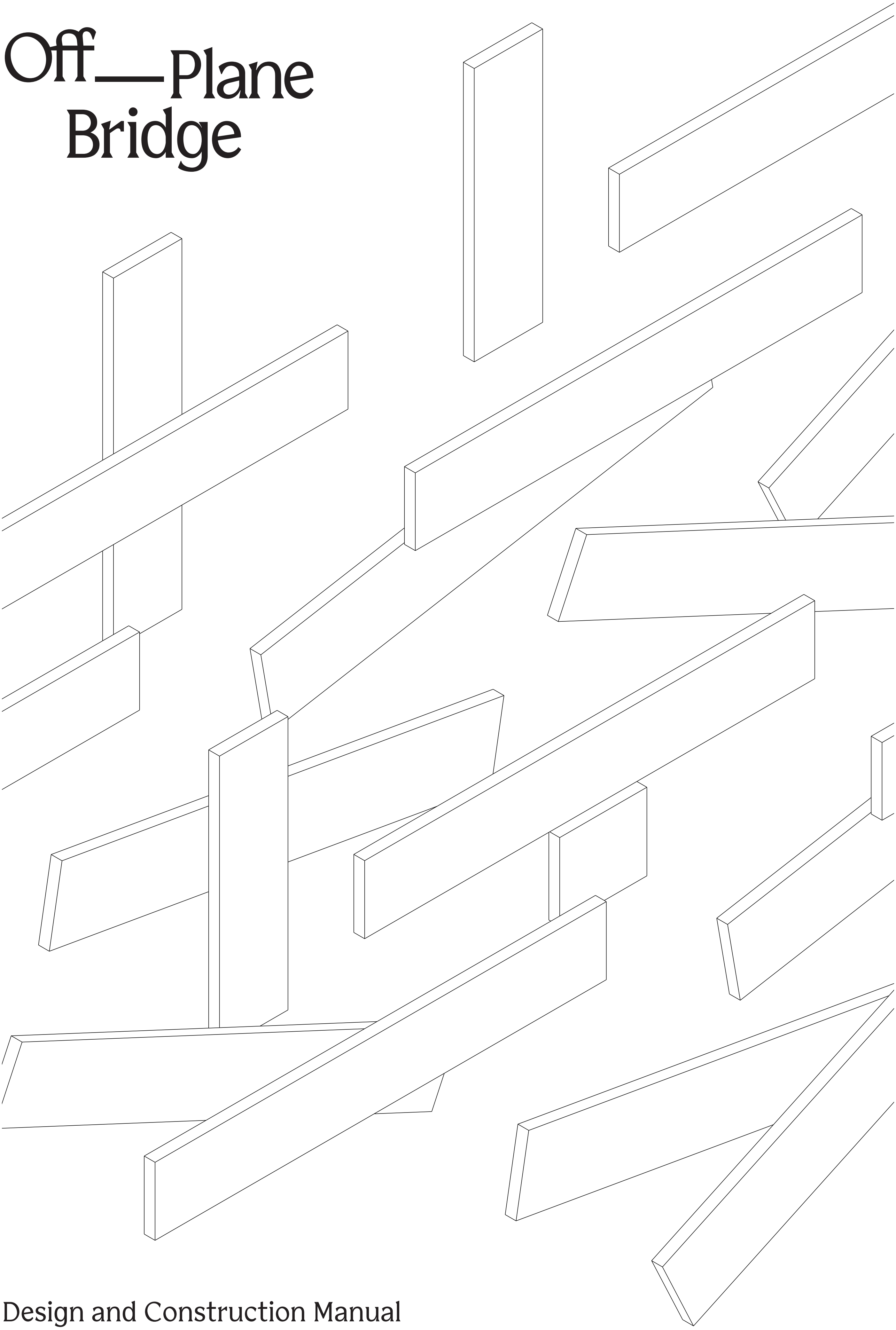
Off—Plane Bridge



Design and Construction Manual

Off-Plane Bridge
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Produced for Minor Archineering at
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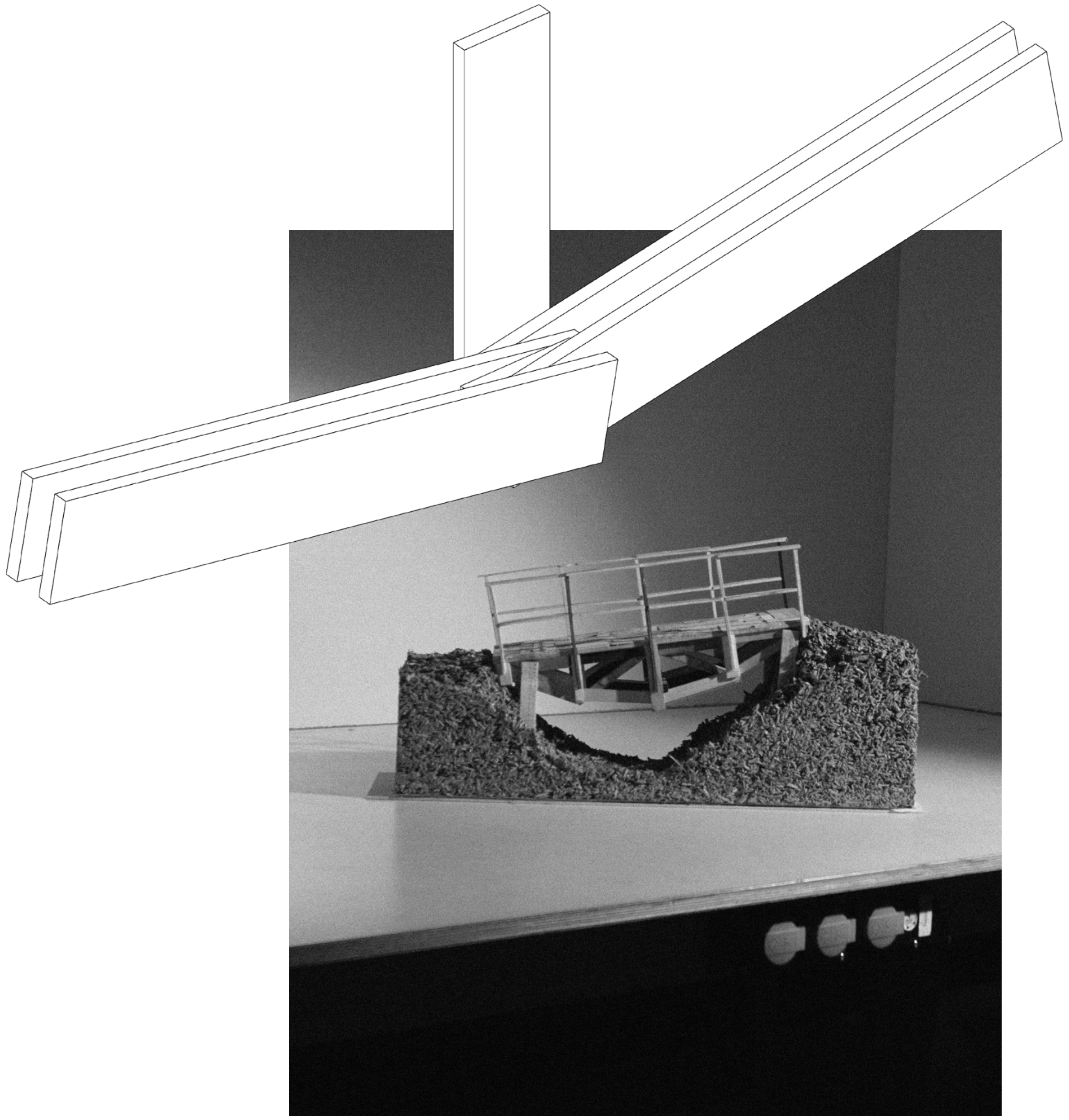


Photograph of 1:10 model with off-plane joint superimposed

Design Statement

The Off-Plane Bridge aims to offer a method of construction for a set of waste timber with varying dimensions and properties. It takes its core design principles to the smallest level of detail, and visually represents the holacratic working manner in which it was created. The bridge utilises off-plane joints; where elements are connected adjacent to each other, remaining in different planes. This minimises the amount of joinery needed, which could create unreliable connections when dealing with an unknown palette of timber.

Instead, the fasteners between the wood become the determining factor for the strength of the joint. In an effort to simplify the construction process, and experiment with new innovations in timber, this design proposes to use Lignoloc densified wooden nails to create dowel-type connections between the timber boards. This product has not been tested in this way before, and as such the Off-Plane Bridge has the potential to become a world first. This design and construction manual aims to demonstrate the depth of research and testing already carried out to prove the viability of this proposal, and the design changes that have been made to improve the strength and efficiency of the structure.

Early inspiration came from the work of Fabio Gramazio and Matthias Kohler at ETH Zurich, who’s sequential roof for the new ITA building explored the possibilities of collated nails in an off-plane structure. Their incredibly dense wooden truss system drastically reduced the shear in each joint, allowing for only a few nails per layer. This was something we also discovered during our design process, and have consequently increased the number of layers per truss.

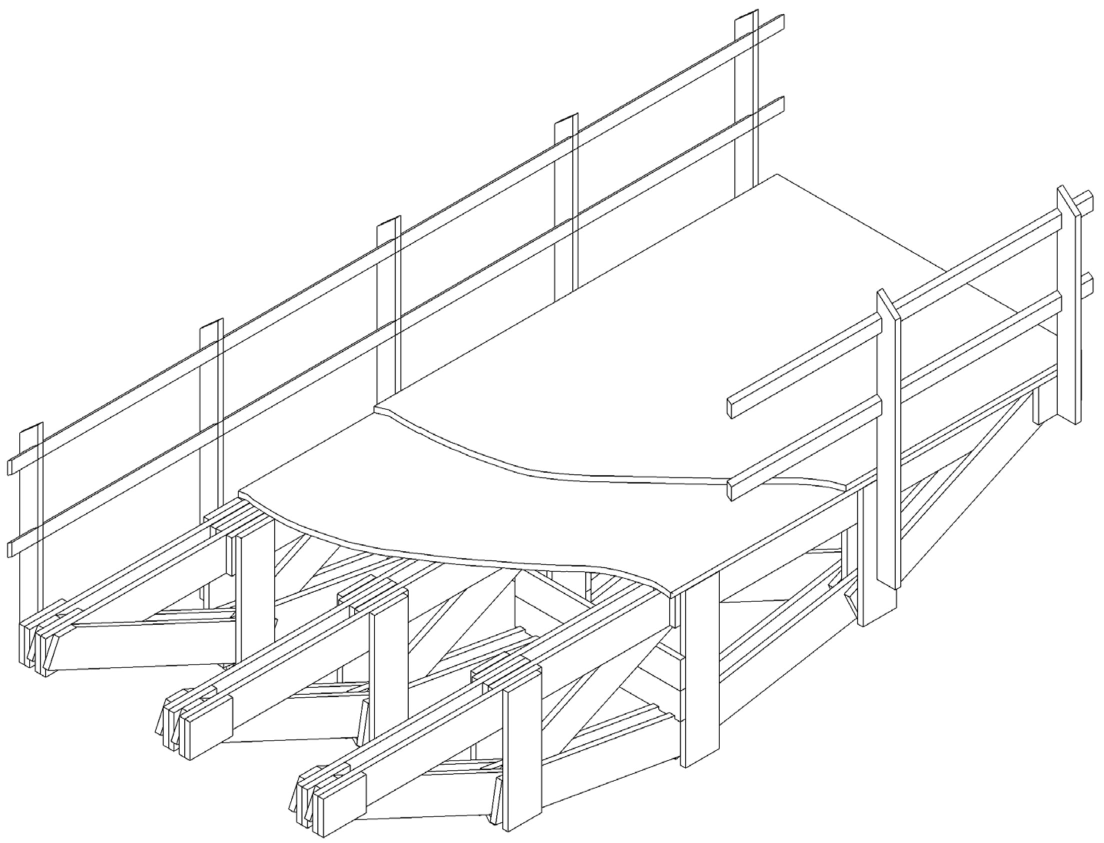
Indeed, we have followed an iterative design process, informed by 1:1 maquettes, testing, and input from a variety of experts. We spoke to Beck Fasteners, the producers of Lignoloc, to further understand the possibilities and restrictions associated with the product. Combined with our own structural analysis, this information has helped us to design a connection we believe can support 30 people, and is compliant with the Eurocode regulations.

The off-plane principle has informed our design at every stage and level of detail. At the smallest level, the individual nails are arranged in an off-plane grid to ensure they do not create straight lines along the grain. This example typifies the design attitude present in the Off-Plane Bridge, where complexity and intricacy coming from the structural design helps to create a unique visual aesthetic.

One key feature of both visual and structural design is the discretisation of different elements of the bridge. We have distinguished the truss, walkway, handrails, and foundations as the four components which form the bridge. These have been developed by autonomous groups in a holacratic manner, and the final coalition of elements reflected the horizontal organisation structure that has defined our creative process.

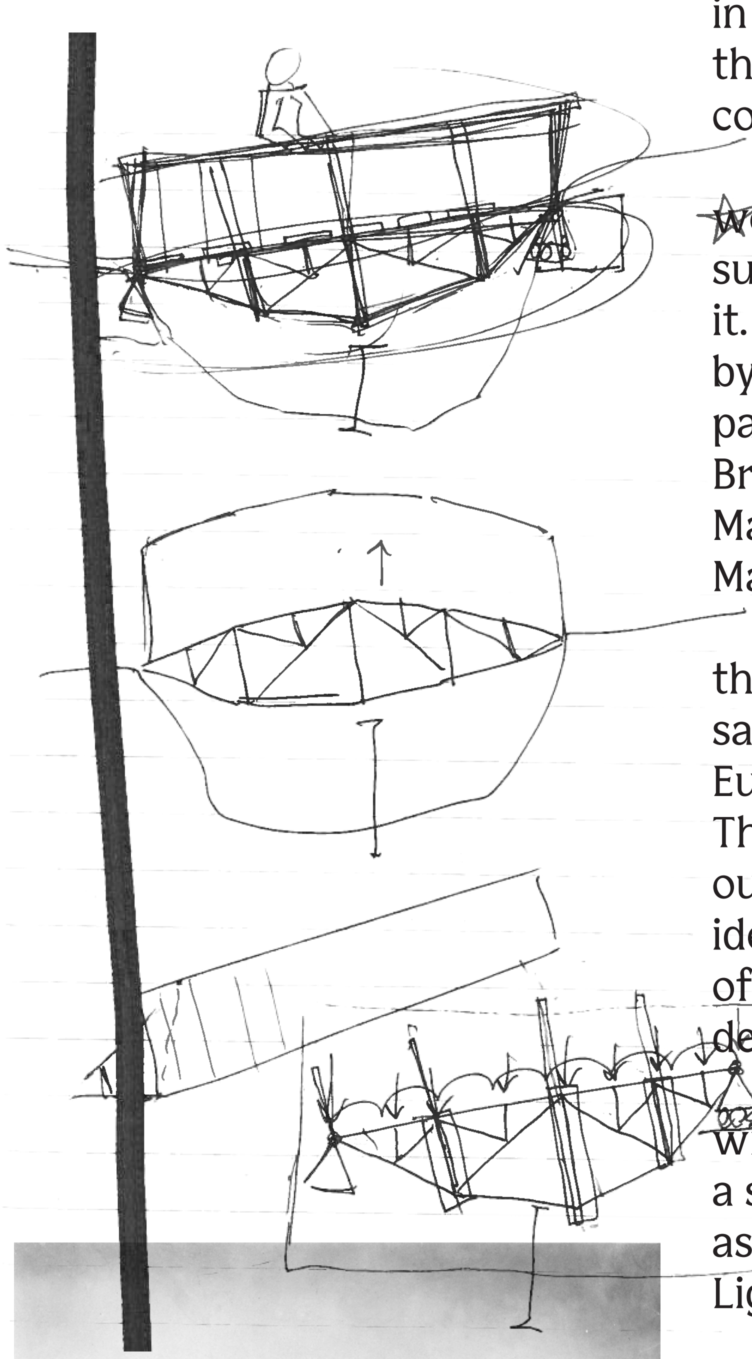
By dividing the bridge and working group into smaller components, we have reduced alienation in the design phase. In a more traditional structure, some individuals may be given specific tasks which appear divorced from design discourse. By compartmentalising this process, we have ensured that every member of our group is able to fully contribute to their component, as well as exploring how they come together to form the bridge. Any knowledge learned by one group has been openly shared and discussed with everyone to aid the design of every component.

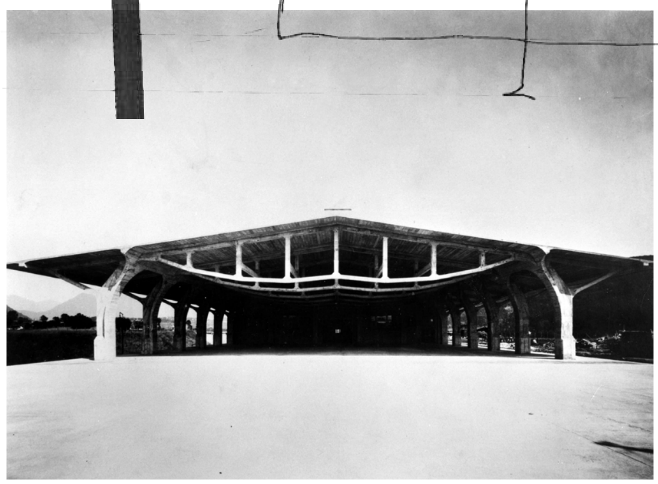
The resultant bridge is a representation of the structural principles that underpin it, as well as the mindset of collective work that has created it. We hope it acts as a valuable contribution to research around design with waste timber, timber fasteners as part of an all-timber structure, and the possibilities of a more cooperative way of working.



Cutaway axonometric diagram

Truss





The truss design is the clearest illustration of the off-plane principle. Initially, we conceived it in wireframe, with the intention that then any piece of waste timber could be assigned to the design.

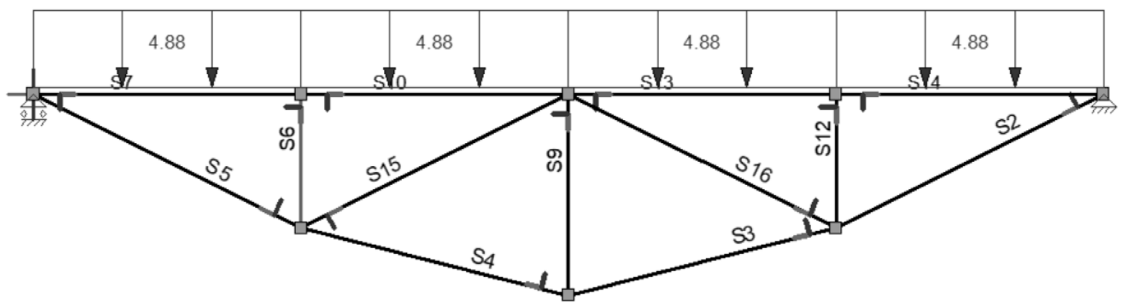
Exploring a range of options, we settled on a curved design that supports the walking surface above it. The form is loosely inspired by the bridges of Jurg Conzett – particularly the first Traversina Bridge – and the Lagerhaus der Magazzini Generali by Robert Maillart (shown below left).

We calculated the forces in the wireframe, with a significant safety factor (in line with Eurocode) included in the load. This understanding then guided our design of the joints, which we identified to be the most likely point of failure as a result of the off-plane design.

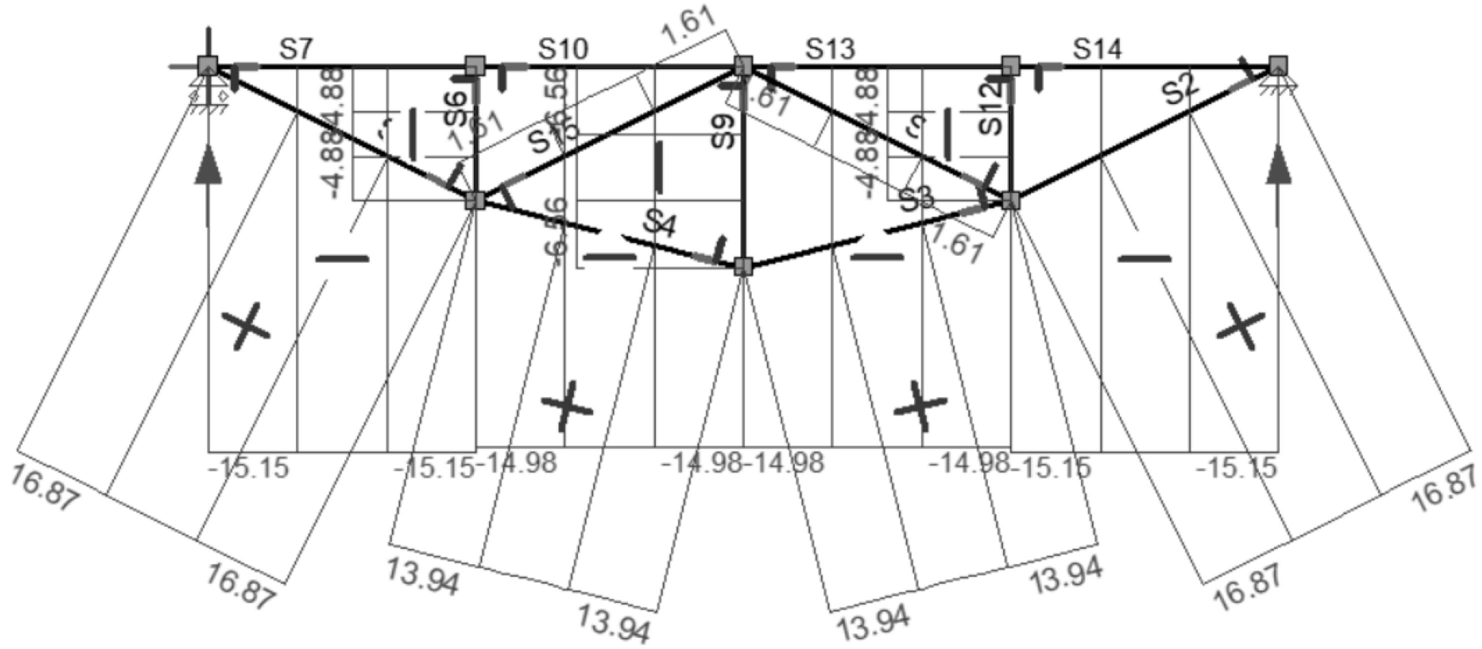
We also focussed on the joint with the highest load and, with a safety factor applied, used this as the basis for our design for the Lignoloc joints.

We also tested a number of different iterations of the truss as models – often 1:1 in the case of joints – to help us get a better idea of how it would perform in reality. Based on the results from the models we have able to refine the design to be as lean as possible while reflecting the core concepts of the bridge and enabling our world-first connections.

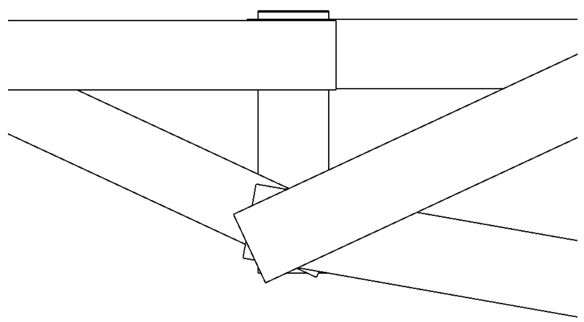
Loads



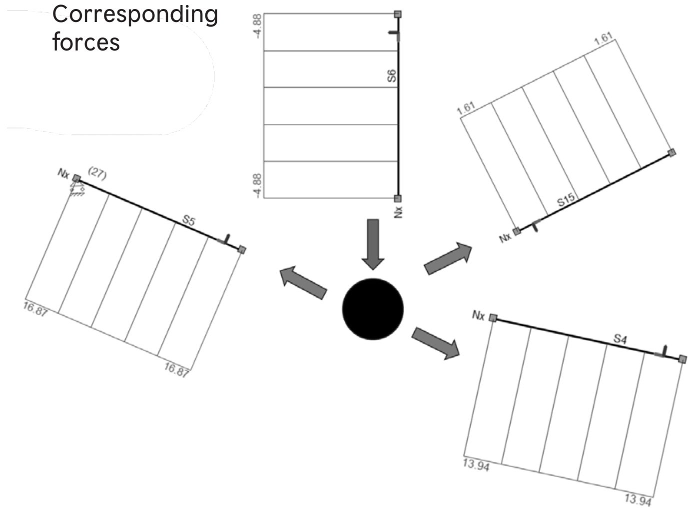
Forces



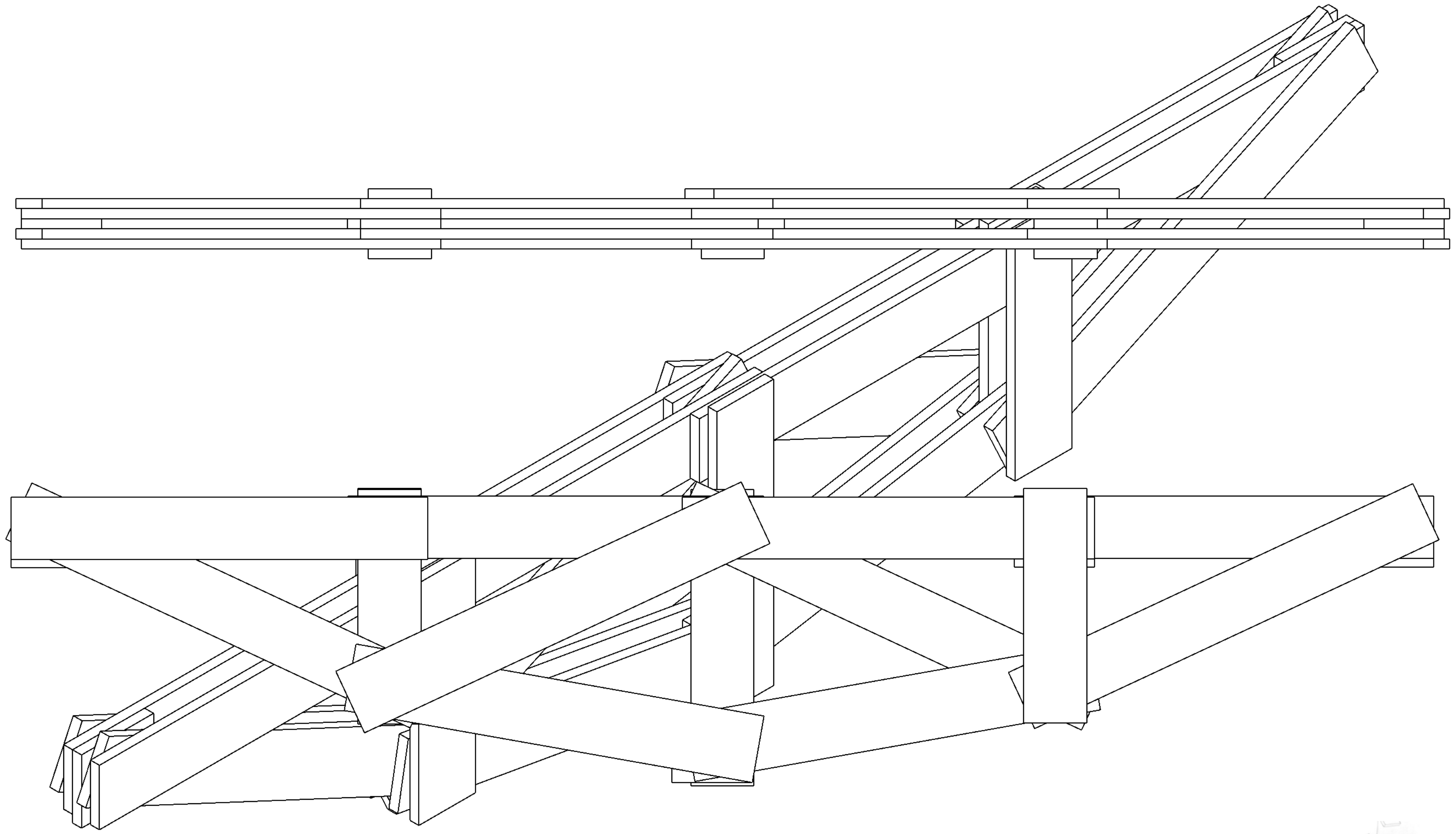
Highest-load joint

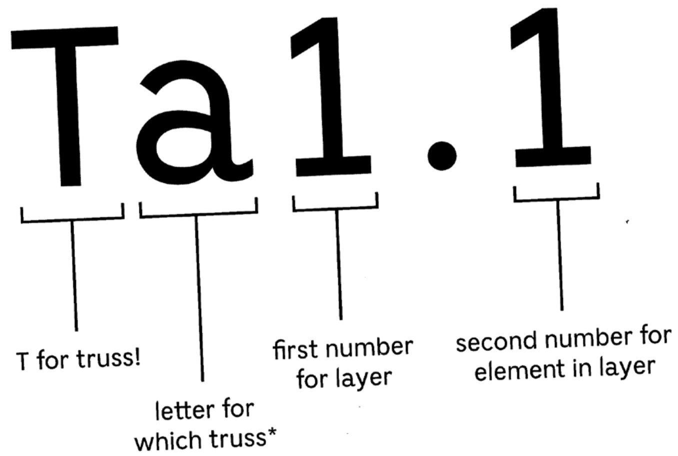


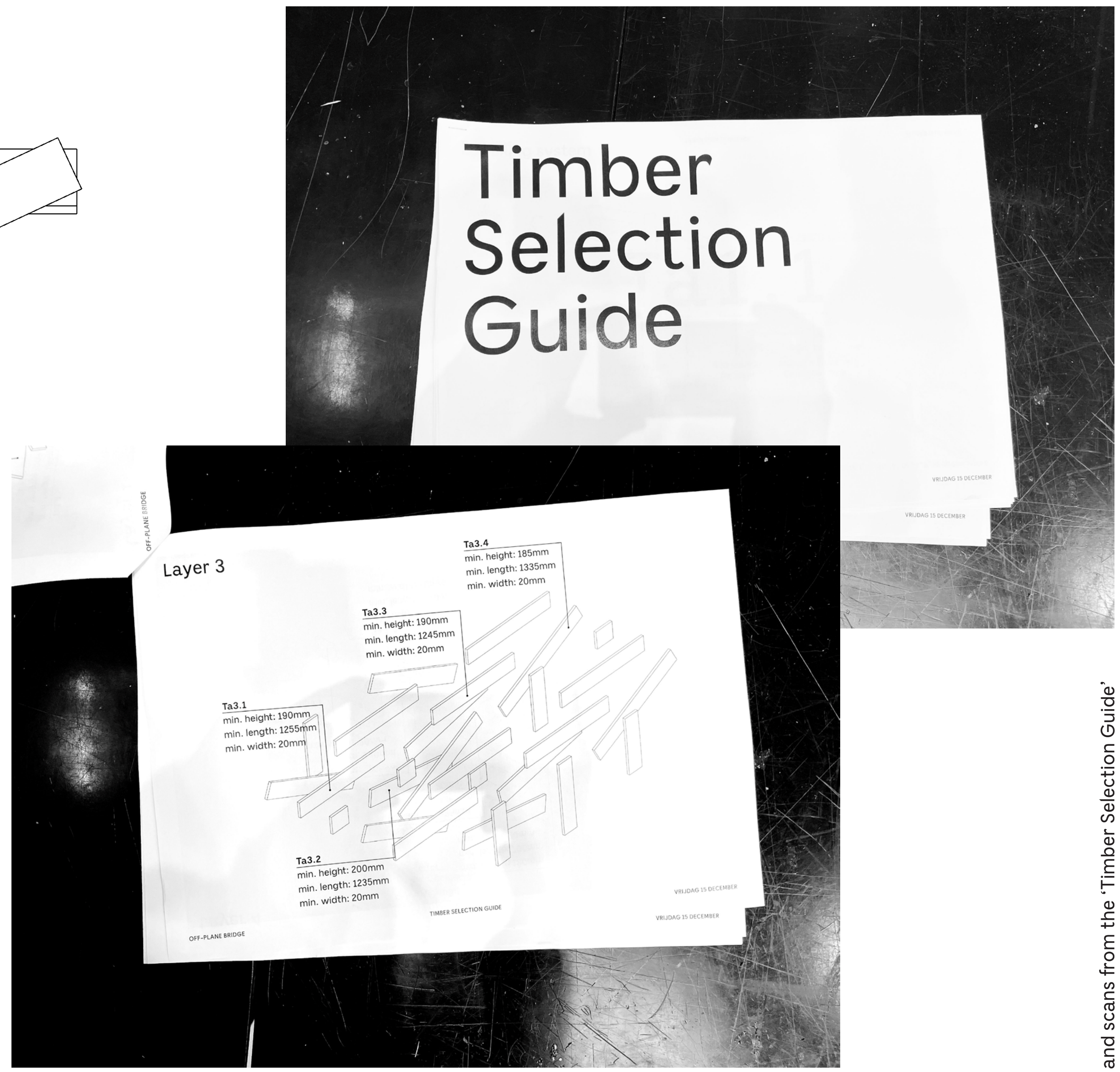
Corresponding forces



Opposite: early sketches for the truss design



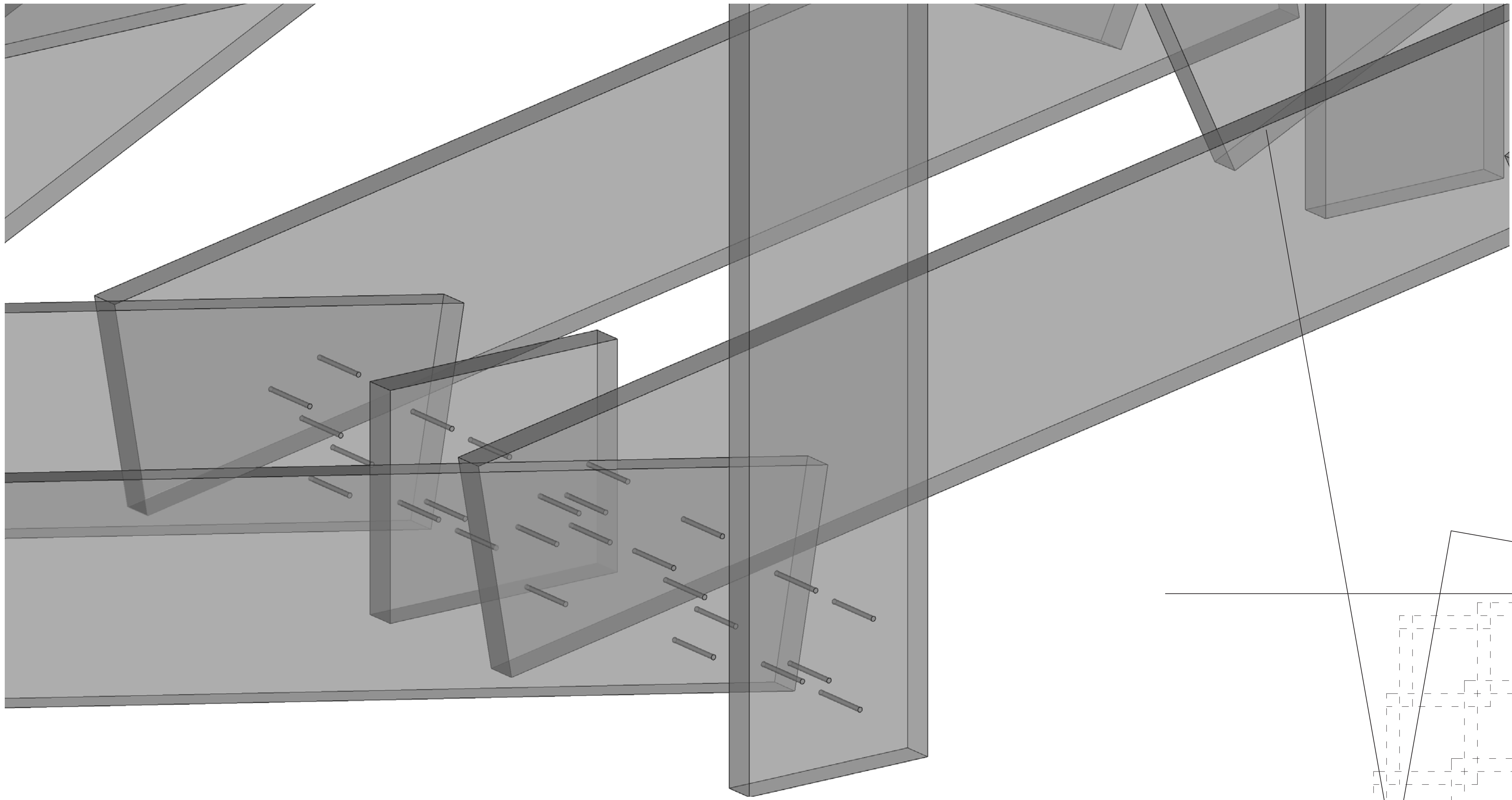


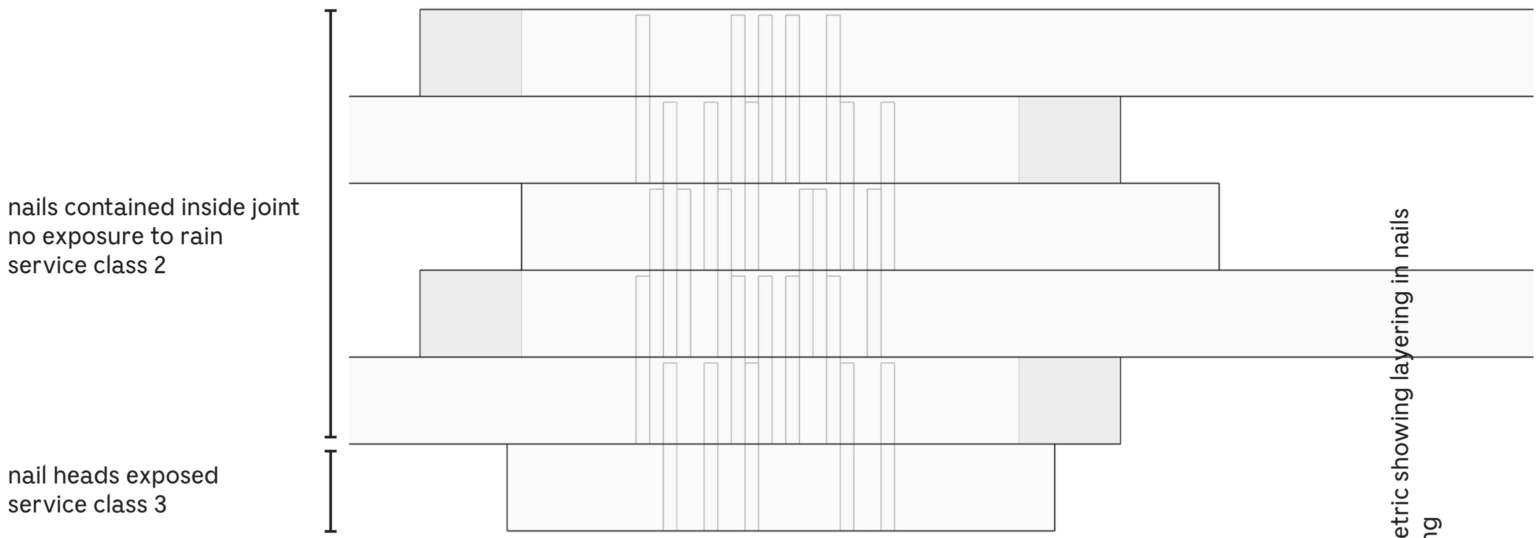


The layering within the truss its is most significant visual and structural characteristic. By increasing the number of members, the shear forces in each joint are divided, reducing the stress on each individual nail within the connection. This ensures that, while the nails individually may not be strong enough, together they can support a significant load. Labelling each member and layer was therefore crucial for design and construction.

Plan, elevation and axonometric of one truss, 1:20 @ A3

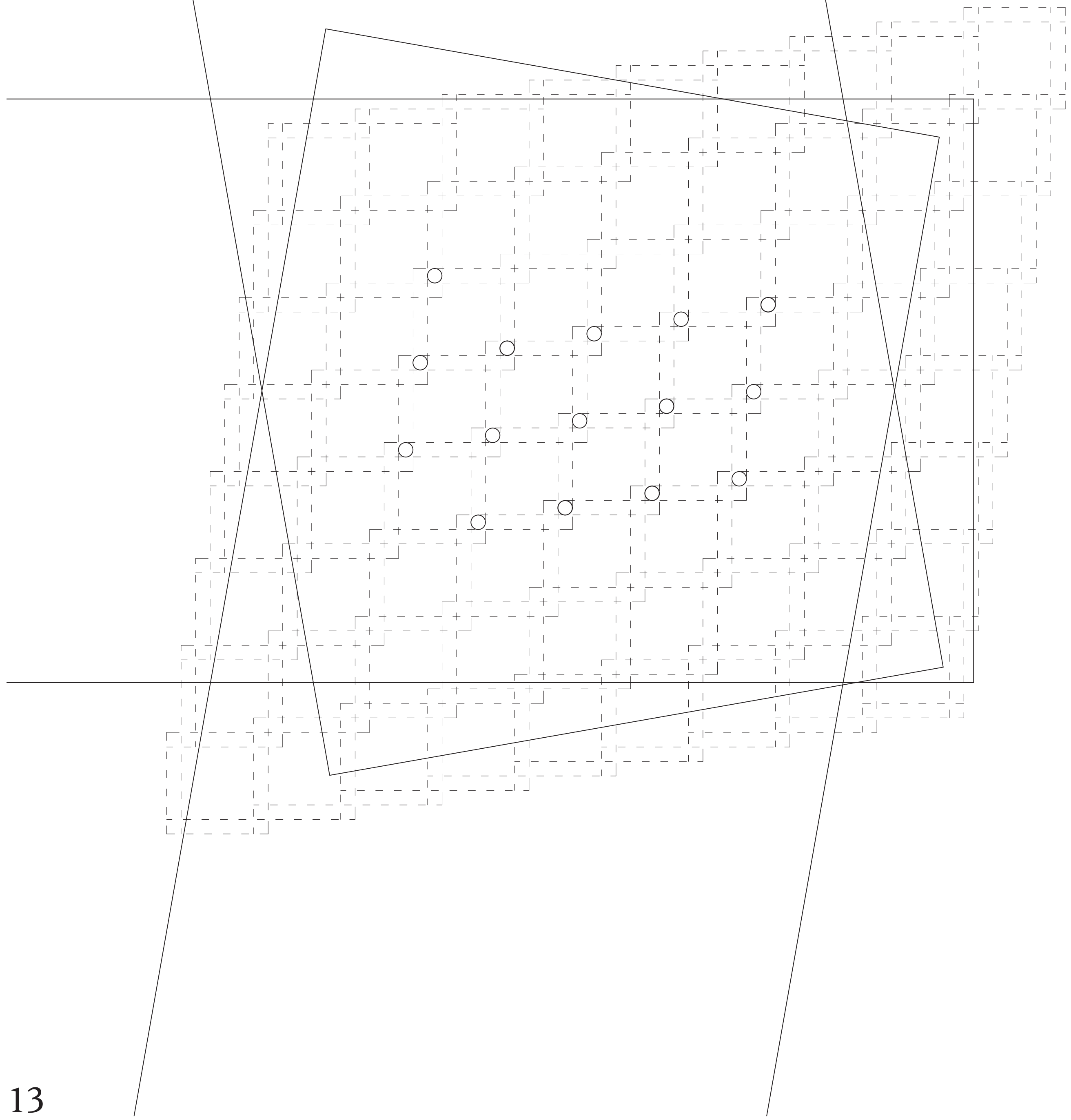
Images and scans from the 'Timber Selection Guide'



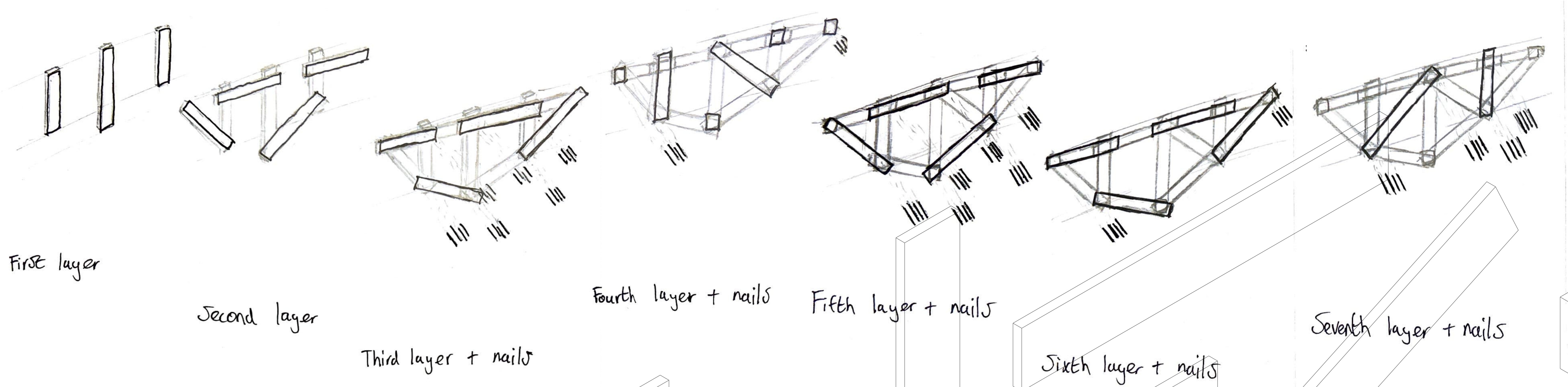


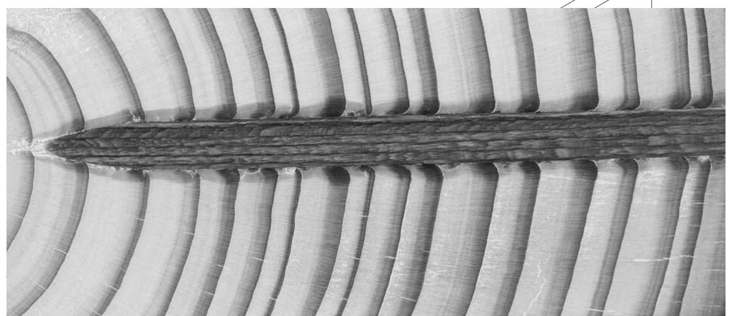
Top: Exploded axonometric showing layering in nails
Left: Plan of nail layering

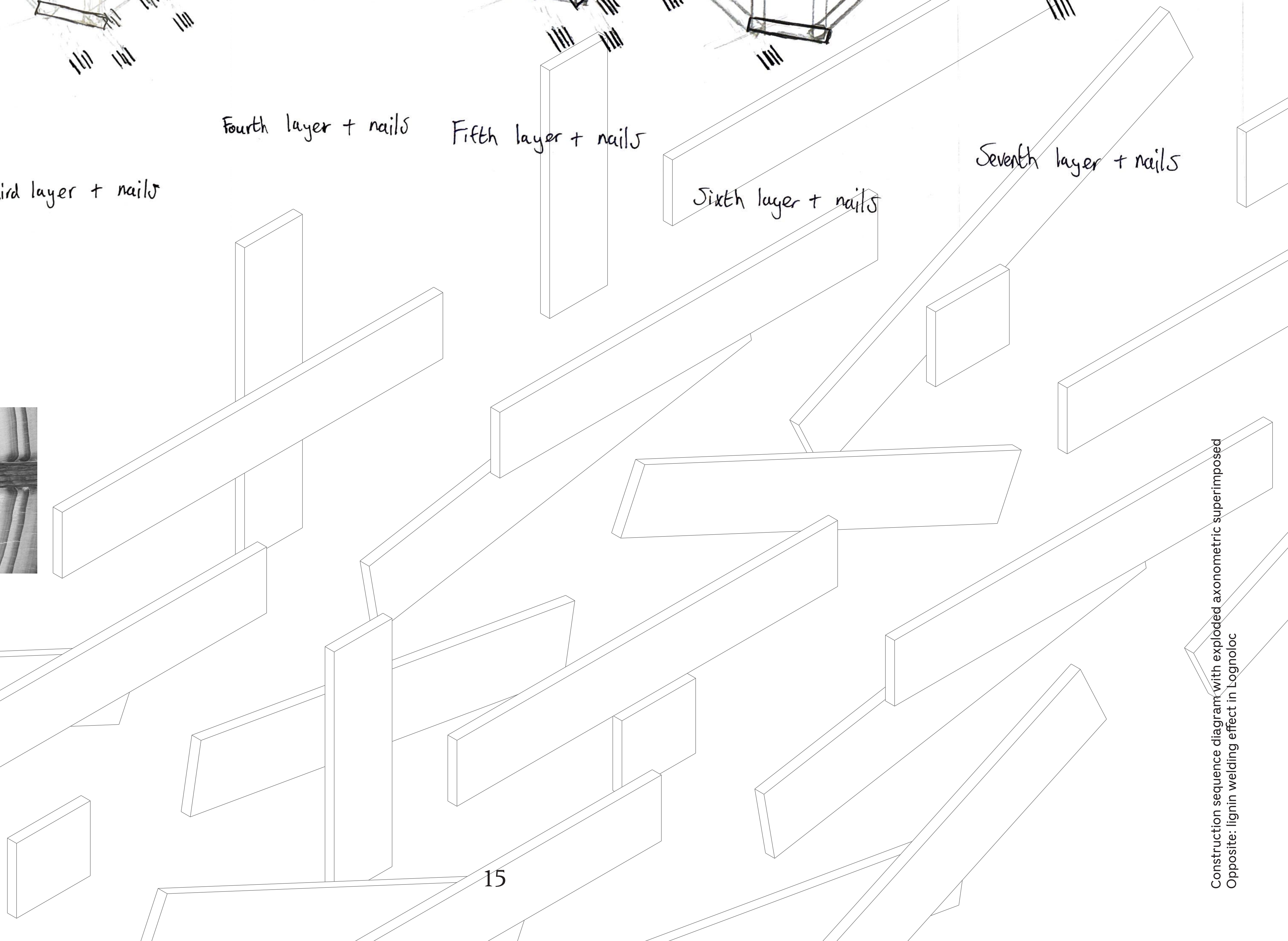
The distribution of the nails is informed by Eurocode regulations. We established a minimum edge distance and a minimum distance between each nail, and - knowing the required number of nails in each joint - could calculate the minimum size for each element. The nails are spread across the 6-7 layers of the truss in a configuration that maximises the distance between them.



Detail showing nail placement with off-plane grid superimposed, 1:2 @ A3



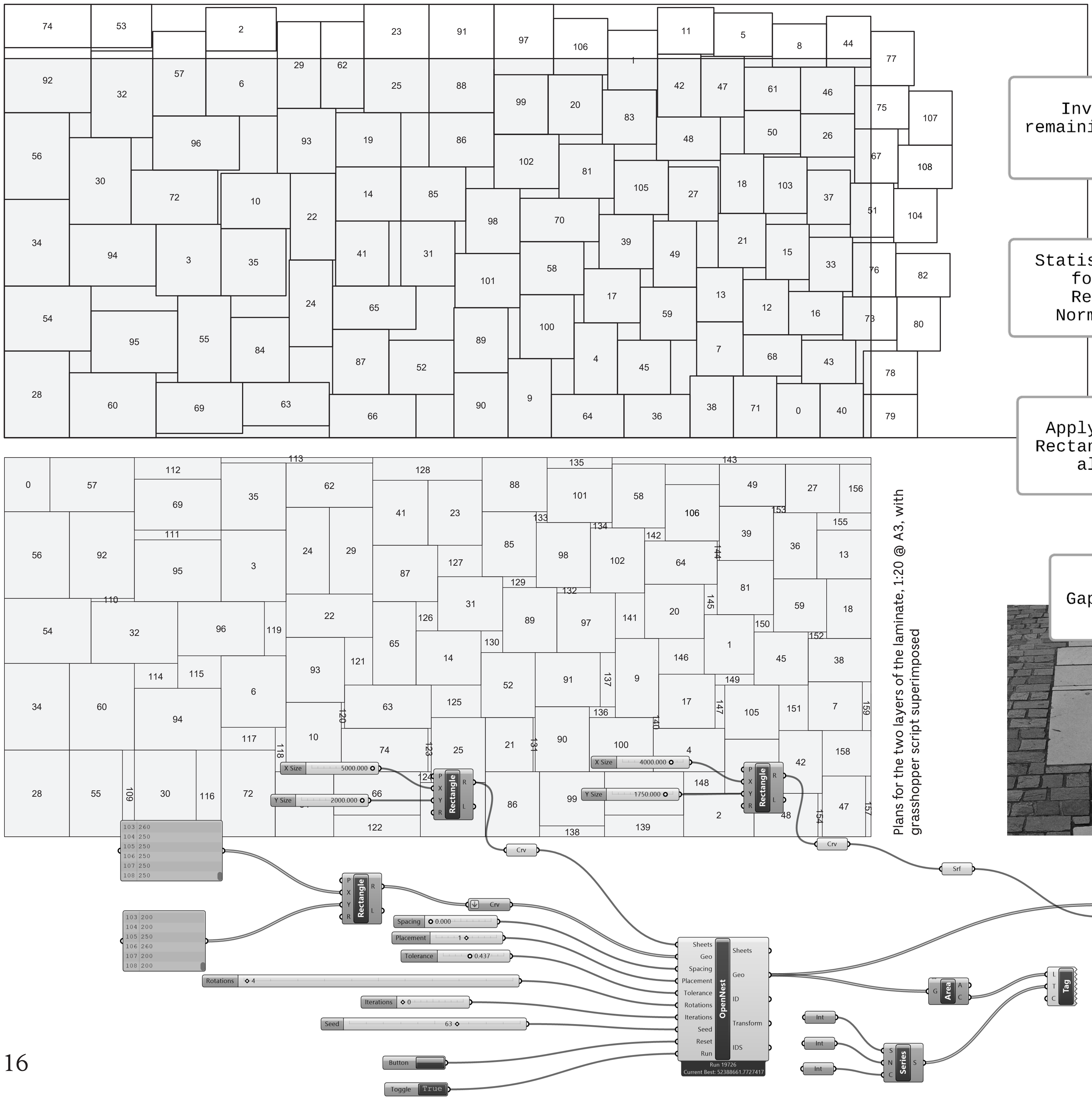




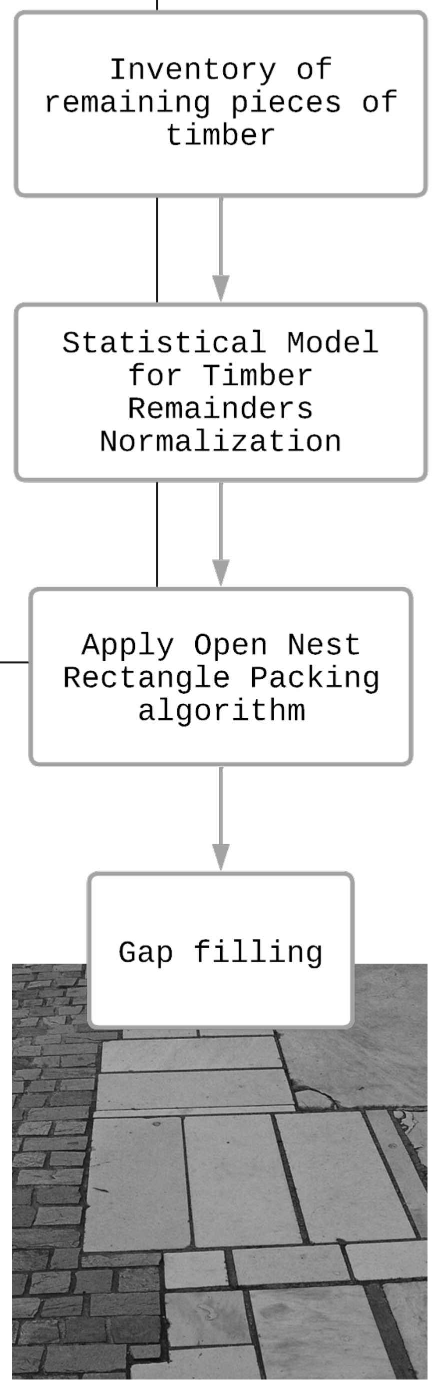
The construction sequence was one of the first things we considered, and indeed it was this that triggered the interest in an off-plane system. Timber elements can be laid flat with each layer added and nailed on top. The labelling system, combined with the rapid assembly possible with the collated timber nails, makes construction quick, clean and efficient.

Construction sequence diagram with exploded axonometric superimposed
Opposite: lignin welding effect in Lognoloc

Walkway



Plans for the two layers of the laminate, 1:20 @ A3, with grasshopper script superimposed

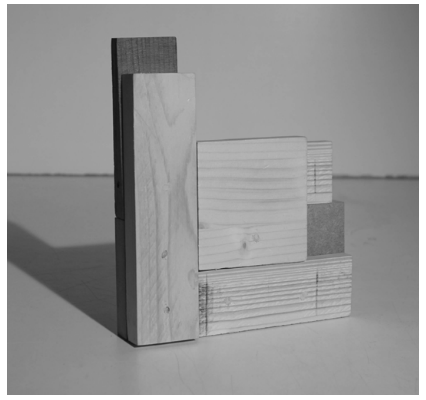


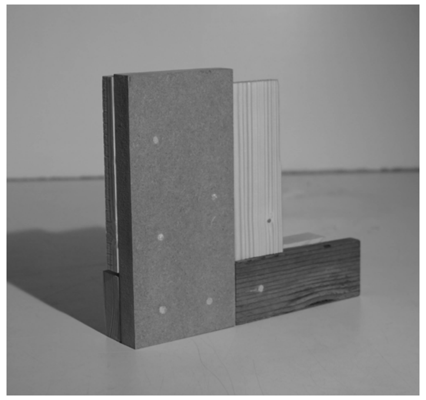
Acting both as a walking surface and bracing for the bridge, the walkway is also a novel system, with a digitally automated design process. Based on cross laminated timber, it uses Lignoloc densified timber nails to create a rigid, two-layered surface. The computational process for the layout of the timber front-loads the labour required in the design process. Now we have established a model, any waste timber can be used.

After creating an inventory of the timber pieces, they must be normalized before applying the rectangle packing algorithm to achieve optimal results. A statistical model using the median and standard deviation, along with predefined limits for the dimensions of the pieces, is applied to effectively identify and adjust outliers. This process ensures the dimensions are within a practical and usable range, facilitating the algorithm's efficiency and material utilization.

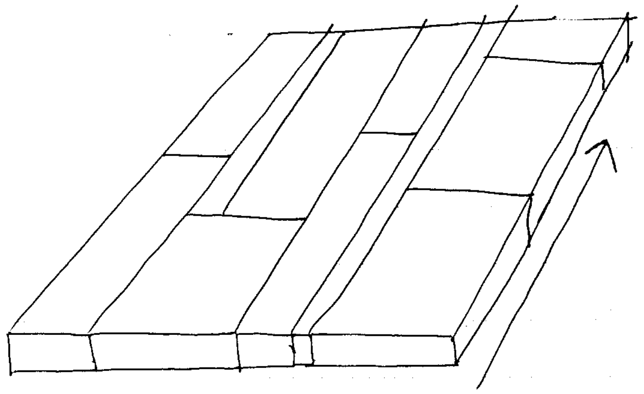
Next, the Open Nest plugin for Grasshopper is used to arrange the pieces of timber into a rectangle with bigger dimensions than the bridge flooring, in order too increase its packing capabilities for the reduced size of the actual flooring. The pieces on the rectangle edges are then cut to the dimensions of the bridge flooring, and the small gaps that remain are filled with additional waste timber pieces.

The assembly process is straightforward. Lamellas of waste timber - adjusted to be 30mm thick - are laid out according to the algorithmic design discussed previously. Onto this, the second layer is added, with grain in the perpendicular direction. Finally, the Lignoloc nail gun is used to seal the layers. A bio-based coating is added to protect the product from rotting.

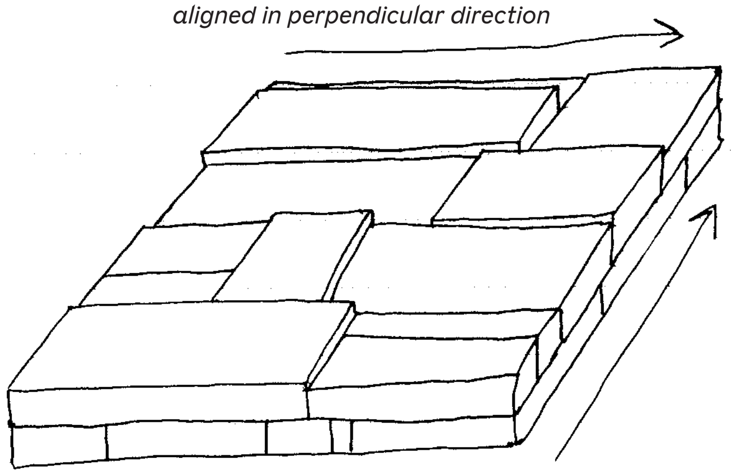




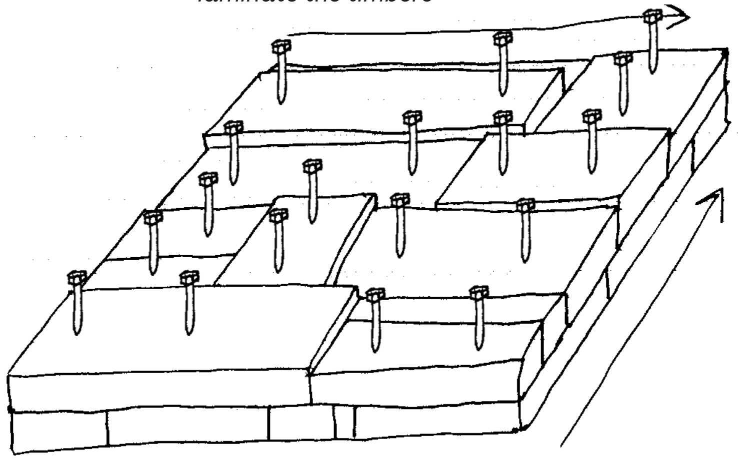
Planks of the same thickness aligned in one direction



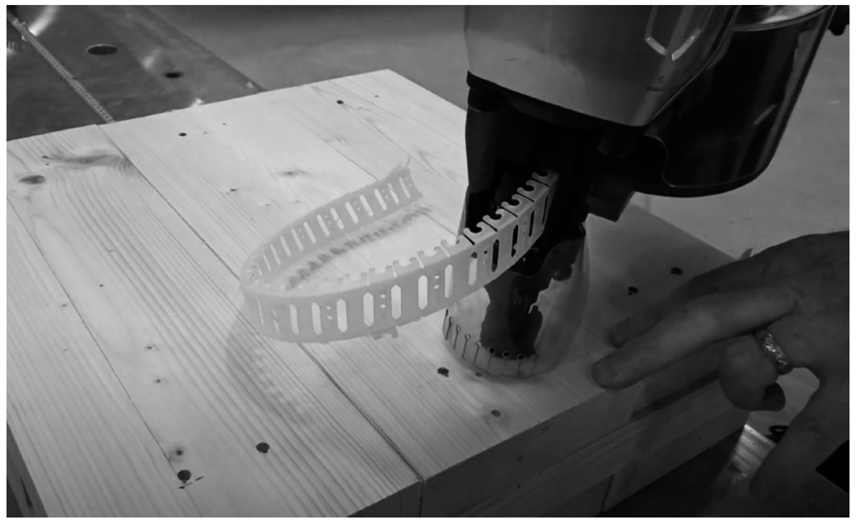
Elements with varying thicknesses aligned in perpendicular direction

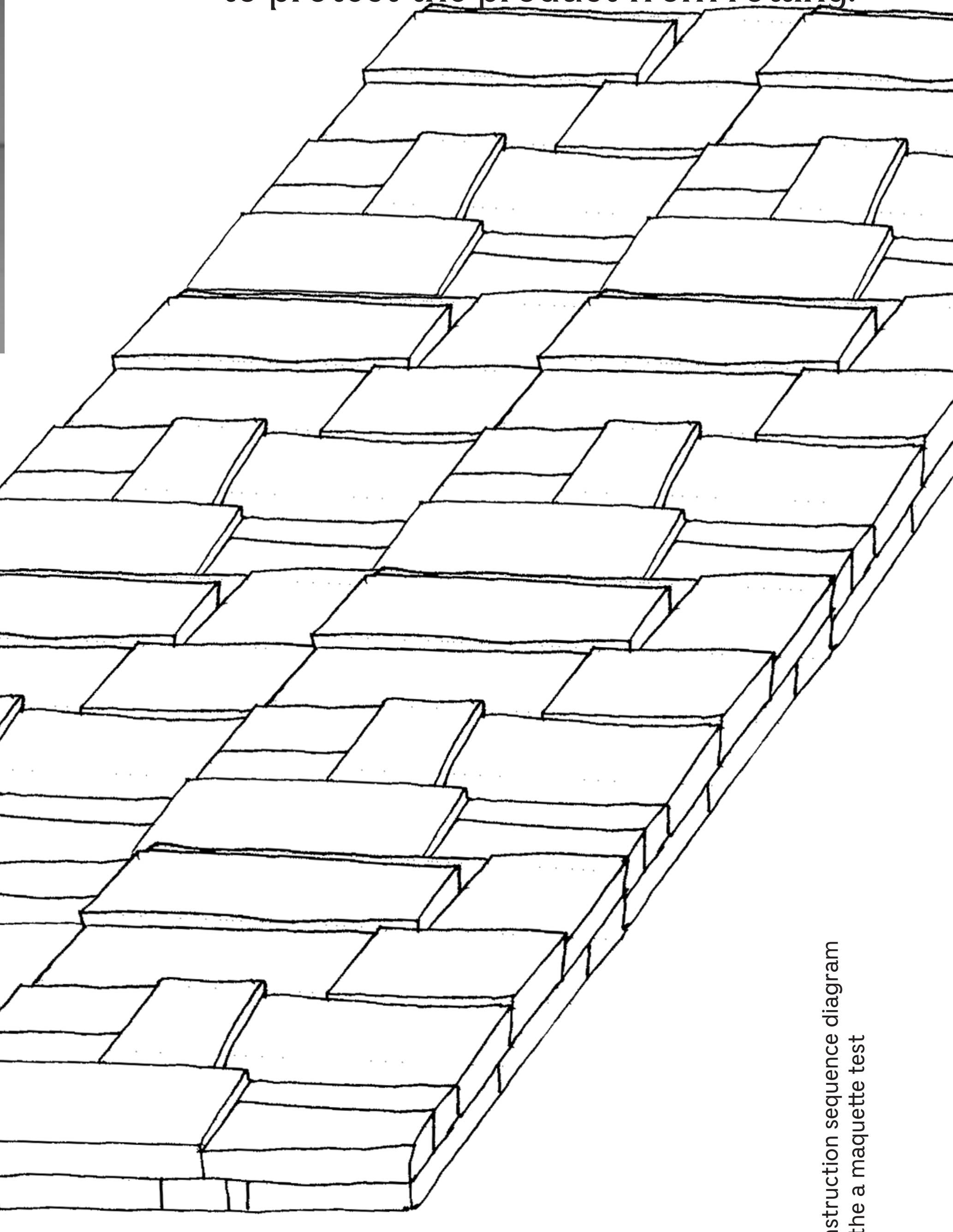


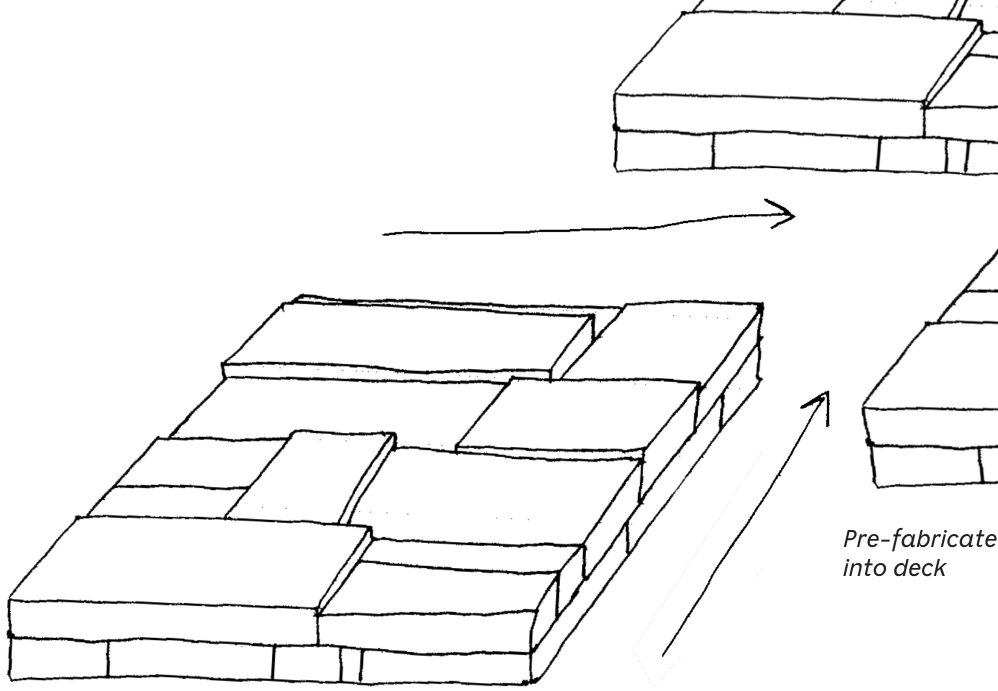
Densified wooden nails used to laminate the timbers



Bio-based coating added to preserve laminated timber panels



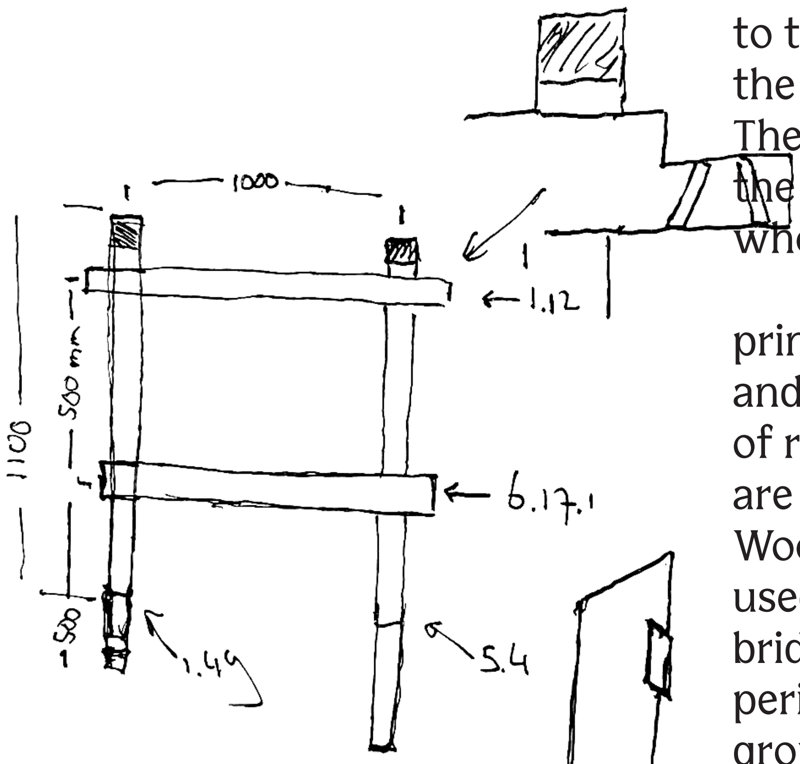




Pre-fabricated panels combined into deck

Opposite: Construction sequence diagram
Top: views of the a maquette test

Handrail

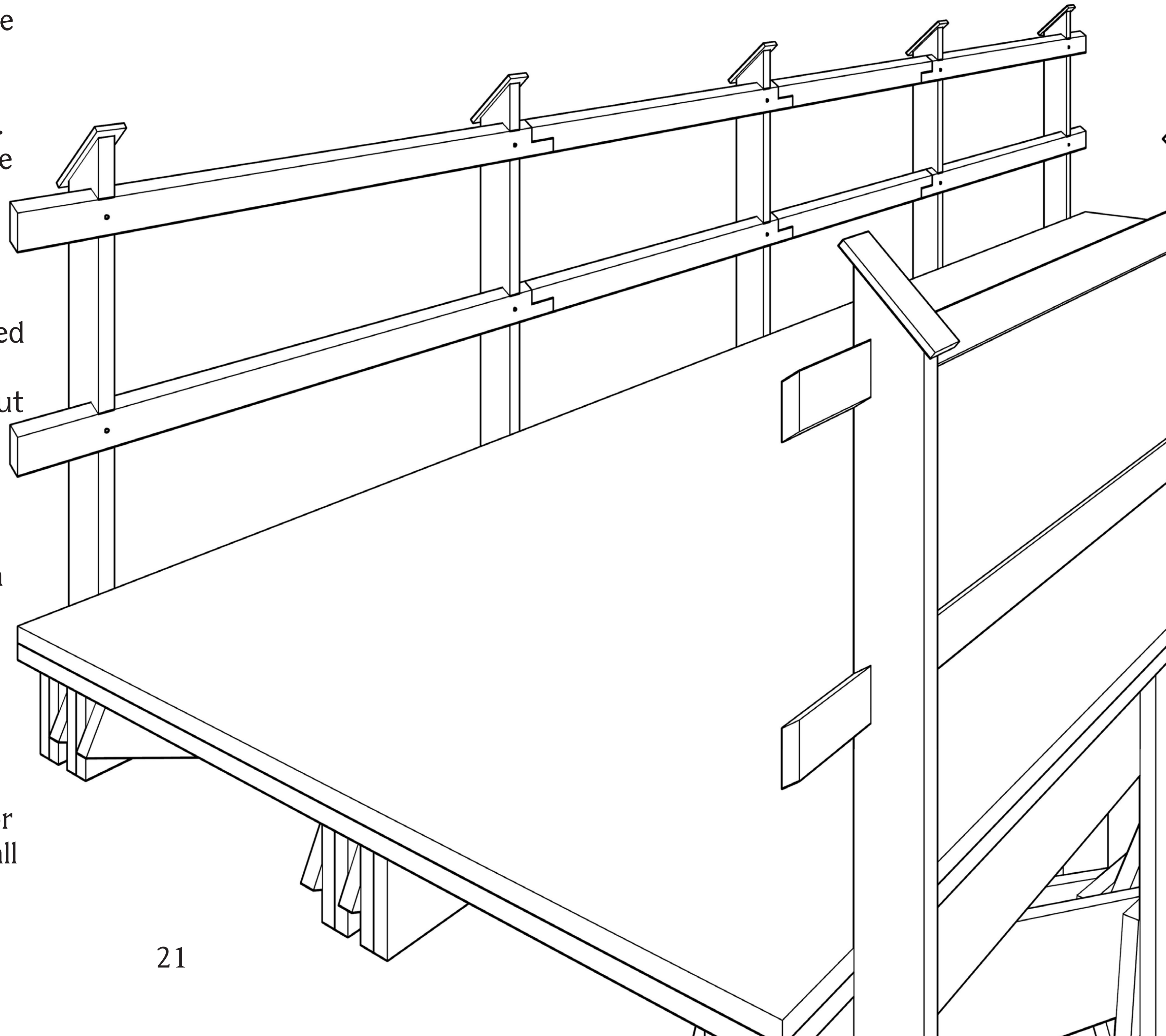


In sharp contrast to the heavy truss beneath, the handrail is comprised of lightweight elements oriented perpendicular to the direction of the bridge, making them appear thinner from a distance. This also responds to the dominant structural load on the railings, which comes laterally. The design consequently illustrates the properties of timber to those who use the bridge.

Following the off-plane principle of the design of the bridge and to accommodate for the use of reclaimed timber, the railings are joined in an asymmetrical way. Wooden pins and simple joinery are used to make the assembly of the bridge feasible in the given time period, and with the skills of our group.

The bridge railings are designed to withstand the rainy and windy weather of the Netherlands without too much maintenance. Grain direction in the timber is oriented horizontally as much as possible and where the water can get through due to vertical orientation of the grains, sacrificial pieces are placed.

The railings are prefabricated and attached to the trusses off-site. This is possible as the final dimensions and weight of the two attached components is feasible for transport in an easily rentable small van. The construction process for the handrails is comprehensively explained on the following spread.

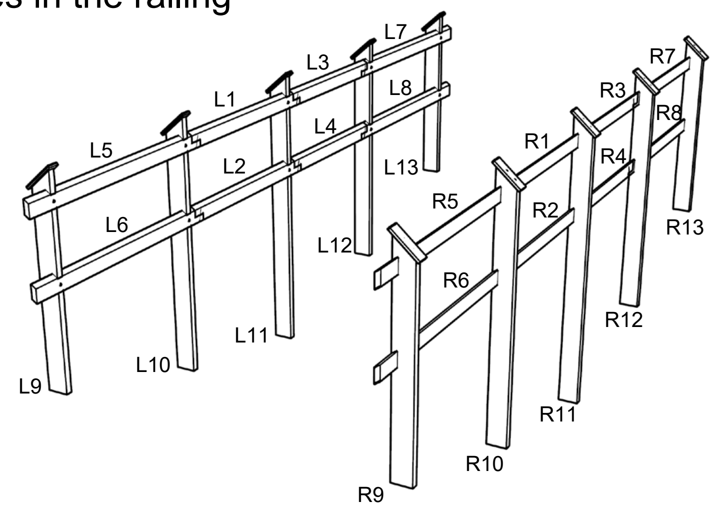


Step 1:

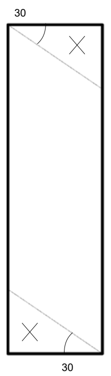
Gather all the pieces assigned to the railing. These are given below.

Rightside:		Leftside:	
R1	1.37 (split)	L1	6.10 (cut)
R2	1.20 (split)	L2	6.10 (cut)
R3	1.6 (split)	L3	6.10 (cut)
R4	1.37 (split)	L4	6.10 (cut)
R5	6.17.2	L5	4.2
R6	6.17.1	L6	6.25
R7	4.25	L7	6.7
R8	6.19	L8	4.7
R9	1.49	L9	2.22
R10	5.4	L10	5.5
R11	5.34	L11	2.31
R12	5.16	L12	5.32
R13		L13	2.45

Pieces in the railing



Step 1

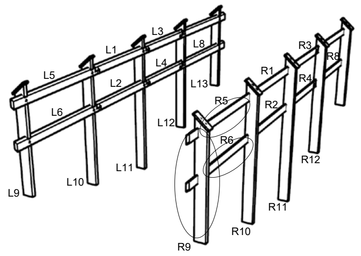


After gathering all the pieces for the railing, all the horizontal pieces need to be cut at an angle of 30 degrees on both the top and bottom sides of the railing, as shown in the picture (viewed from the small side of the beam, side view)

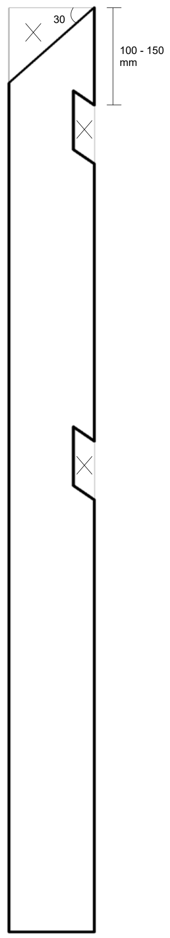
This would be done with the table saw in the model hall.

Step 2

Start with the assembly of the railing by choosing one of the two railings, left or right, and one of the ends. The prototype in this case started with the right side with pieces: R5, R6 & R9.



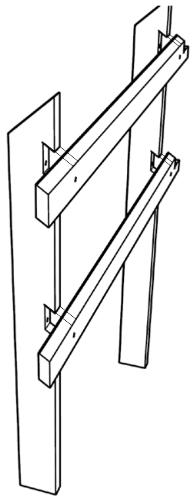
Step 3



Based on the shape and size of the horizontal pieces, you would make cuts on the vertical pieces.
1. Start with the angled cut on the top of the vertical piece. This will be on the inside, about 100-150 mm.
2. Use a table saw or a Japanese saw to cut a general cut for the horazontal pieces. To do this; first, mark 100 mm from the top, which is the top of the first horizontal piece. Then, mark the thickness. Next, at a maximum distance of 500 mm apart, mark the top of the bottom horizontal piece and mark the thickness of that piece.
3. Then use a chisel to alter the pieces so they fit together.
* Do this fo every vertical piece and the associate horazontal pieces.

R13

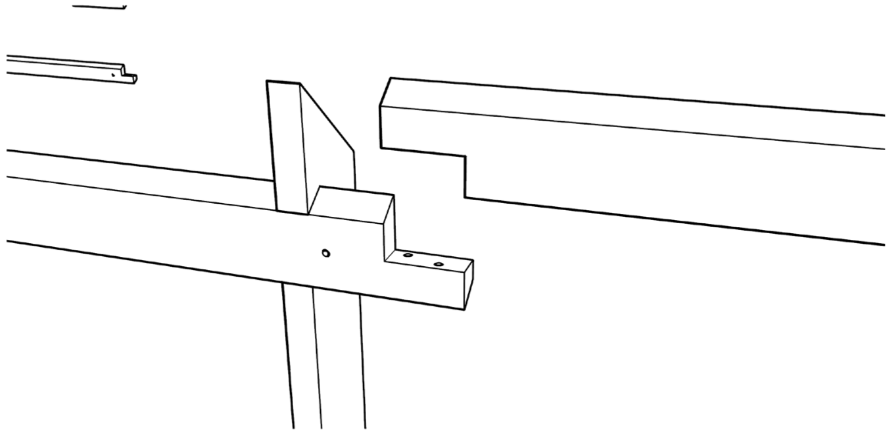
Step 4



Fit the vertical and horizontal pieces together by sliding in the horizontal pieces.

Step 5

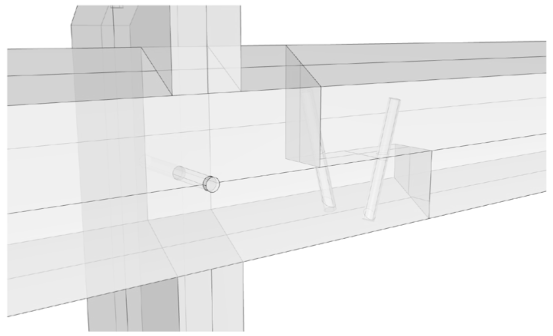
Now take the horizontal pieces of the railing and create a half-lap joint with the next two horizontal beams. Repeat this until you finish the whole side of the bridge by looking at the general overview, the half-lap joints, and closely paying attention to step 3 and 4.
* Do this for the horizontal elements at the 1000 mm height and the 500 mm height.



Step 6

After sliding in the horizontal elements, it's time to secure them together. This is done by clamping the elements in place and drilling holes, which will later accommodate the dowels. If lignoloc is used, there's no need to drill holes; the lignolocs can be shot in at an angle, as shown in the images. The same applies to the dowel holes.
* This is done in the same way for the half lap joints. See the pictures below

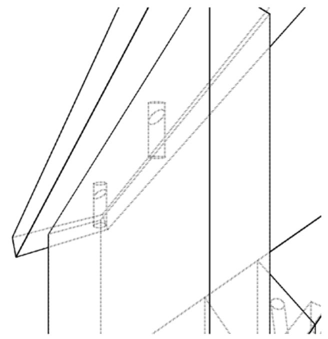
The dowels that are attached to the halflap joint are either drilled in from below or shot into it. This ensures that the connection remains watertight. However, it is important that no hole remains at the top.



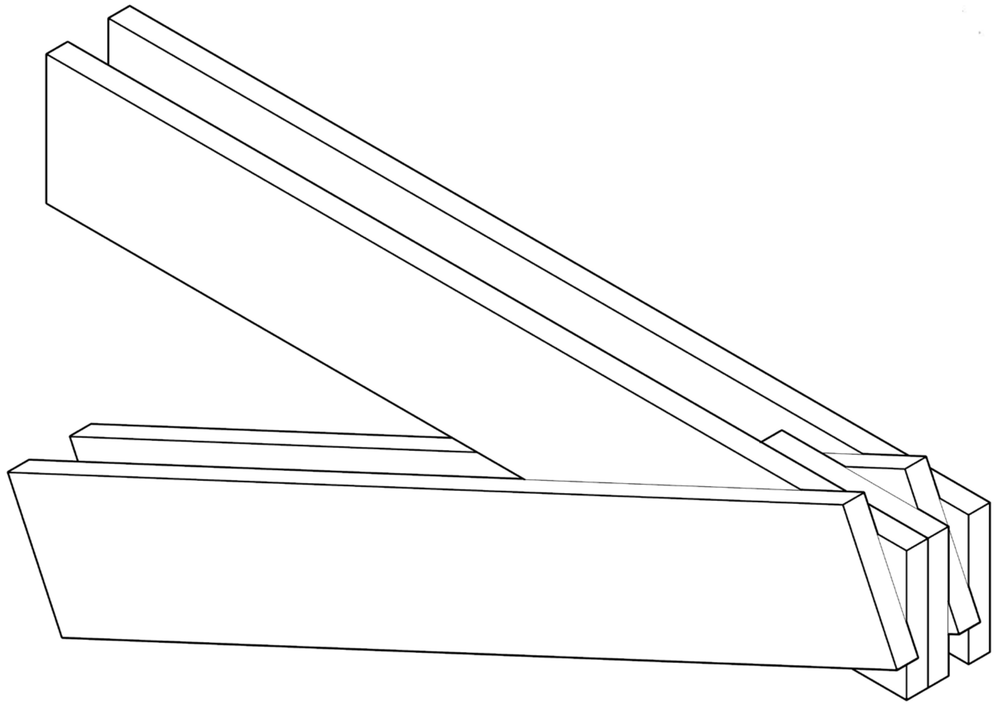
For the horizontal and vertical element connection, only one connection is made, as the mechanical connection is very strong, and only a slight hold in place is needed.

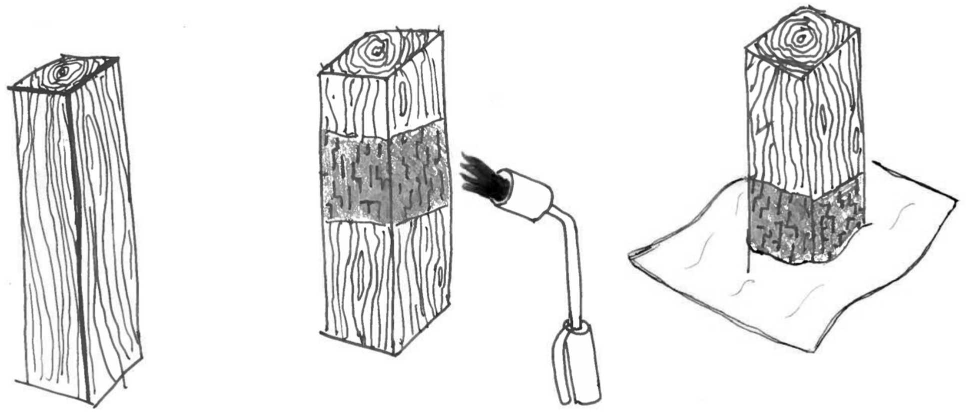
Step 7

Now create the final part by drilling a hole at the top of the vertical elements of the railing and a small hole in another piece as sacrificial wood. In this way, the joint is not exposed to the rain and is protected, and the vertical elements are also protected against rot.



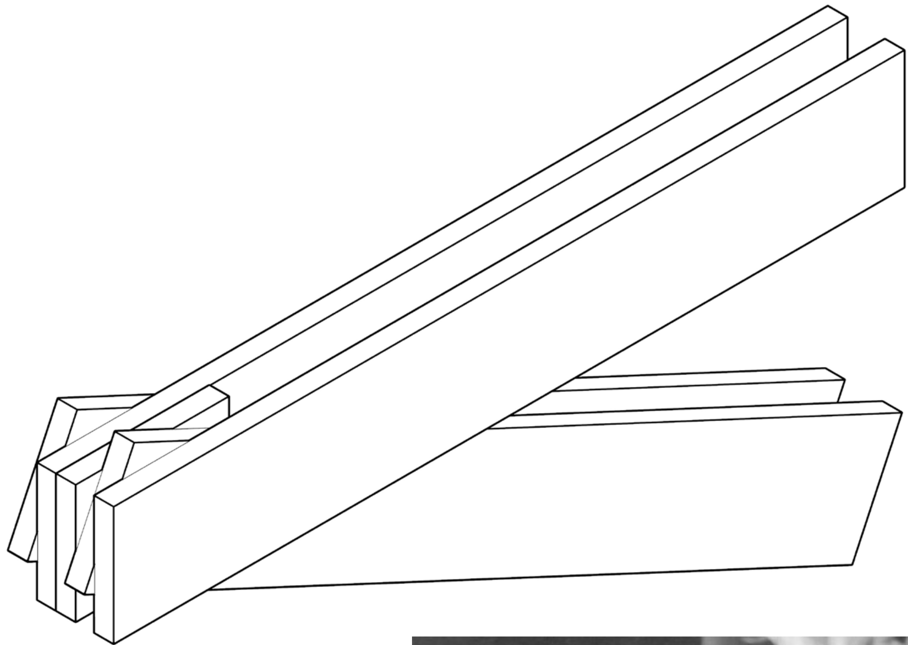
Foundations

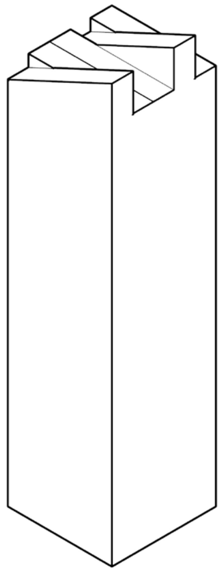


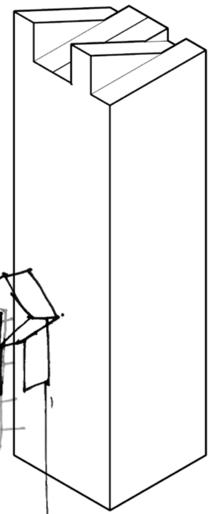


Sketch of the process of fire-treating the columns

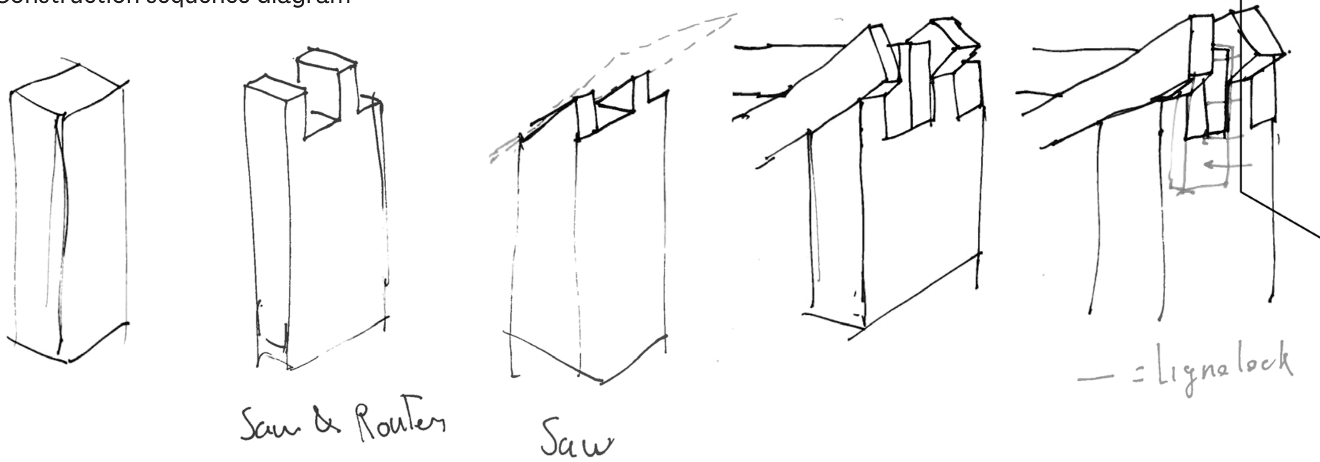
Axonometric views of the foundation columns







Construction sequence diagram



The foundations represent one of the most challenging components of the bridge, by virtue of the difficulty using timber in a situation where it does not dry out.

It is common in the Netherlands for buildings to have deep timber pile foundations. This is possible since the timber is burried below the water table, and consequently is in anaerobic conditions.

Equally, it it common in other countries for timber to act as foundations in the form of stilts - suspending a structure off the ground. This method relies on a solid base for the timber to rise from, and as a result is not possible in our bridge.

It has therefore been a challenge to develop an bio-based design for the foundations. We intend to have timber piles which rise out of the ground, with the portion lying beneath the ground treated with the sho sugi ban technique of wood preservation. This entails charring the exterior of the wood to prevent it reacting to the surrounding moisture.

Above this, we propose a simple joinery which slots into the layering of the truss. The diagram opposite shown the simple process for attaining this seemingly complex geometry.

For the exhibition, we have designed a structure from reclaimed wooden palettes which supports both sides of the bridge. The design is optimised to use a minimum number of palettes.

The palettes will be attached using straps, making the temporary structure non-interventional and fully reversible.

The palettes will return to their existing use after the exhibition.

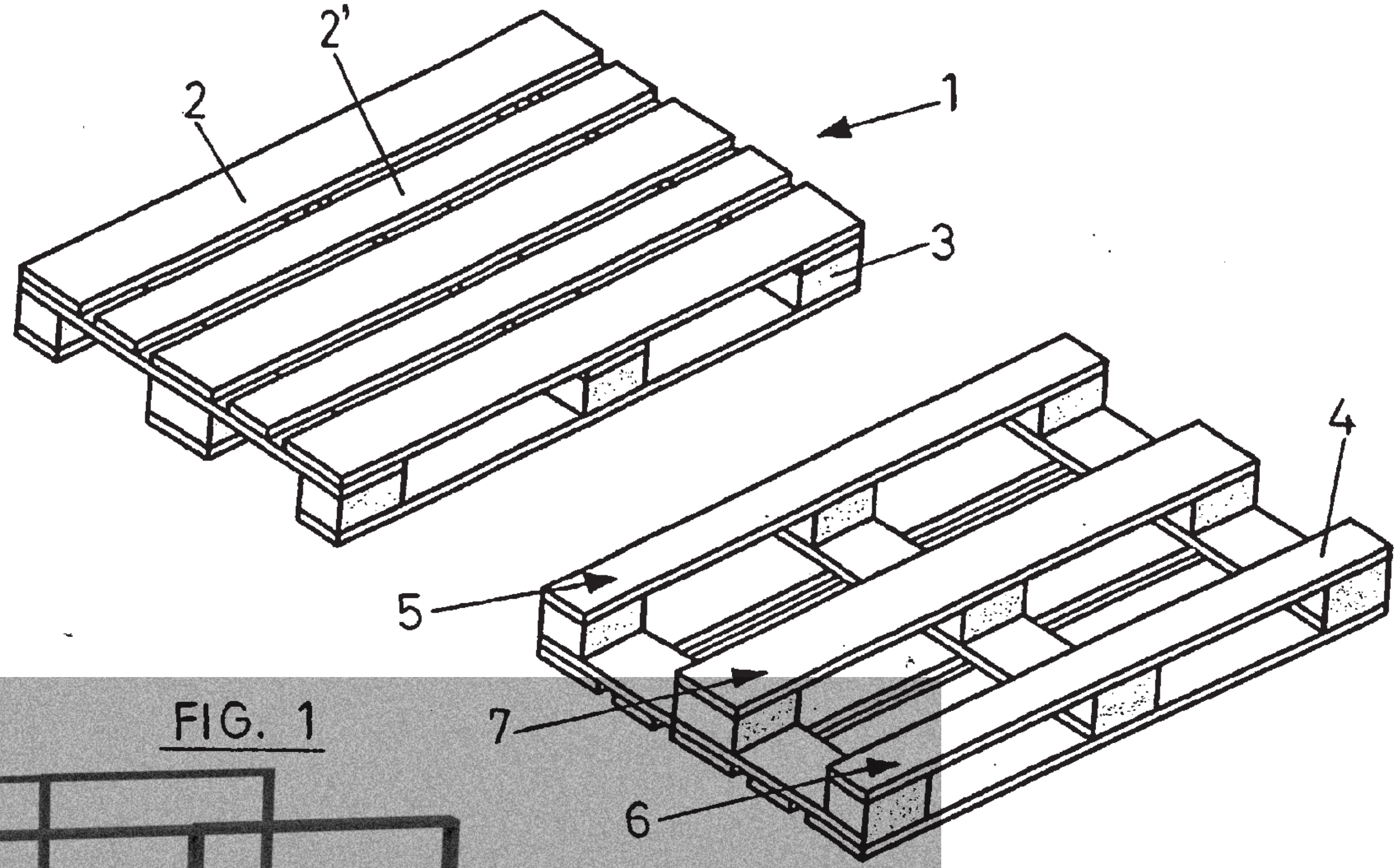
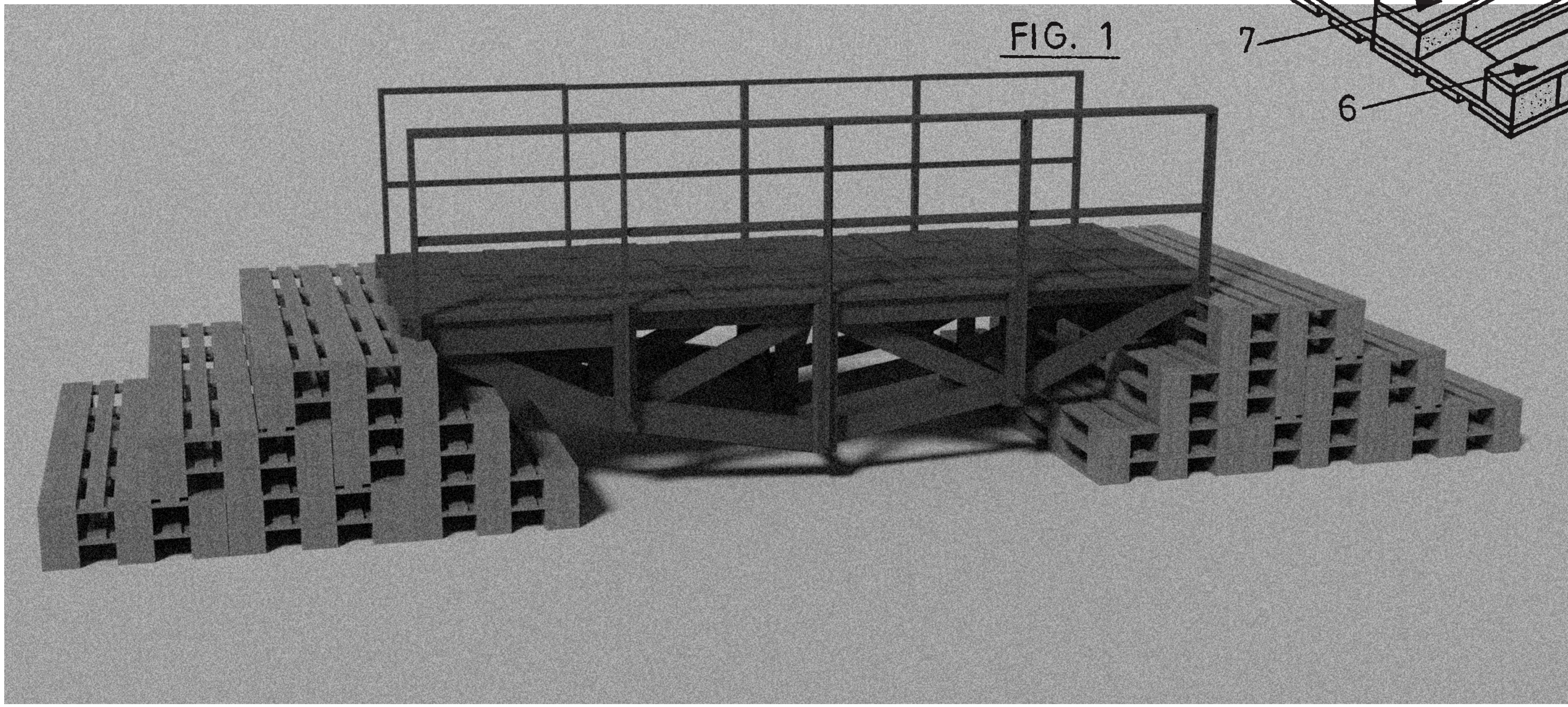
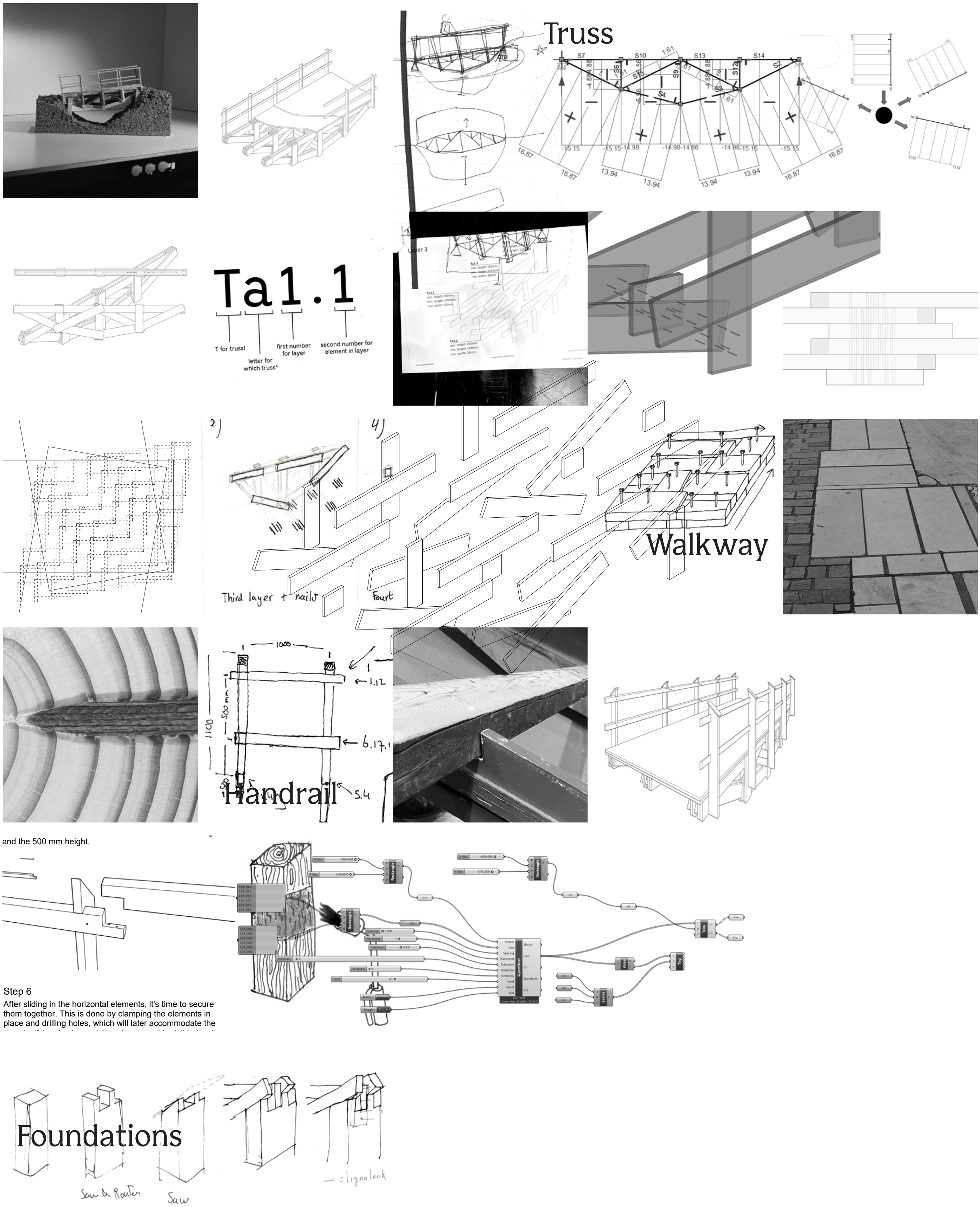
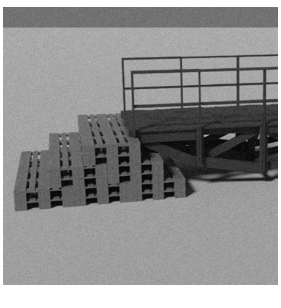


FIG. 1



Opposite: render showing exhibition foundations
Top: Illustration of a typical palette





Off — Plane Bridge