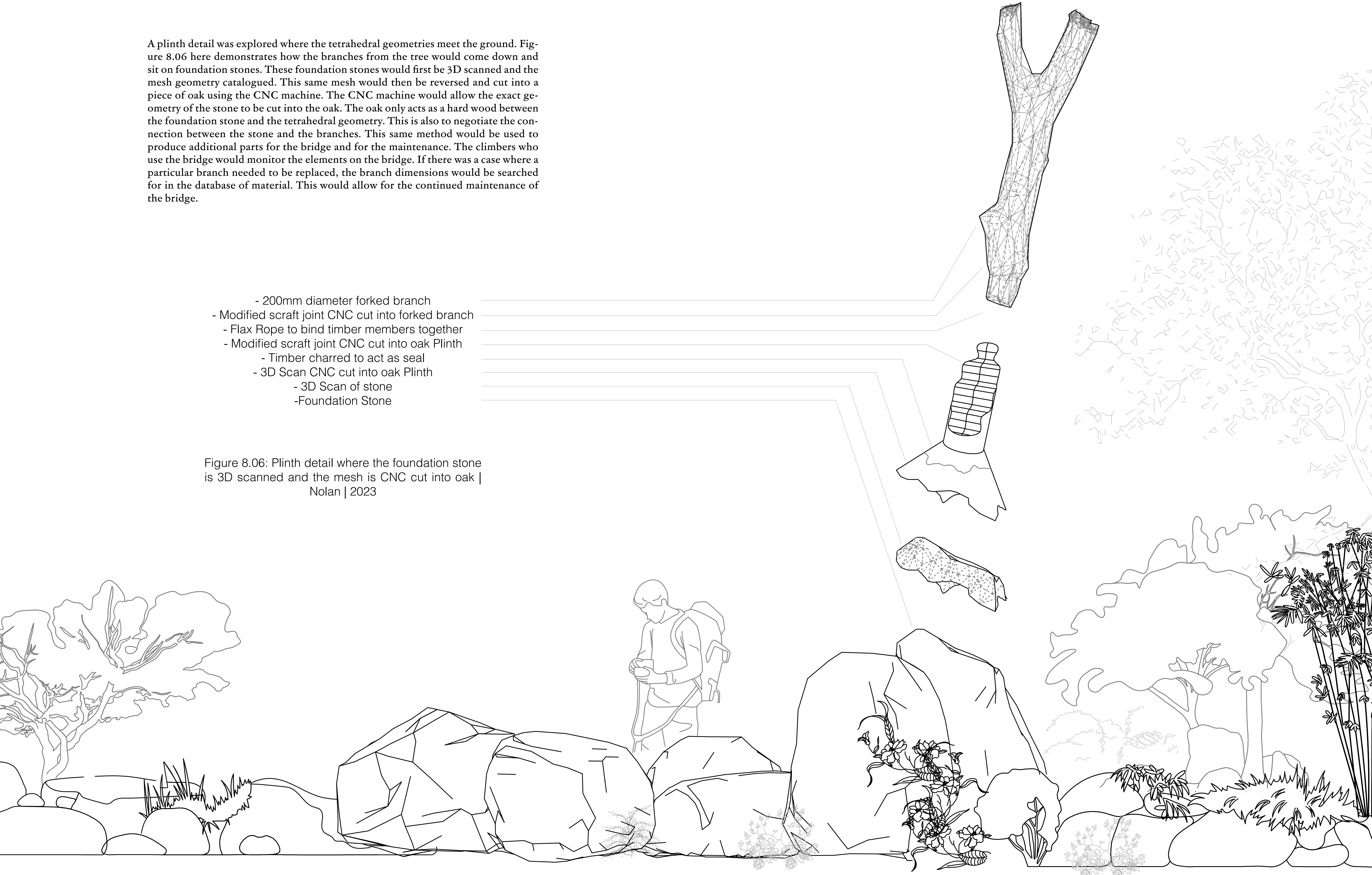


Figure 8.05: Section through the bridge | Nolan | 2023

A plinth detail was explored where the tetrahedral geometries meet the ground. Figure 8.06 here demonstrates how the branches from the tree would come down and sit on foundation stones. These foundation stones would first be 3D scanned and the mesh geometry catalogued. This same mesh would then be reversed and cut into a piece of oak using the CNC machine. The CNC machine would allow the exact geometry of the stone to be cut into the oak. The oak only acts as a hard wood between the foundation stone and the tetrahedral geometry. This is also to negotiate the connection between the stone and the branches. This same method would be used to produce additional parts for the bridge and for the maintenance. The climbers who use the bridge would monitor the elements on the bridge. If there was a case where a particular branch needed to be replaced, the branch dimensions would be searched for in the database of material. This would allow for the continued maintenance of the bridge.



- 200mm diameter forked branch
- Modified scraft joint CNC cut into forked branch
- Flax Rope to bind timber members together
- Modified scraft joint CNC cut into oak Plinth
- Timber charred to act as seal
- 3D Scan CNC cut into oak Plinth
- 3D Scan of stone
-Foundation Stone

Figure 8.06: Plinth detail where the foundation stone is 3D scanned and the mesh is CNC cut into oak | Nolan | 2023

Figure 8.07: Huntstown Bridge | Nolan | 2023

Next Page - Figure 8.08: Photo demonstrating the drawings and diagram presented at final crit | Nolan | 2022


"Nature treats materials as expensive and designs with apparent care and attention to detail. This results in durable materials and cheap structures that are easy to recycle under ambient conditions". Julian Vincent, 'Survival of the Cheapest' (2002)
B01
B02
B03
B04
B05
B06
B07
B08
B01
Profile A
Surface A
B06
Profile B
Surface B
B04
Profile A
Surface A
B03
Profile B
Surface B
Profile A
Profile B

ESSAY CONCLUSION

The synthesis of my research demonstrates how utilising timber elements that are on a site can be rearranged under specified requirements to manifest an architectural structure that is unique to these requirements, and does so in a sustainable way. This was achieved first by analysing what material is available and digitally assembling specified material to create a desired structure. This intelligent use of timber available on site through this methodology critically reduces the energy required to achieve the design of a data centre and bridge. The research indicates that the structural integrity of the bridge is realised when proposing the breakdown of the bridge elements into subassemblies that are further embedded in one another. This design project conveys an architecture that utilises timber's natural form and is evident in the types of spaces these structures generate. This is reassured in the fabrication of the connection joint at a scale of 1:1. This ability to effectively connect one branch to another proves how the branches in the bridge come together indicating the possibility of such a structure. A sustainable structure that is evidently utilising timber from the site in an intelligent way to create a low energy bespoke architecture.

Figure 9.01: Assembly of the 4 branches to create the Tetrahedral Geometry | Nolan | 2023

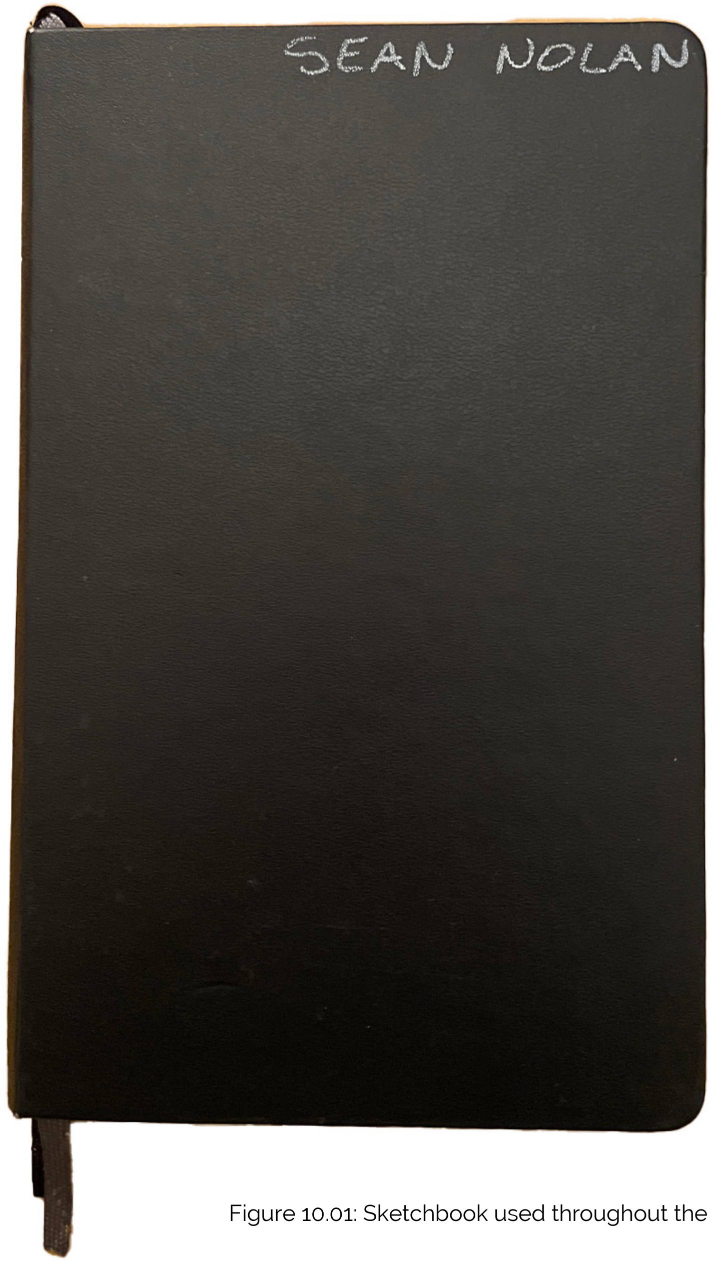


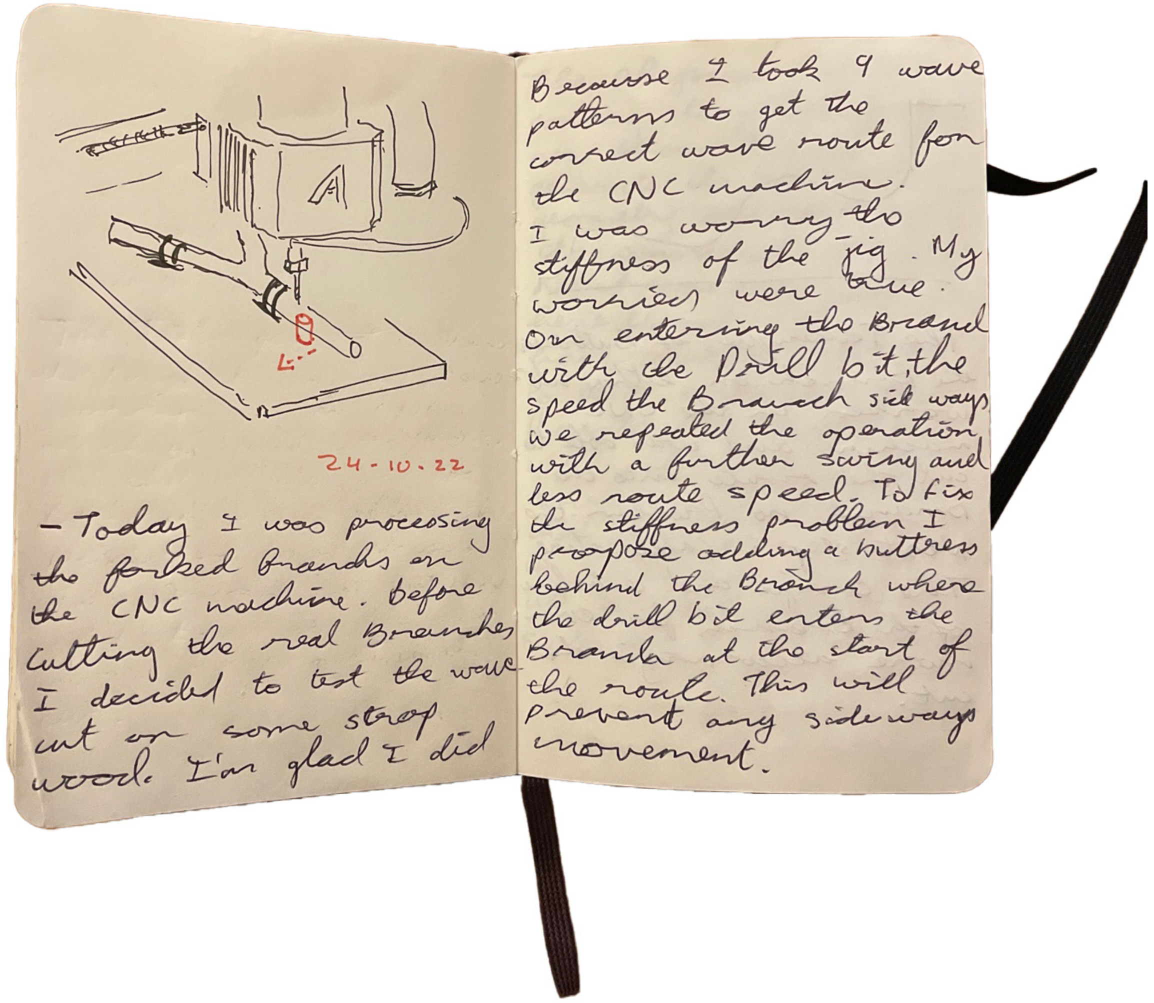
Figure 10.01: Sketchbook used throughout the duration of the masters | Nolan | 2023

APPENDICES

Throughout the research project, a crucial tool in completing every task was my sketch book. This documented all my thoughts through drawing. This led to additional documentation of the work by the means of a website which tracked and updated my work. Reflective thinking and writing also became important. A second notebook was dedicated to critical reflection. This was reassured when taking some critical distance over the Summer between semesters.

The writing continued coinciding with documenting my experience on El Camino De Santiago. I spent some time over the Summer in Spain where I travelled as a pilgrim visiting places of architectural heritage along the way.

Construction of the table has begun with the carcass of the display cabinet almost complete. Through the methodologies explored in this dissertation I intend on constructing a small shelter. This shelter would also be made from branches on the particular site. I have been in contact some Irish music festivals about the possibility of making this happen.



24-10-22

- Today I was processing
the forked Branchs on
the CNC machine. before
cutting the real Branches
I decided to test the wave
cut on some strap
wood. I'm glad I did

Because I took 4 wave
patterns to get the
correct wave route for
the CNC machine.
I was worry the
stiffness of the jig. My
worries were true.
On entering the Brand
with the Drill bit, the
speed the Branch side ways
we repeated the operation
with a further swing and
less route speed. To fix
the stiffness problem I
propose adding a buttress
behind the Branch where
the drill bit enters the
Branch at the start of
the route. This will
prevent any sideways
movement.

Figure 10.02: Reflective writing entry | Nolan | 2023

Figure 10.03: Assembling of the top carcass for the display Cabinet | Nolan | 2023

BIBLIOGRAPHY

Achim Menges, Tobias Schwinn & Oliver David Krieg. (2017). Advancing Wood Architecture. Oxon: Routledge.

Andrea Rossi & Oliver Tessmann. (2019). From Voxels to Parts: Hierarchical Discrete Modeling for Design and Assembly. DDU Digital Design Unit – TU Darmstadt, Darmstadt,, (pp 3).

Desai, I. (2020). Designing structures with tree forks: Mechanical characterization and generalized computational design approach. Massachusetts: Massachusetts Institute of Technology . (pp. 30)

Donald, O. M. (2001). A Small-Angle X-ray Scattering Study of the Effect of Hydration on the Microstructure of Flax Fibers. In Biomacromolecules (Vol. 2, pp. 672-680). ACS Publications.

Fast Radius. (2021, September 21st). 3-axis vs. 5-axis CNC machining — what you need to know. Retrieved from Fast Radius: https://www.fastradius.com/resources/3-axis-vs-5-axis-cnc-machining/#:~:text=5%2Daxis%20machines%20rely%20on,reposition%20the%20workpiece%20between%20operations.

K. Haag, J. M. (2015). The use of flax fibres as reinforcements in composites. (M. S. Omar Faruk, Ed.) Woodhead Publishing (pp 35-85).

Lukas Allner, Christoph Kaltenbrunner, Daniela Kröhnert, Philipp Reinsberg. (2022). Conceptual Joining. Vienna: Birkhasuer (pp 199).

Merriam Webster. (2022). Crotch. Retrieved from Merriam Webster Dictionary: https://www.merriam-webster.com/dictionary/crotch#:~:text=%3A%20an%20angle%20formed%20by%20the,two%20legs%2C%20branches%2C%20or%20members

Merriam-Webster. (2022, November 13th). Merriam-Webster.com dictionary. Retrieved from Veirendeel Truss: https://www.merriam-webster.com/dictionary/Vierendeel%20truss

Nolan, S. (2022, January 13th). Utilising timber's natural complexity and form. Dublin, Technical University Dublin, Ireland.

Oxford Learners Dictionaries. (2022, November 10). Dictionaries. Retrieved from Oxford Learners Dictionaries: https://www.oxfordlearnersdictionaries.com/definition/english/intelligence

Piker, M. (2017, 10 05). kangaroo physics. Retrieved from Food4Rhino: https://www.food4rhino.com/en/app/kangaroo-physics

Rosen, L. (2021, July 27). Material Science. Retrieved from 21st Century Tech Blog: https://www.21stcentech.com/concrete-consumed-material-planet-earth-enormous-contributor-global-warming/
Rossi, A. (2021, September 27th). Wasp. Retrieved from Grasshopper3d: https://www.grasshopper3d.com/group/wasp?overrideMobileRedirect=1

Self, M. (2017). Hooke Park. Advancing Wood Architecture. Oxon: Routledge. (pp 141 - 153)

Vincent, J. (2002). Survival of the cheapest. Materials Today., (pp 28).

Wang, Y. (2017). Hooke Park Biomass Boiler House. Advancing Wood Architecture. Oxon: Routledge. (pp 169 - 181)

IMAGE LIST

Figure 1.01: Huntstown Bridge | Author's own | 2023.

Figure 2.01: Plant altering its form to get sunlight | Author's own | 2021.

Figure 2.02: Natural-form timber elements for Ship Building | Marine | 1798. Image from 'Advancing Wood Architecture' by Achim Menges, Tobias Schwinn & Oliver David Krieg. (2017). Oxon: Routledge. pp 150

Figure 2.03: Huntstown Quarry batch mixing | Author's own | 2022.

Figure 3.01: Hooke Park Woodchip barn | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2017. Image found at: Mairs, J. (2016, February 23rd). AA Design & Make students use a robotic arm to build a woodland barn. Retrieved from Dezeen: https://www.dezeen.com/2016/02/23/architectural-association-students-london-robotically-fabricated-barn-dorset-woodland/.

Figure 3.02: Exploded axonometric diagram | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016. Image found at: Mairs, J. (2016, February 23rd). AA Design & Make students use a robotic arm to build a woodland barn. Retrieved from Dezeen: https://www.dezeen.com/2016/02/23/architectural-association-students-london-robotically-fabricated-barn-dorset-woodland/.

Figure 3.03: Joint Fabrication | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016.

Figure 3.04: Forked Branch | Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang | 2016. Image found at: Design and Make. (2016). Wood Chip Barn. Retrieved from Design and Make by the AA School: https://designandmake.aaschool.ac.uk/project/wood-chip-barn/.

Figure 3.05: Forked Branchs coming together from the Database | Mollica | 2017. Image from 'Advancing Wood Architecture' by Achim Menges, Tobias Schwinn & Oliver David Krieg. (2017). Oxon: Routledge. (pp 151)

Figure 3.06: Biomass Boiler House | Sattaveesa Sahu & Yingzi Wang | 2015. Retrieved from Hooke Park AA School: http://hookepark.aaschool.ac.uk/biomass-boiler-house/.

Figure 3.07: Best-Fit Strategy: Digital Process | Sattaveesa Sahu & Yingzi Wang | 2015. Retrieved from Hooke Park AA School: http://hookepark.aaschool.ac.uk/biomass-boiler-house/.

Figure 3.08: 3D Scanning Strategy | Sattaveesa Sahu & Yingzi Wang | 2015. Retrieved from Hooke Park AA School: http://hookepark.aaschool.ac.uk/biomass-boiler-house/.

Figure 3.09: Groups being assigned to section line | Sattaveesa Sahu & Yingzi Wang | 2015. Retrieved from Hooke Park AA School: http://hookepark.aaschool.ac.uk/biomass-boiler-house/.

Figure 3.10: Combined Strategy: Digital Log Wall | Sattaveesa Sahu & Yingzi Wang | 2015. Retrieved from Hooke Park AA School: http://hookepark.aaschool.ac.uk/biomass-boiler-house/.

Figure 3.11: Full scale prototype - assembly | Lukas Allner | 2021. Allner, L. (2021, April 21). FULL-SCALE PROTOTYPE – ASSEMBLY. Retrieved from Conceptual Joing: https://conceptual-joining.com/?p=1399#more-1399.

Figure 3.12: Nut and Bolted Connection | UAA Vienna | 2021. Image from Lukas Allner, Christoph Kaltenbrunner, Daniela Kröhnert, Philipp Reinsberg. (2022). Conceptual Joining. Vienna: Birkhasuer. (pp 199)

Figure 4.01: Huntstown Quarry Batch Mixing | Author's own | 2022.

Figure 4.02: Huntstown Quarry Aggregate Factory | Author's own | 2022.

Figure 4.03: Huntstown Aggregate Factory | Author's own | 2022.

Figure 4.04: Huntstown Area | Author's own | 2022.

THANK YOU