Craftmanship by Machinery

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To my beloved Mother

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Abstract

This thesis investigate the possibility of reinterpret vernacular wooden joints, where craftsmanship is replaced with computerized tools, to be used with modern building techniques in an Swedish context.

The industrial revolution changed the role of the craftsmen. The need for handcrafted joinery were no longer needed with the introduction of new materials and fabrication methods. Wood was also replaced as the primal material, for tools and buildings. The old carpender profession, with the deep knowledge of wood and wood joinery was forgotten.

The iron bridge, built 1781 by Abraham Darby the third, marks an interesting turning point. The bridge was built with the new material cast iron but with traditional wooden connections, since Darby did not know how to design in the new material. Much like today, when we use wood at a higher rate again, but as CLT we treat it as a monolithic material to be used with monolithic building systems.

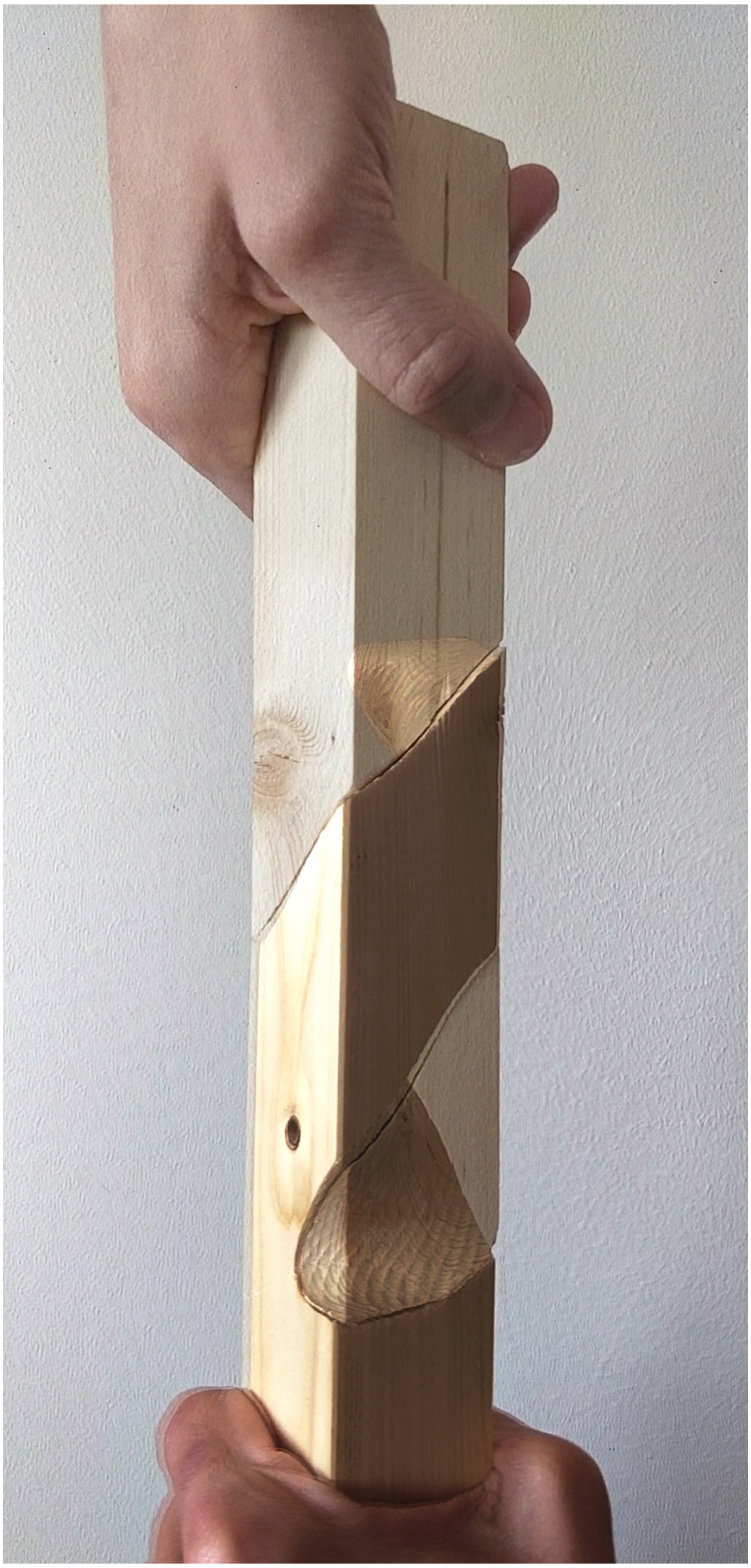
Looking at historical wooden buildings the connections are expressive and a visible part of the whole. The structural logic of the building can be read and the precision of the connections give the buildings structure an ensuring impression. If we were to try to implement the building methods of old in modern building environment computorized tools is the only path. With the help of digital machines the precision required can once again be reached and the forgotten art of joinery can even be developed further.

By looking at history, with the aid of modern digital tools and machines, this thesis hopes to contribute to the reinvention of traditional joints and help shape a new design language more appropriate for the material wood in our current context.

Content

Introduction

Chapter one



Introduction

Purpose

The purpose of this thesis is the aim to bridge the gap between the tradition and the modern building techniques of working with wood. As well as create disjointable, reusable and beautiful joinery without the aid of adhesive or other materials. By making the joint a design feature instead of a necessary evil a design language more interlinked with the past can be created.

Thesis Question

Considering the historical wooden joints done with high craftmanship, is it possible and is it relevant to reinterpet these joints, made with todays modern digital machines, for contemporary architecture?
In relation to this, when you treat the joint as something carefully designed and expressive, what architecture will this result in?

Background

In today's pursuit of building in wood there is a schism with the wood building tradition prior to the 20th century. When we now build with wood we focus on enhancing the material to fit today's building methods specified for other materials than wood.
In this thesis the historical art of joining wood and building with wood is investigated and adapted to todays digital tools and machines.
Point of departure is the work of the digital research groups ICD, ITKE in Stuttgart, Christopher Robeller in Lausanne and Blumer Lehmann outside of Zurich, all of which work with wood with digital tools and machines to create joinery.

Discourse

This thesis design and evaluates wooden milled joints through handsketches, computational design, robotics, structural evaluation, historical and wood research.
It does this with the objective to implement the milledcrafted joint in modern constructions techniques.

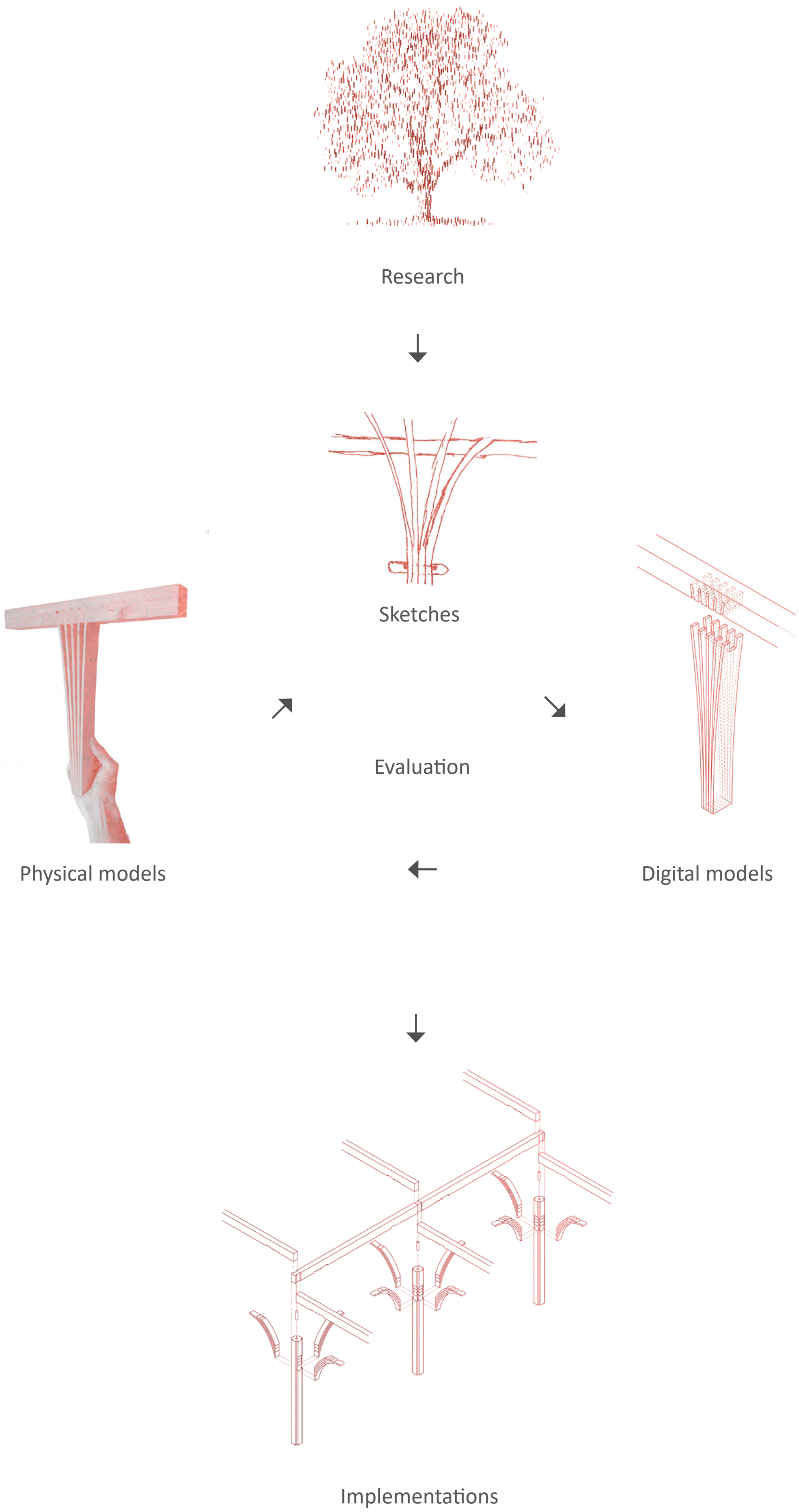
Reading Instructions

The thesis is divided into three chapters; An introduction to the subject, background of the study and investigations into historical joints and wood.
A database of investigated and constructed joints, with fabrication, strength and design details.
In the third chapter implementations have been made of some of the joints into naked structures, where the reader is the one who informs the use and gives life to the buildings.

Delimitations

This study only focus on wooden joinery, without adhesive or metal aid. In order to make the analysis less complex acustical demands have not been taken into account, making the joints suitable for a less variety of structures. Pillar and beam have been the main focus of the investigation and therefor log structures have not been elaborated on. In order to be able to investigate and construct a more thorough database of connections only a simple indicatory structural analysis have been made on the joints.
The designed joints is limited to be able to be constructed with an 4th axis milling CNC machine as it was the machine availible at chalmers.

Figure 1. Joint, Personal photo (L.P.)


Research
Sketches
Evaluation
Physical models
Digital models
Implementations

Method

General

This thesis have been done with an research by design method, with pre and parallel investigations into historical joints and building methods and wood as a material. At the begining the designed joints were more based on historical joints where at the end of the thesis the designed joints were based on a wider range of inputs, deriving from strengths of the material to strengths of the modern digital machines.

Research

Research was made into the material wood, historical joinery design and building methods as well as contemporary building methods and relevant designers and producers and architects in this context.This was the starting point informing the design of the produced joints.

Design phase

Based on the reasearch, sketches of joints where transformed to 3d softwares and then g-code in order to inform the CNC. Wood was prepared into straight 40x40 mm elements from which the joints were milled out.

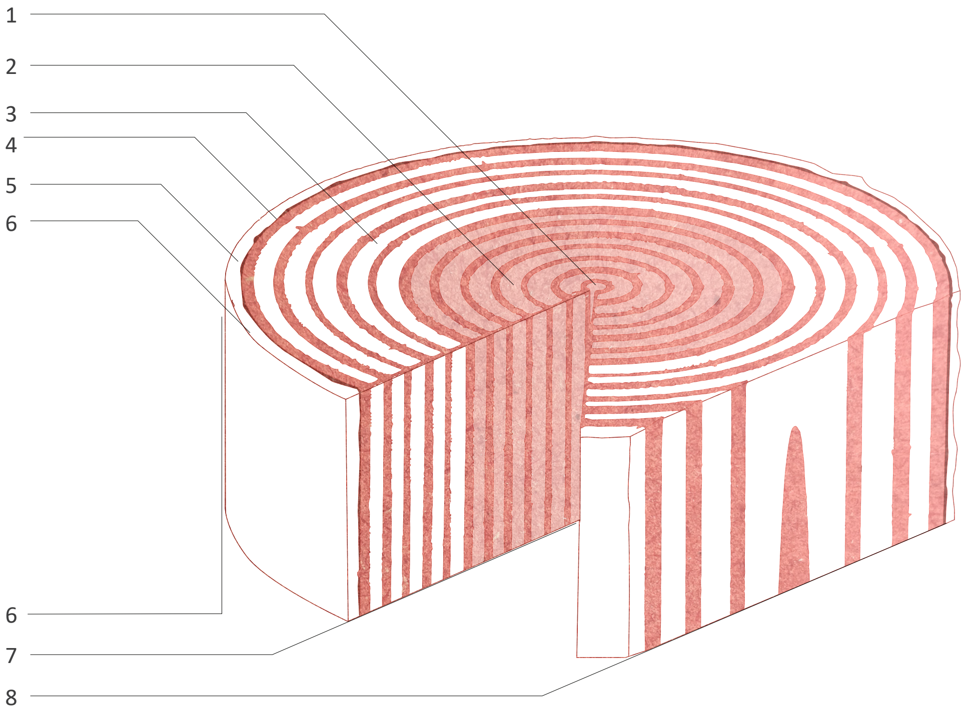
Implementations

With the designed connections inspirational structures are created in order to more easily see the possibilites of the joints. The structures are designed with the "iceberg" effect in mind, where the design is as naked as possible where the reader is the one who informs the implementations and give them life after their own visions.

Figure 2. Diagram of Method (L.P.)

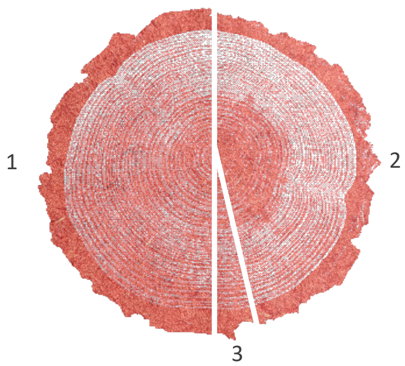
Figure 3. Spread joint, Personal photo (R.P.)

Cross section of the trunk



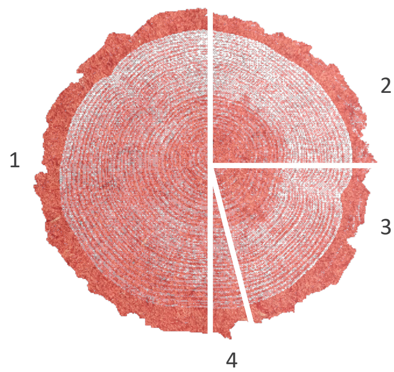
1. Pith
2. Hearthwood
3. Sapwood
4. Cambium
5. Inner bark
6. Outher Bark
7. Longitudinal direction
8. Radial direction
9. tangential direction

Substances



1. 50% Carbon
2. 44% Oxygen
3. 6% Nitrogen

Molecular components



1. ~50% Cellulose
2. ~20-30% Hemicellulose
3. ~20-30% Lignin
4. ~10% Other substances (Oil, resins etc)

Wood

General

Wood is an complex inhomogenic and anisotropic material with more than 30 000 known species, with different capabilities. In contrast to some other common building materials, wood comes in limited sizes and shapes, with weaknesses as branches and cavities in the materials. This can be seen as something problematic or be view as something beneficial for the structures.

The trees cambium increases the thickness, while the bark protects it from external damages. This growth gives wood its characteristic year rings, with different thickness and apperance if its early or late wood and a good or a bad season. The longitudal growth takes place at the tip of the stems. (Natterer, 2004, p.30-31)

Anisotropy

Wood is an anisotropy material due to the elonged shape of the cells, i.e. fibres. The fibers lie in the longitudal direction of of the three and gives the material very different properties its different directions. Both for swelling and shrinkage and load bearing capabilities. As an example is the permissable stress for spruce parrallel to the grain is 4.4 times higher in pressure and 180 times higher in tension than perpendicular to the grain. (Natterer, 2004, p.30-31)
The anisotropy of the material makes it more difficult to calculate structural capabilities and more to considering whilst designing the joints.

Moisture

Wood has the ability to absorb and release moisture when the humidity change, which have a positive impact on the indoor climate as it reduce the fluctuations. But due to the anisotropy of the material it swells and shrinks very different in different direction. Longiudinal shrinkage is typically very small and inconsequential in relationship to radial and tangential. As it is very different between the different species the tangential/radial shrinkage ratio is informative.
For pine, the shrinkage difference is per 1% moisture content change:
<0.01% Longitudal direction
<0.15-019% Radial direction
<0.27-0.36% Tangential direction
I.e. the T/R ration is: 1.85.

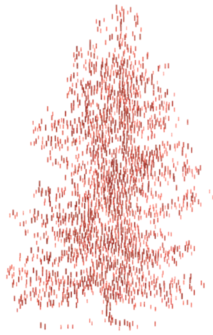
This becomes a issue when it is combined with the fact that the moisture content in different zones is different, i.e:
9 +- 3% Heated enclosed structures
12 +- 3% Unheated enclosed structures
15 +- 3% Roofed open structures
18 +- 3% Exposed structures
(Natterer, 2004, p.30-31)
Due to the different moisture equilibrium in different zones the size of the wood members in different direction will differ, which is something which needs to be considered in order for the joints to fit on site even if they will not fit in the fabrics where the computational tools is located.
The shrinkage and swelling in different directions could as well be used as an locking mechanism for the joints.

Figure 4. Diagram of cross section (L.P.)

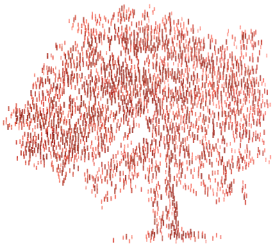
Figure 5. Diagram of structures (L.P.)

Spruce

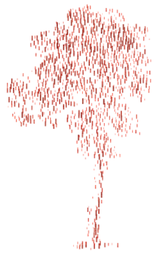
Pine



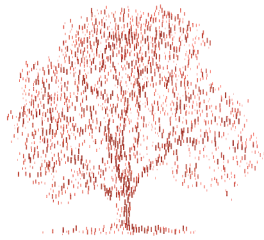
Larch



Oak

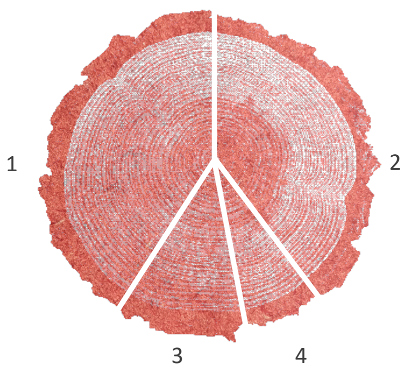


Beech



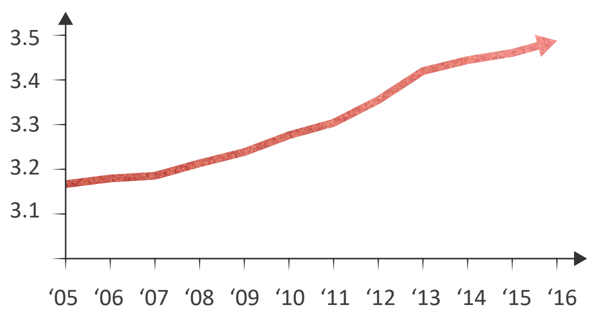
Elm

Share of species in Sweden



1. 40.8% Spruce
2. 39.3% Pine
3. 12.4% Birch
4. 7.5% others

Amount of wood in sweden



Billion m^3sk per year

Types of trees

Trees can be divided into two types, confif-erous and deciduous.
Confierous is the evolutionary elder of the two. It is also called evergreen because it keeps it “leaves” for several years. It has one cell structure which transports water and nutrients. Spruce and pine is confierous species and the most common trees in Sweden, typically used as building material.

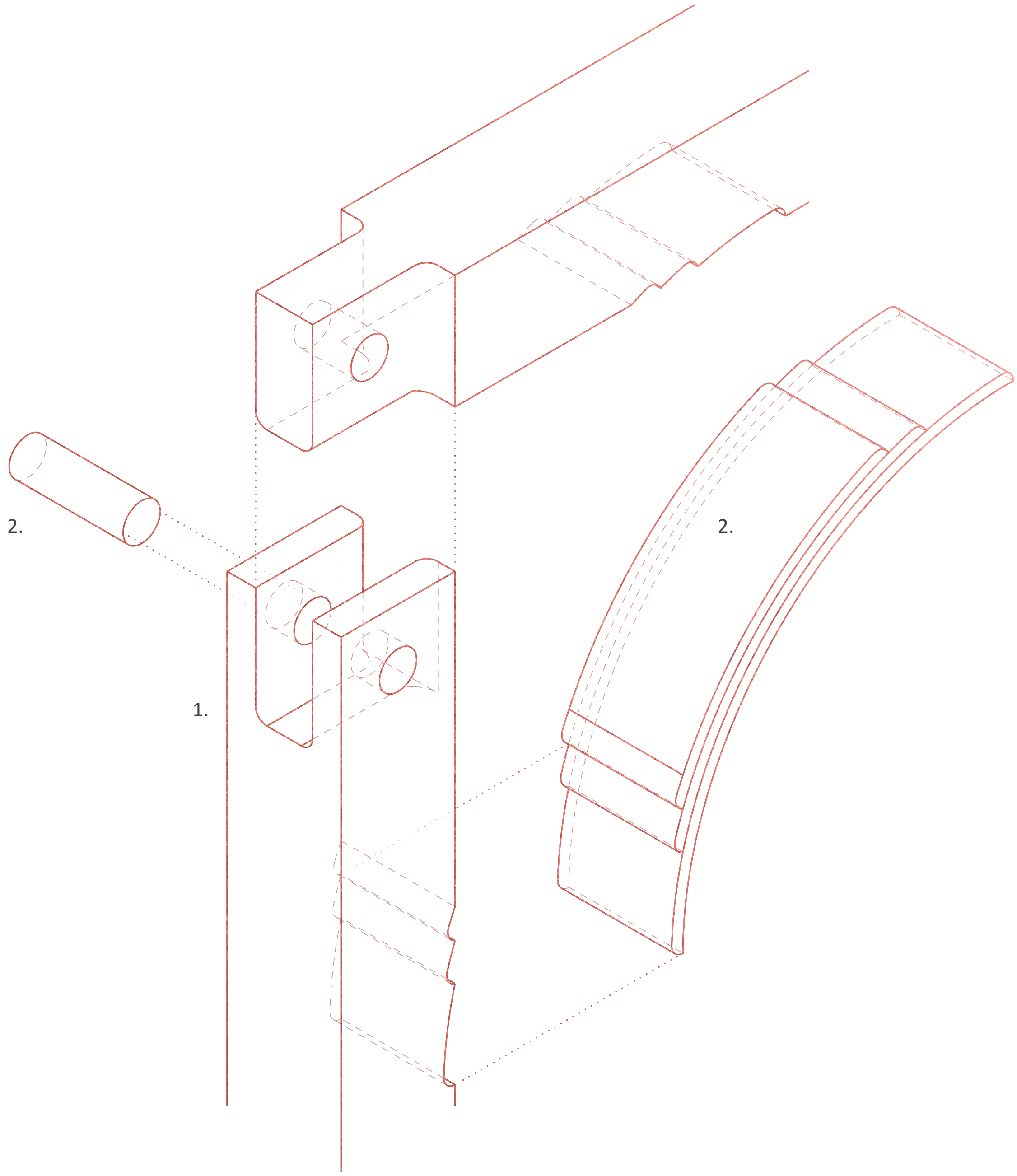
Deciduous is more evolved and complex. It has several cells which are more special-ized. Some species of deciduous is Oak, Beech, Birch etc. (Natterer, 2004, p.30-31) Oak has strong straight fibers, good for compression zones. Elm has interwined strong fibers, which makes it good for non axial pressure. Traditionally used in the hub of wooden wheels, in this thesis, the hub of the joints.

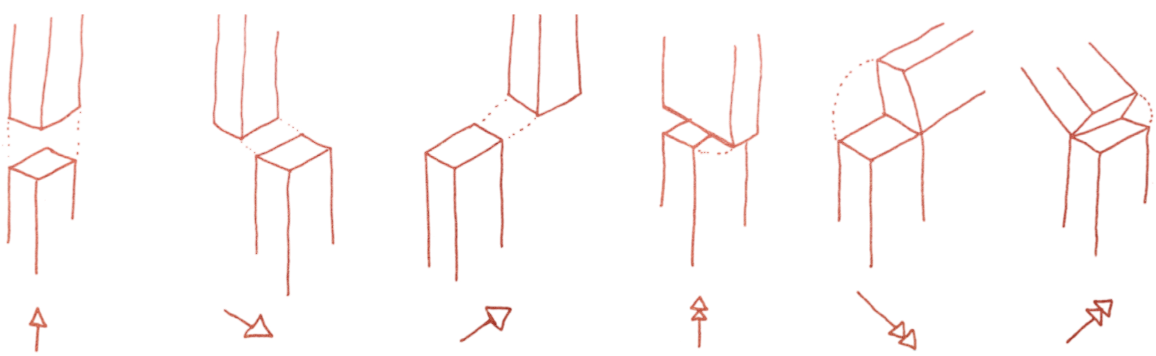
Types of tree trunks

Trees can also be divided considering how they transport water and nutrients. This has an impact of both the visuals and the load bearing capabilities of the tree.
Sapwood trees transport it in the entire cross section of the trunk. Examples, Limes and Birches.
Ripewood trees use the outher rings primary as transport. Examples of this is Spruce, fir beech.

Hearthwood trees transport nutrients and water in the centre of the trunk, giving a distinct difference in colour between the trees heartwood and sapwood. Oak, pine, Larch are examples of this group. (Natterer, 2004, p.30-31)
The different qualities of the different tree trunks have not been explored further this thesis.

Figure 6. Diagram of wood species (L.P.)
Figure 7. Diagram of share and quanaties (L.P.)
Figure 8. Timber floatiing, Björn Svensson (R.P.)

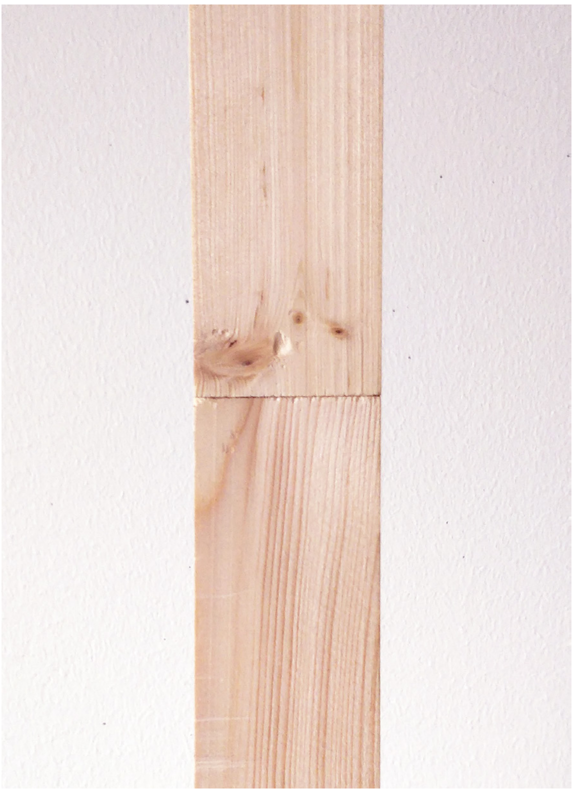




3.

1. Primary tenon joint
2. Secondary joints

3. Degrees of freedom



How to join wood

Definition of joint

In order to understand how to join we first must understand why we join wood. Wood comes in limited size and shapes.
The width of Parthenon was not limited by the architects curage but the height of the trees used for its roof. Since then we learned how to extend and widden wood elements. In this thesis this is refered to as **extension joints** and **thickness joints**. The third catagory used in this thesis is **oblique joints**.

Structural heirachy

In contrast to steel and adhesive joints, a wooden connection between two elements is always an weakness in relation to an continues member. Especially in tension (P.Bergkvist, 2015, p.112). To overcome this the joint can be made by stronger hardwood species, placed in an area where the capacity of the elements is not fully utalized or, as was very common historically, secondary joints, shown in the diagram to the left, were used to increase the strength of the joint.

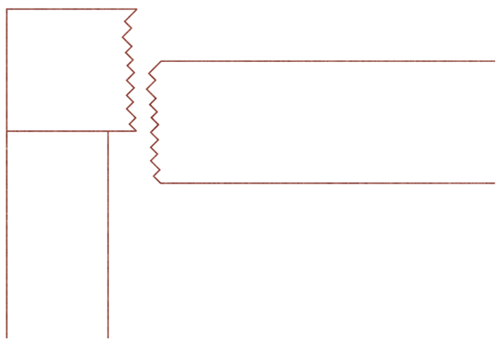
Degree of freedom

In simplest terms in order to join two members together the movement between them have to be restricted. Either by locking all of the members different movements and rotations together, or designing the structure as such so the movements would not be possible in the first place or a combination. The butt joint in the picture above is sufficient if the only force it will be exposed of is straight pressure between the elements.

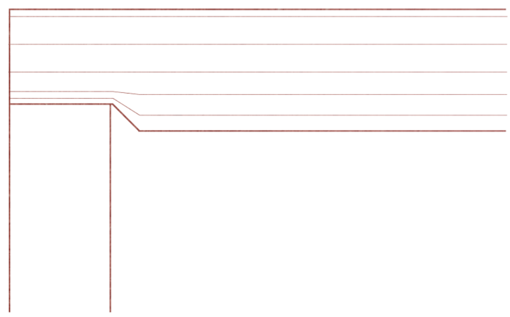
Locking methods

This thesis have defined four different locking methods. **Geometry joints** where the geometry of the members interlocks. **Locking piece** when a final piece is added to lock the joint. **Moisture expansure** when the added element has lower moisture and the swelling of the element locks the connection. **Pre tensioned** when the wood is bent into a shape where the built up force locks the joint.

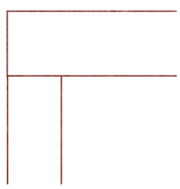
Figure 9. Diagram of structural heirachy (L.P.)
Figure 10. Sketches of degrees of freedom (L.P.)
Figure 11. Butt joint, personal photo (R.P.)



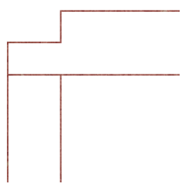
Shear Failure



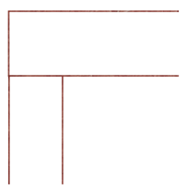
Pressure failure



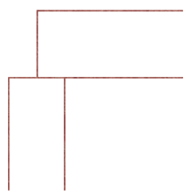
example of 100% shear utilization



example of 50% shear utilization

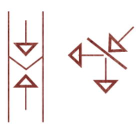


example of 100% pressure utilization

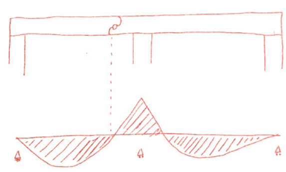


example of 50% pressure utilization

End fibers



Force composants



Placement of joints

Structural assessment

General

Wooden connections can break in several ways, but the two most common is shear failure and presure failure perpendicular to the grain. In order to be able to compare the structural capabilities of the joints an basic calculation of these were made. The result was simplified into an factor, more easily understod and compared.
(Robert Jockwer and geir Söderin, personal communication, May 08, 2020).

Placement of joints

Important to be aware of is that the forces is not constant throughout the structure and structural members. Therefor it is possible to place the joint places where the utalisation of the structural members is low, which would allow the joint to have a lower relative strength factor.

Shear Failure
f*F/A < S --> A/Rel. A < S --> Rel. shear strength

f = Shear stress factor
F = Shear force in beam
A = Cross section Area of beam
S = Shear Strength

Pressure failure
F/A < S --> A/Rel. A < S --> Rel. pressure strength

F = Shear force in beam
A = Area of beam against pillar
S = Strength prependicular against fibers

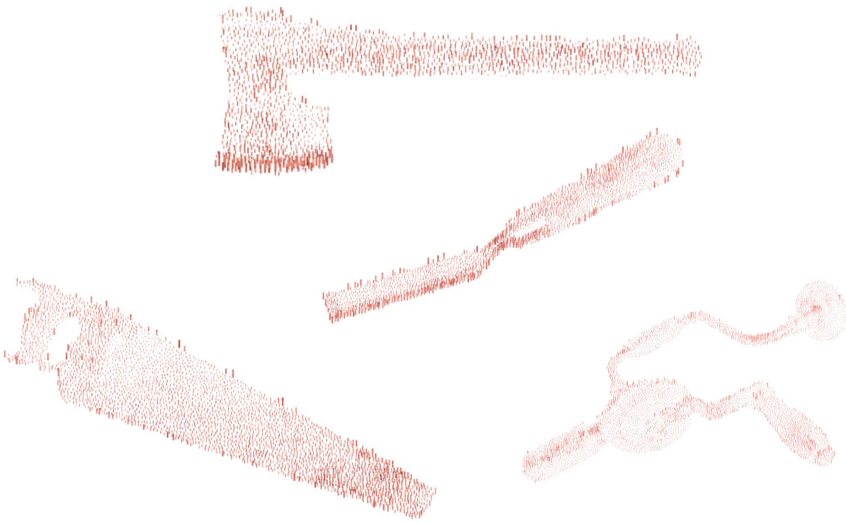
Shear failure

Shear failure is when wood breakes parallel to the direction of the force, in radial or tangential direction. This breakages occurs between the fibers and is related to the anisotropic qualities of the material, where the material is much stronger in the direction of the fibers. (Hans Lund, 2016, p.18-19) (Per Bergkvist, 2015, p.44-45)

Pressure failure

Too high pressure failure prependicular to the fibers direction will crush the tube shaped fibers. When all the fibers are crushed the stress level can rise again, there is therefor wrong to define it as a true failure. But in order to be able to reuse the elements uncrushed fibers are prefered. (Per Bergkvist, 2015, p.43)

Figure 12. Diagram of shear failure (L.P.)
Figure 13. Diagram of Pressure failure (L.P.)
Figure 14. Joints, personal photo (R.P.)
Figure 15. Diagrams of critical areas (R.P.)



Traditional hand tools

Computational machines

The importance of tools

Tools importance

Tools is what governs what we are able to create. With the tools existing during the iron age, the axe, hatched, chisel and drill all the handcrafted joints up until now could be created. This is true for both European and japanese craftsmen but there is still important differences between the different wood cultures. The japanese tools were developed for working with softwood, generally working towards the body wich gives higher control. Since the tools did not need the same power they could be thinner, generating higher detailed joints. The european tools where in turn developed for hardwood, generally working away from the body, where more power could be used, but the finish where in turn lacking. (Zwerger, 2015, p.67,p.116) With the arrival of the modern CNC milling machine we today have higher level of detail than the japanese and more power than the european cultures.

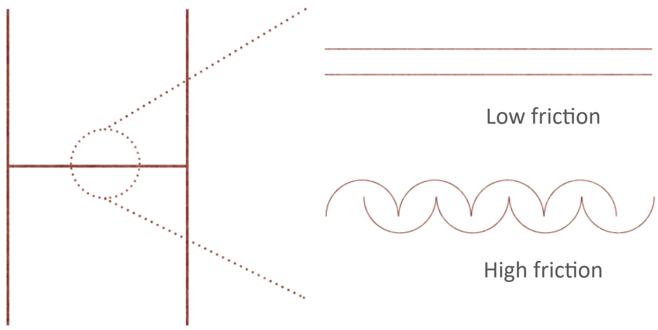
Differences

An major difference between hand tools and computational machines is that milling machines is not able to cleave wood along the fibers, which is an major disadvantage due to the qualities gained by this method such as, for instance, higher water repelling qualities.

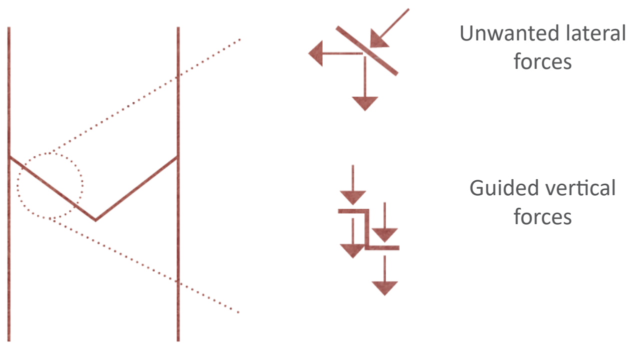
Another one is that milling machines, which is used in this thesis, is unable to create inner corner, which is visible in the traditional joint above. Although it might be a good since sharp corners have a tedency to amass concentrated forces and create an crack in the wood.

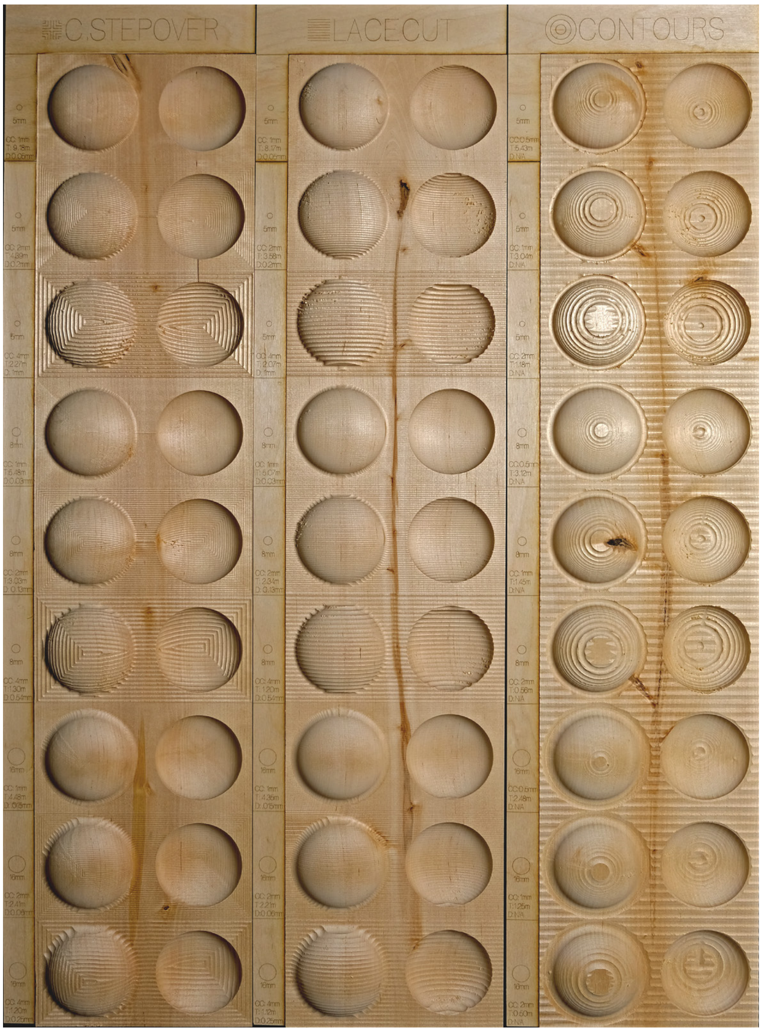
Figure 16. Diagram of tools (L.P.)
Figure 17. Traditional joint (R.P.)
Figure 18. Milling, personal photo (R.P.)

Designed friction



Guide force direction





Milling

In comparision the handcrafted joints, where the wood could be cleaved along the fibers to create high quality surfaces the milling machine cuts the wood regardless of the fibers direction, although when milled against the fibers there is a risk for the wood to cleave unintentionally. The kimla milling machine utilized in this theis has an precision of o.oo1 mm, this brings intresting posibilities. The friction of a flat surface with such precision is very low, and would require an long milling time, but if we allow the surface to be curved, as in the diagram, we can achive higher friction improving the connection. Different settings have been explored, as seen in the image, of how to design friction among others.

Guide Forces

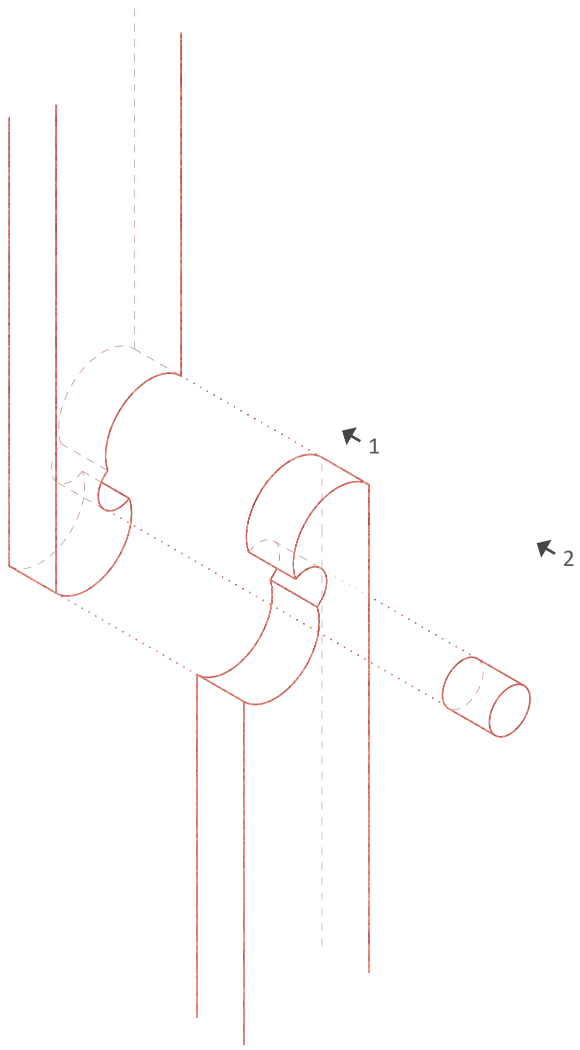
As seen in the diagram to the left having angled surfaces creates unwanted latera forces, but with the precision of the machine theoretically it is possible to guide forces to prevent unlateral forces, for instance as you see in the example. This would allow the creation of more complex connection surfaces, not perpendicular to the direction of the force.

Figure 19. Diagram of designed friction (L.P.)
Figure 20. Diagram of force direction (L.P.)

Figure 21. Milling studies, personal photo (R.P.)

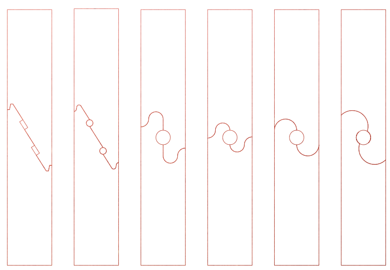
Joints

Chapter Two



Spruce

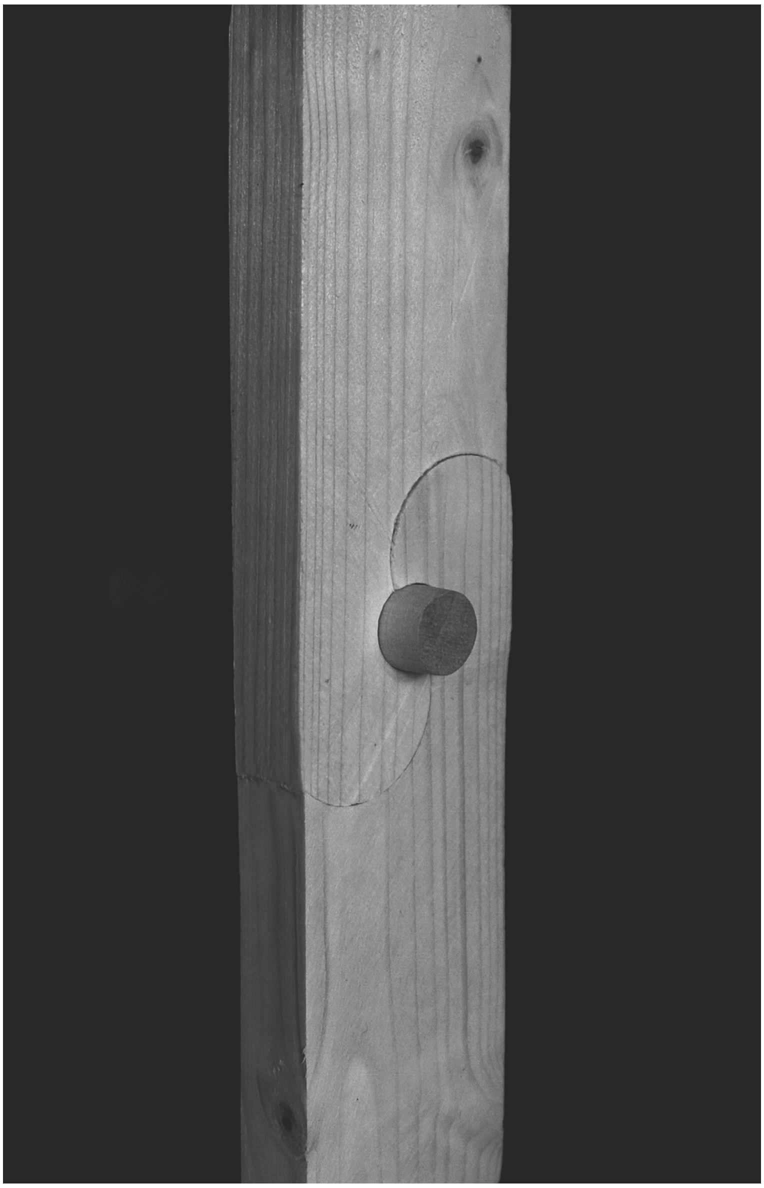
Elm



Design iterations

1. place the two members in position.

2. Insert the locking piece.



Yin Yang Joint

The yin yang joint derives from the traditional japanese joint isuka-tsugi (Zwerger, 2015, p.252) but through iterations has an geometry without corners but more soft milled edges, which removes force concentrations. Suitable species selections could be the softwood species spruce for the joining members and the hardwood psecies alder for the locking piece, due to its higher structural capabilities and interwined fibers.

Extension joint

Milling time

2 minutes

Locking method

Geometry, Locking piece

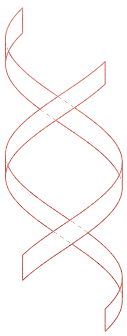
Axis required

3 axis

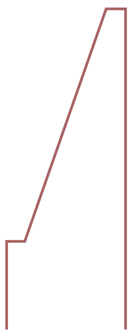
Movement	↓↑	↑↓	↗↙	↙↗	↘↖	↖↘
Shear failure	N/A	33%	100%	25%	N/A	N/A
Pressure failure	100%	33%	75%	25%	N/A	N/A

Figure 22. Diagram of Y.Y Joint (L.P.)

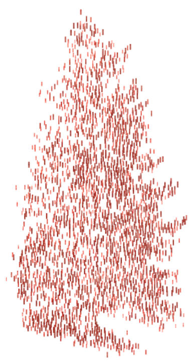
Figure 23. Y.Y Joint, personal photo (R.P.)



Rotated together



Cross section reduction



Spruce

1. Rotate the elements together

Rotational joint

The motion you assemble an joint adds an weekness in the same direction. The rotational joint derived from the idea of joining the wood through an non stressed movement for beam and pillars, in this case rotation. With the gradually cross section reduction with continuous tension force tranfer, this joint has an higher resistance for shear failure in tension. Which makes this joint is especially good in tension.

Extension joint

Milling time
22 minutes

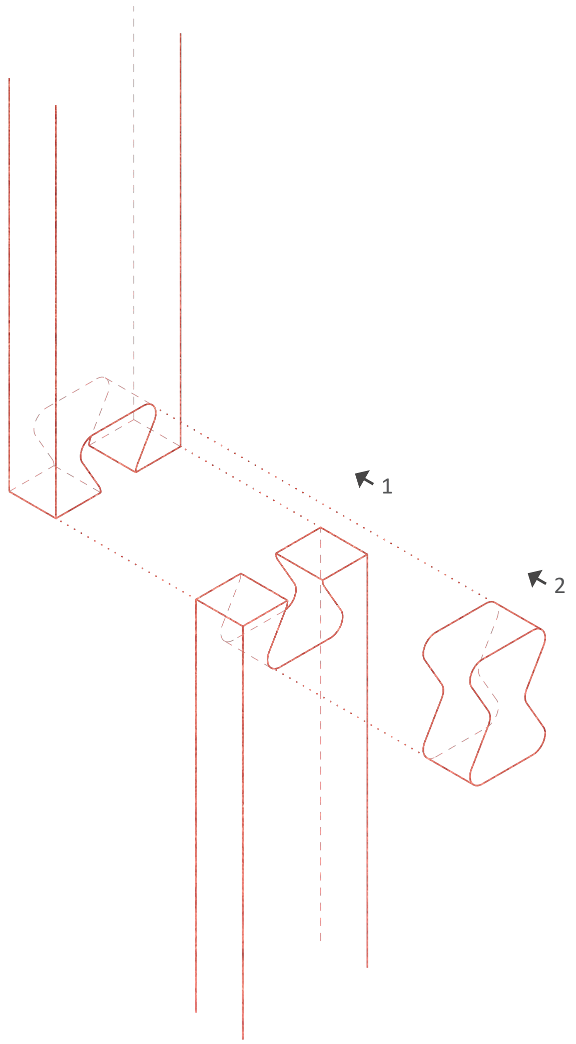
Locking method
Geometry

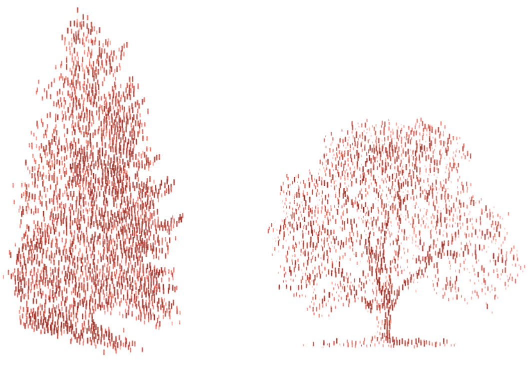
Axis required
4 axis

Movement						
Shear failure	N/A	95%	95%	95%	95%	95%
Pressure failure	100%	90%	28%	35%	26%	27%

Figure 24. Diagram of rotational Joint (L.P.)

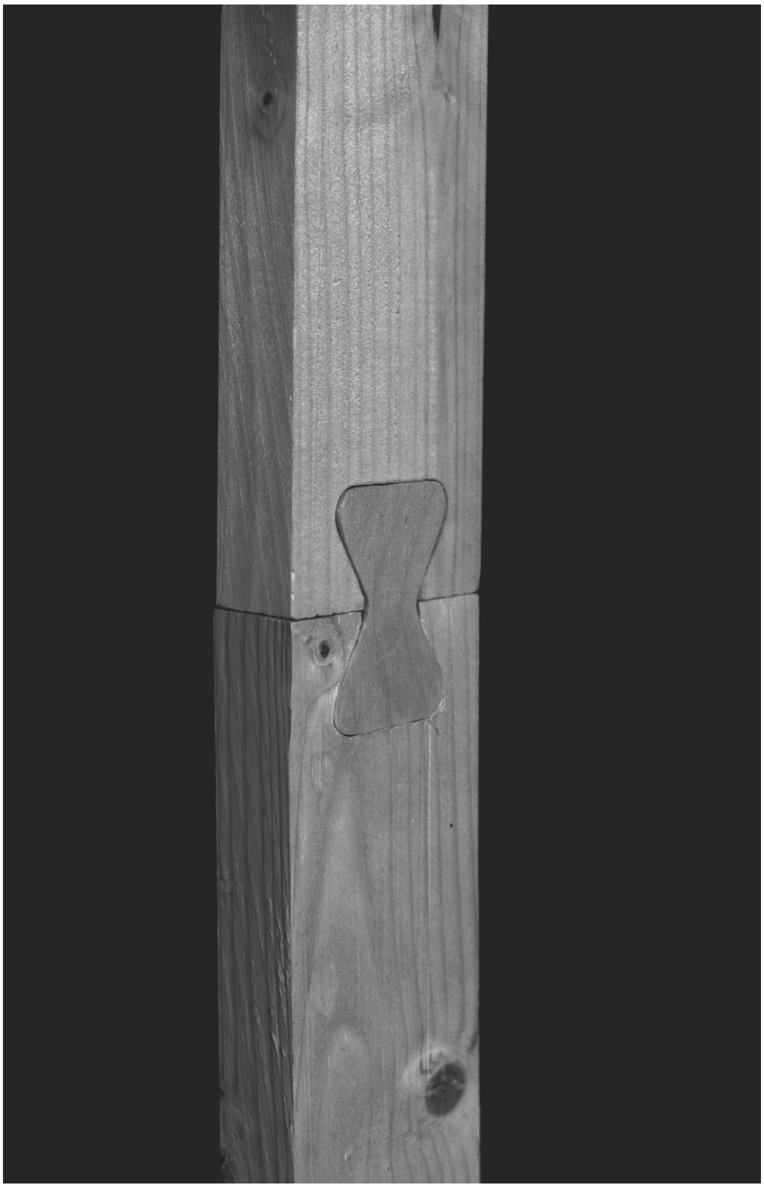
Figure 25. Rotational Joint, personal photo (R.P.)





1. Place the members in position

2. Insert the locking piece



Dove Tail

The dove tail is an common historical joint used for both furniture and construction. The impelementation for the milling machine mainly ment removing the sharp corners, which will lesser the risk of force concentrations and splitting.
In this example the members are in spruce and the locking piece in alder.

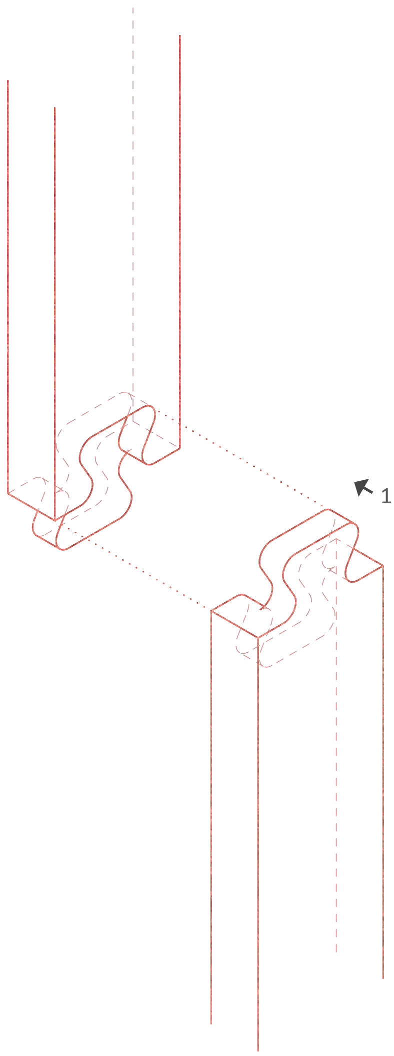
Extension joint

Milling time
2 minutes
Locking method
Geometry, Locking piece
Axis required
3 axis

Movement	↓↑	↕	↗↙	↙↗	↘↖	↖↘
Shear failure	N/A	40%	20%	20%	N/A	N/A
Pressure failure	100%	33%	50%	50%	N/A	N/A

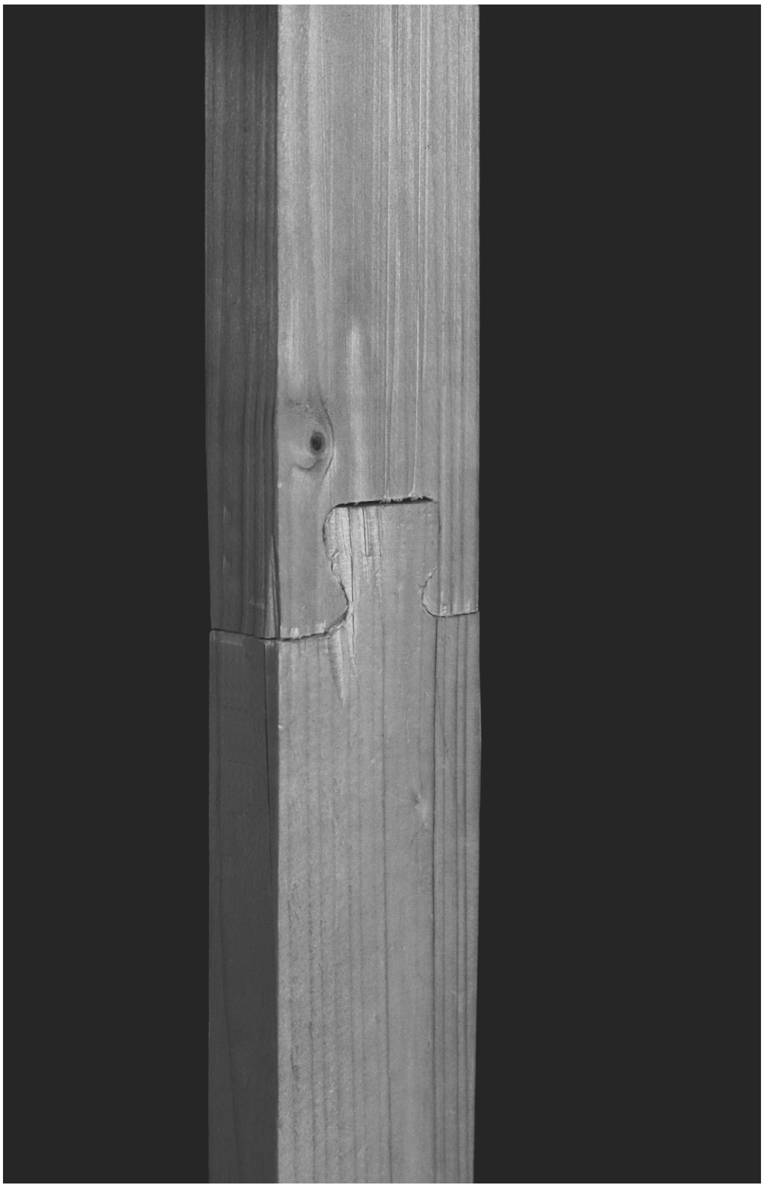
Figure 26. Diagram of dovetail Joint (L.P.)

Figure 27. Dovetail Joint, personal photo (R.P.)



Spruce

1. Place the members in position



Dove Tail Geometry

The geometrical dove tail is much like the dove tail joint but the locking piece is removed. This joint can be viewed as an half scarf joint combined with the dove tail, which was common in Japan. In compari-sion to the dovetail this joint restricts one more movement due to the half scarf.

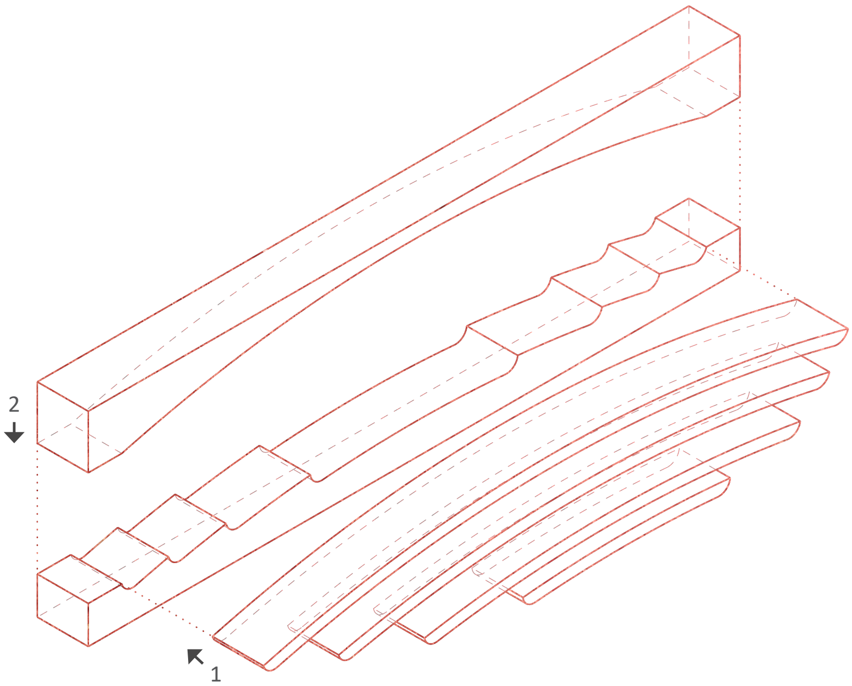
Extension joint

Milling time
3 minutes
Locking method
Geometry
Axis required
3 axis

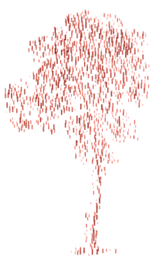
Movement						
Shear failure	N/A	40%	40%	40%	60%	N/A
Pressure failure	100%	20%	50%	50%	50%	N/A

Figure 28. Diagram of g. dovetail Joint (L.P.)

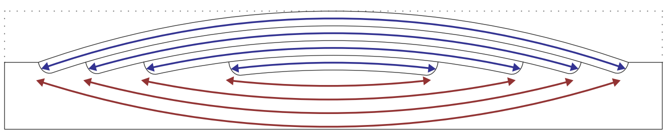
Figure 29. G. dovetail Joint, personal photo (R.P.)



Spruce



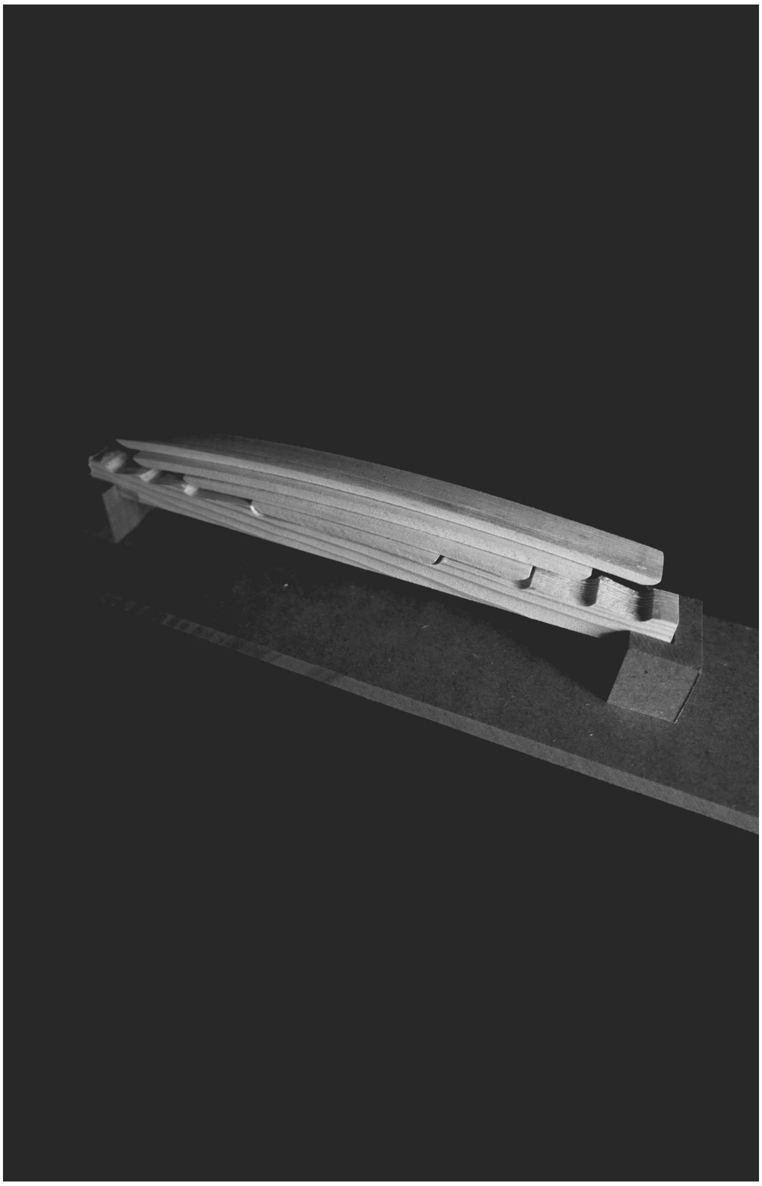
Beech



Structural concept

1. Place the planks in thier given position

2. Place the optional follout form ontop



Bended planks beam

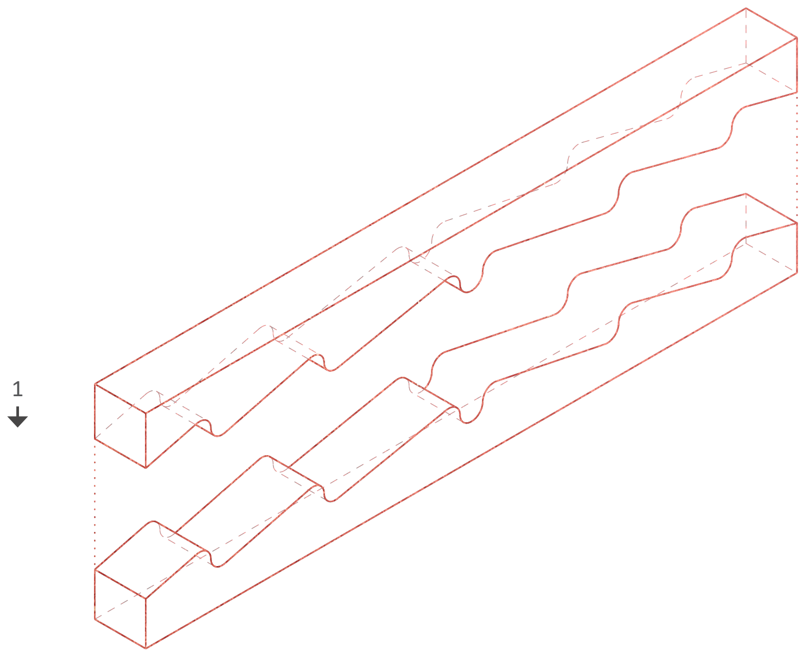
This thesis draws inspiration from Grubenmanns sawshaped beams, where multiple smaller members were joined together, working as one. This is valuable since wood comes in limited size, and smaller elements is less expensive. By bending the planks the fibers in these planks are the same as the pressure force direction when exposed to continuous load. Due to this the beam could achive better structural capabilites than a beam with rectangular cross section. The material selection derives from the hetzer binder, the first glulam beam, which had spruce in the tension zone and beech in the pressure zone due to the species respective structural capabilities. (Samuelsson, 2015, p.148)

Thickness joint

Axis required	Locking method	Milling time
3 axis	Geometry, pre bended	4.5 minutes

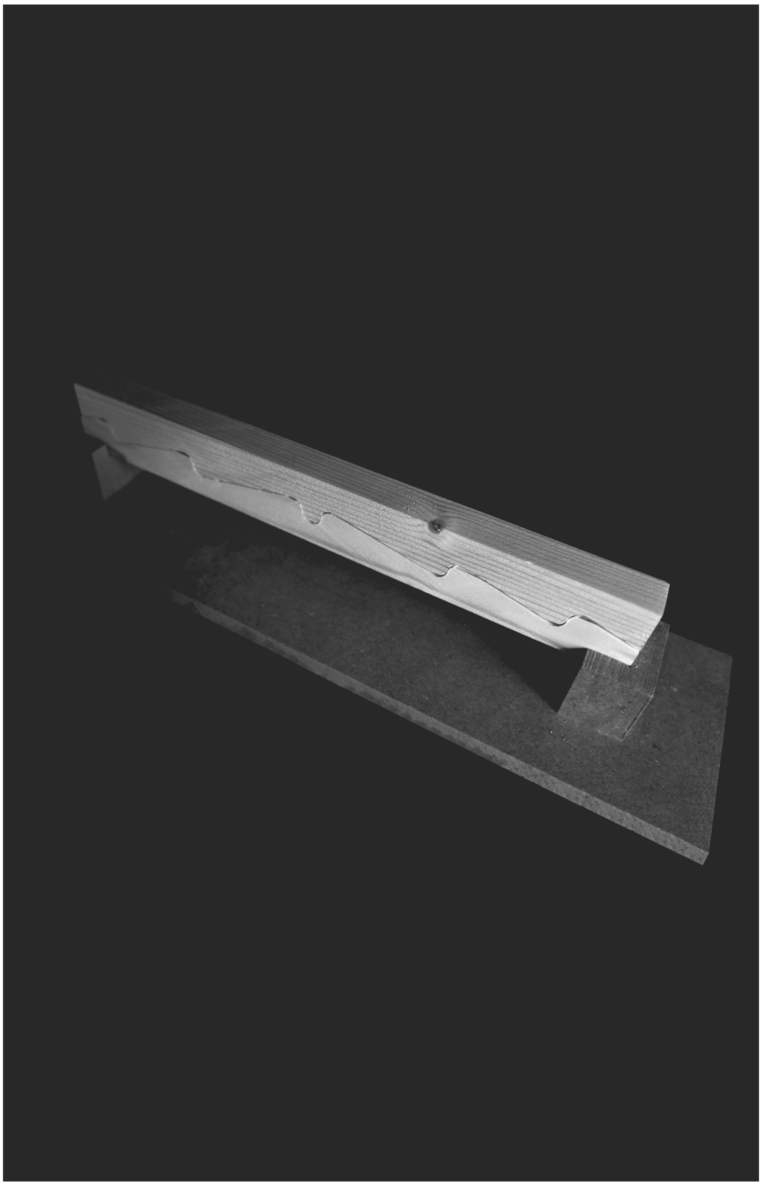
Figure 30. Diagram of b.p. beam (L.P.)

Figure 31. b.p. beam, personal photo (R.P.)



Spruce

1. Place the members in position



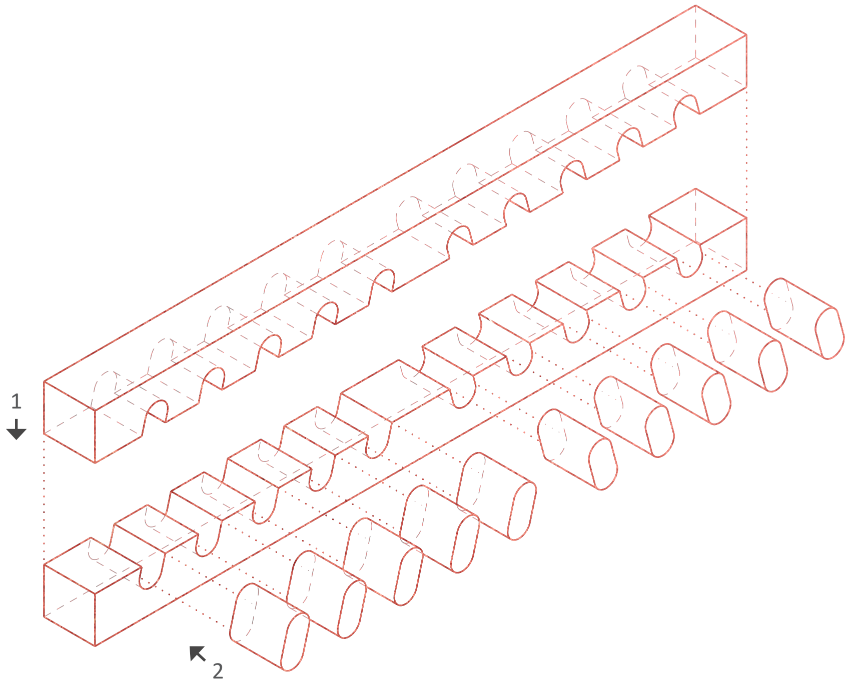
Geometry beam

As the bended planks beam this beam draws is based on the work of grubenmanns bridge. The possibility to construct a beam with higher cross section from smaller cross section is valuable due to the limited size of the cross section of wood. It is also easier to construct with smaller members for small scale building sites.

Thickness joint

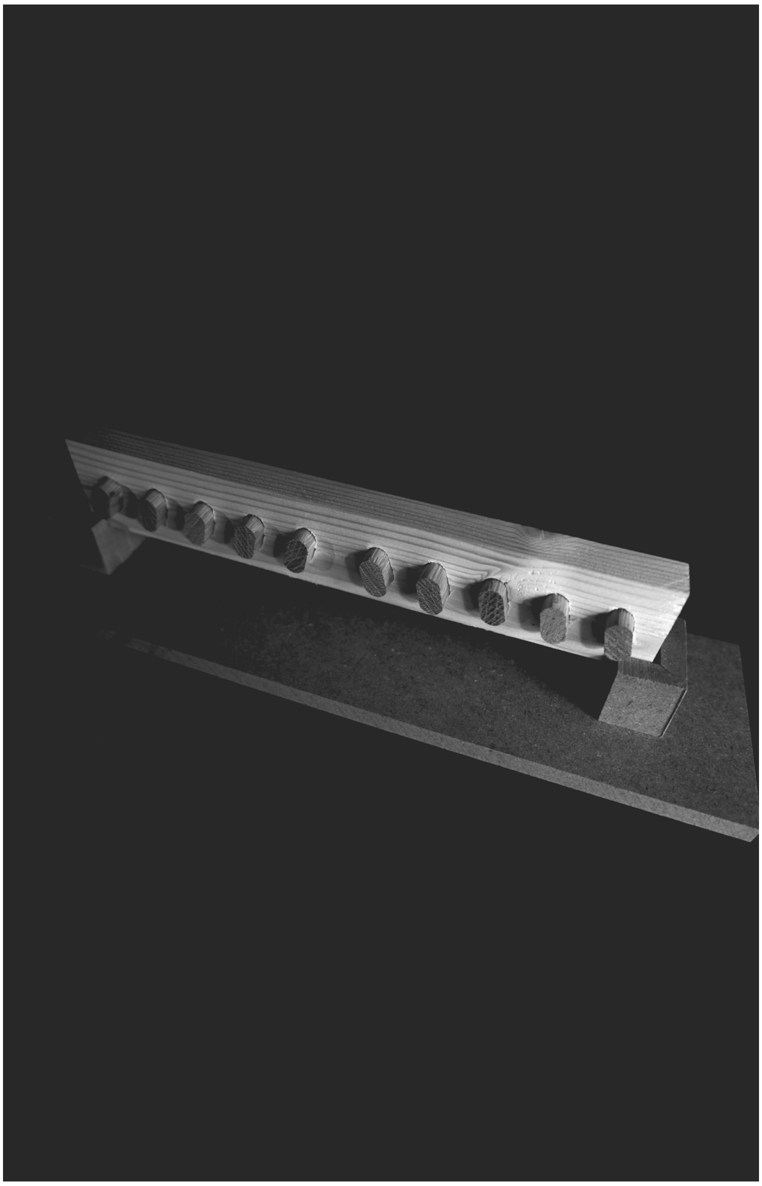
Axis required	Locking method	Milling time
3 axis	Geometry	5.3 minutes

Figure 32. Diagram of geometry beam (L.P.) Figure 33. Geometry beam, personal photo (R.P.)



1. Place the members in position

2. Inser the locking pieces



Locking piece beam

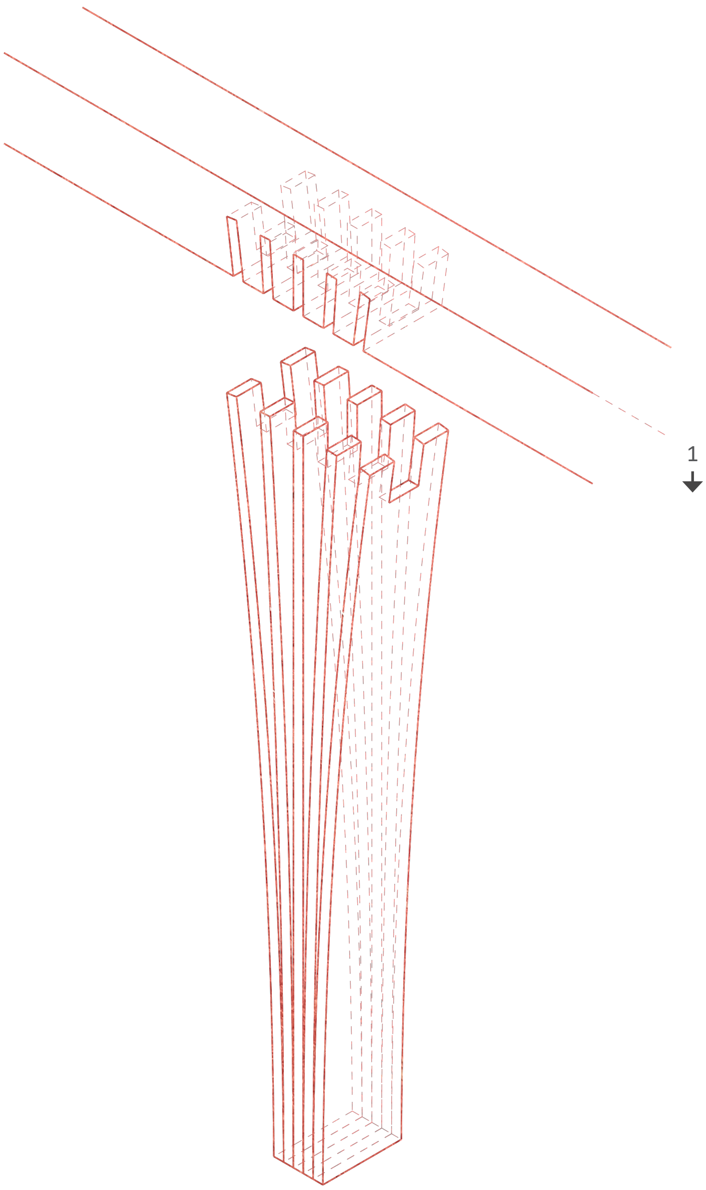
This beams utilizes locking pieces in hard-wood to achive the same as the previous thickness joints. The locking pieces restricts the movement between the members as wells as tells an story of the pressure force direction.

Thickness joint

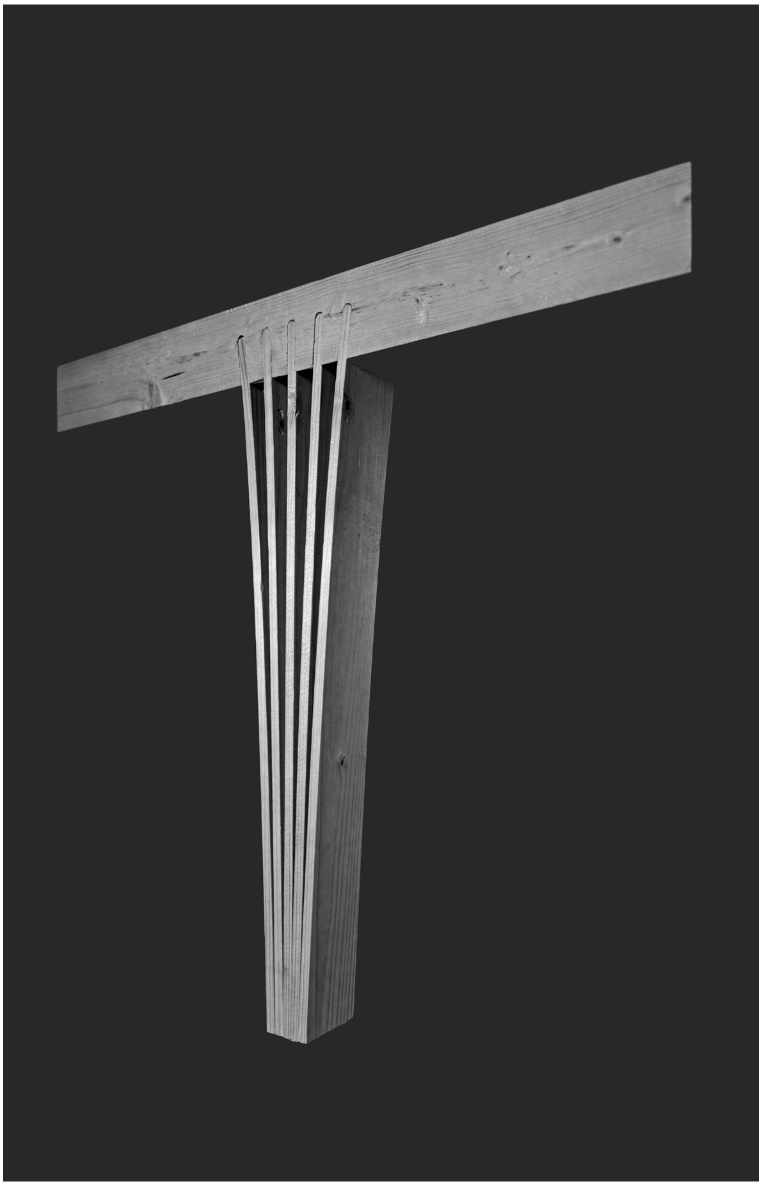
Axis required	Locking method	Milling time
3 axis	Locking piece	6 minutes

Figure 34. Diagram of L.P. beam (L.P.)

Figure 35. L.P. beam, personal photo (R.P.)



1. Bend and insert the plank
beam into its slots.



Spread Joint

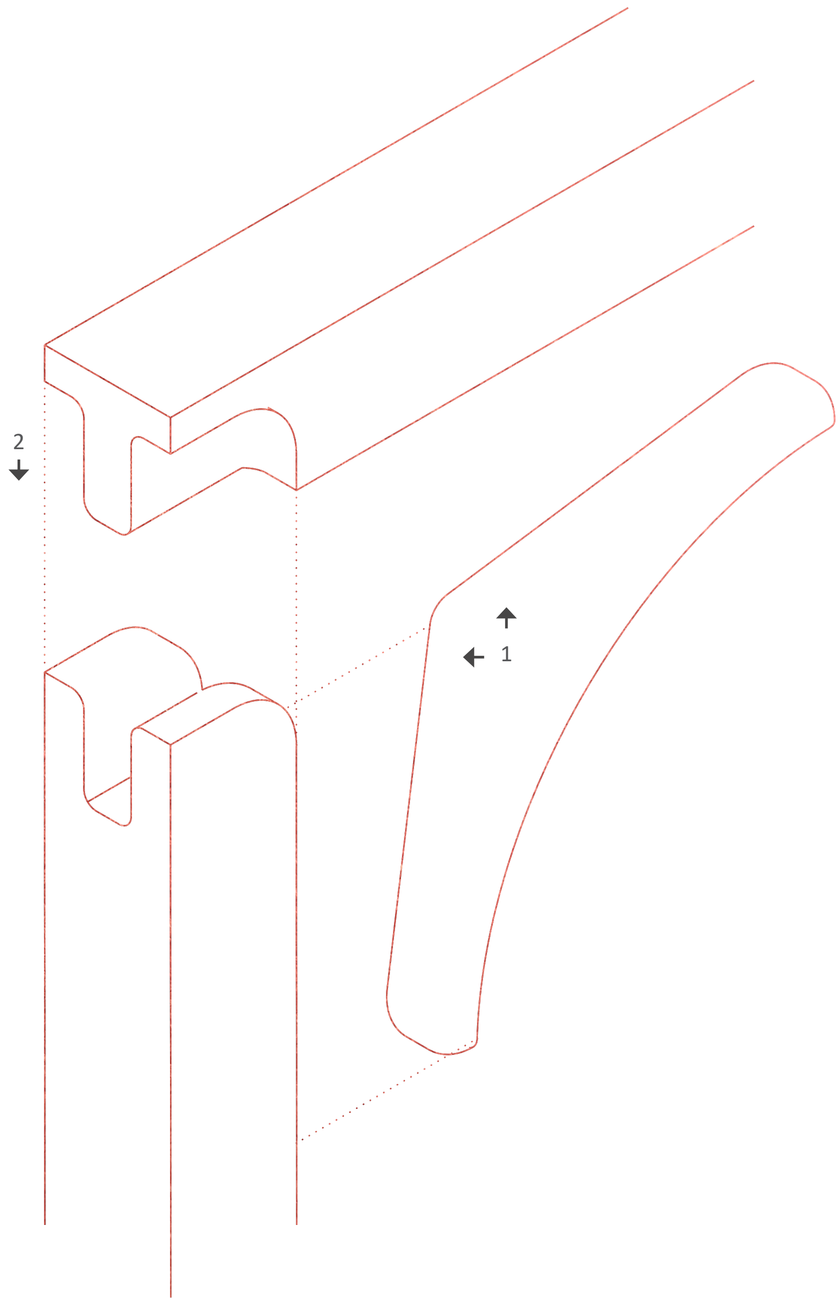
The idea of the spread joint derives from the idea strength by numbers. Although the structural capabilites of the pillar is less relative to a single pillar with the same cross section, the spread out connection to the beam can give an increased pressure failure limit as well as an more rigid connection.

Oblique joint

Axis required	Locking method	Milling time
4 axis	Geometry	3 minutes

Figure 36. Diagram of Spread joint (L.P.)

Figure 37. Spread joint, personal photo (R.P.)



1.Place the secondary rounded corner joint into position.

2. Insert the primary mortise and tenon joint.

Rounded corner

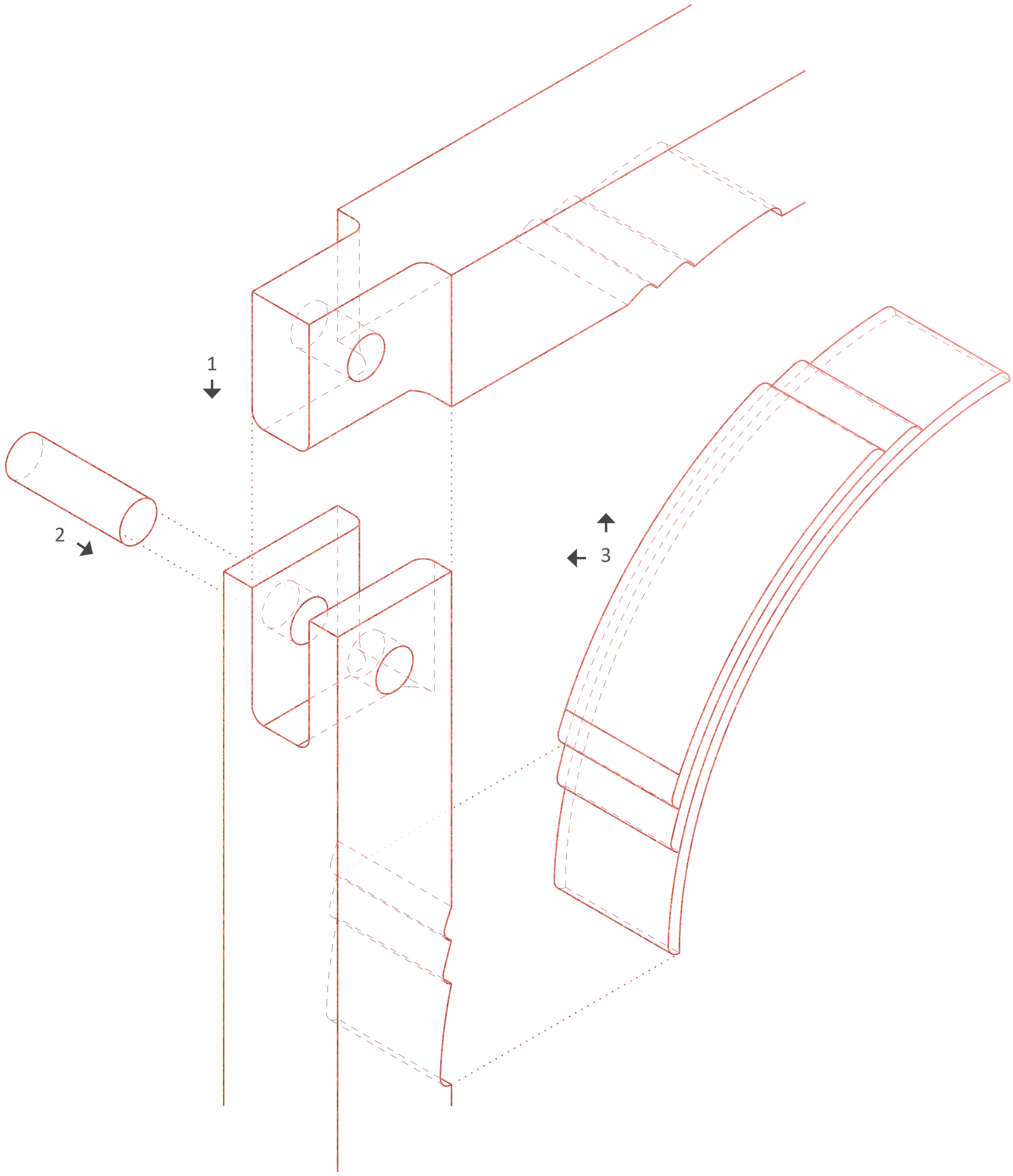
This joint utilizes a primary mortise and tenon beam, with 100% relative shear and pressure failure utilization. In addition it has a secondary rounded corner joint, increasing the shear and pressure capabilities further as well as making the corner more rigid. The secondary joint is based on the rounded corner joints used in the scandinavian stave churches.

Oblique joint

Axis required	Locking method	Milling time
3 axis	Geometry, Locking piece, pre bended	17 minutes

Figure 38. Diagram of R.C. joint (L.P.)

Figure 39. R.C. joint, personal photo (R.P.)



1. Insert the primary mortise and tenon joint.

2.Insert the secondary dowel joint

3.bend the secondary planks into their given position.

Pre bended corner

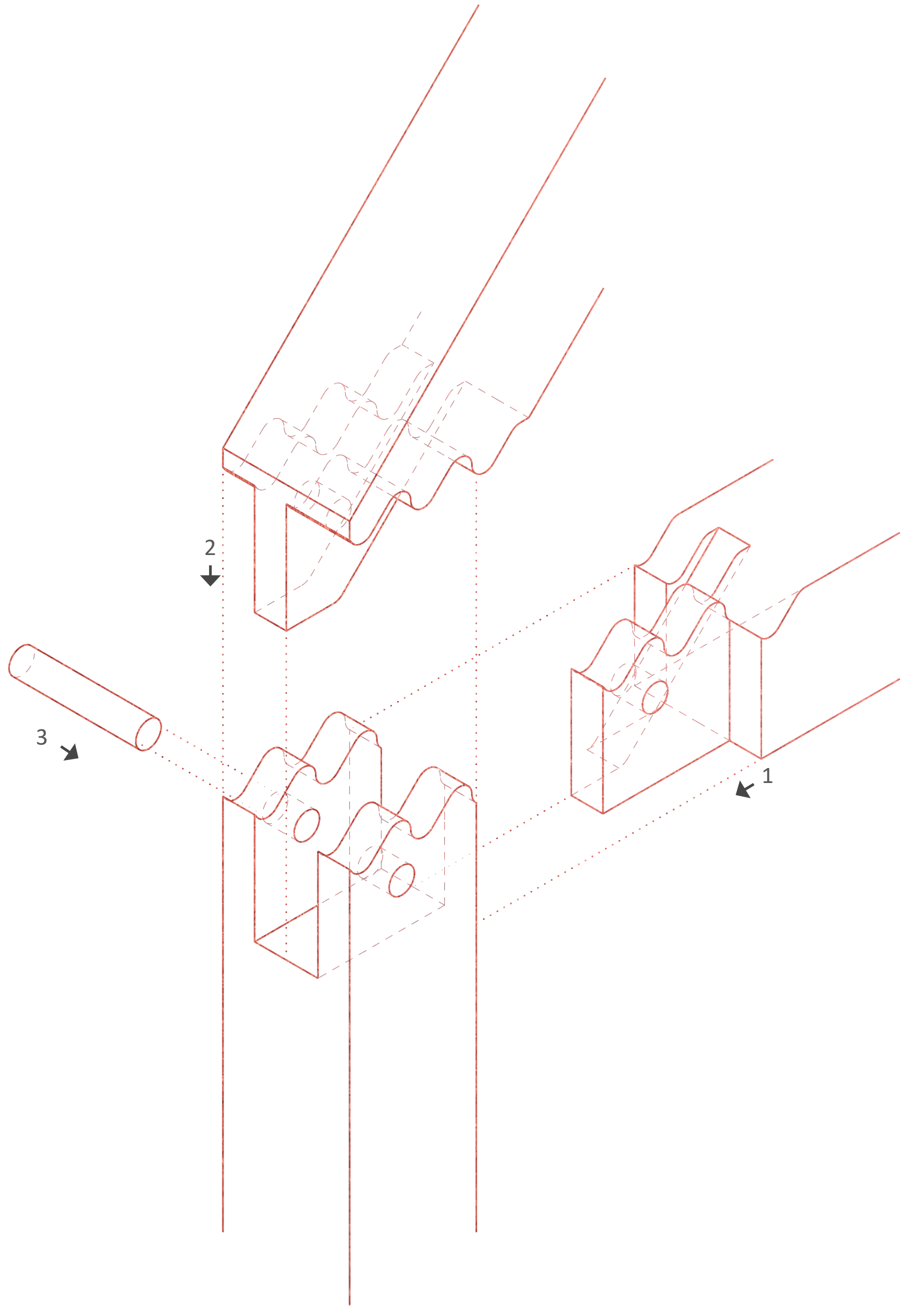
This connection is made from an primary mortise and tenon joint, where the pillar has the posibility of beeing continuous. The secondary bended planks give the connection an more rigid corner as well as increases the load bearing capabilities. The bended planks visually connects the pillar and beam without any kink, framing the room.

Oblique joint

Axis required	Locking method	Milling time
3 axis	Geometry, Locking piece, pre bended	15 minutes

Figure 40. Diagram of P.B. joint (L.P.)

Figure 41. P.B. joint, personal photo (R.P.)



1. Insert the primary horizontal mortise and tenon joint.

2.Insert the primary 45° angled mortise and tenon joint.

3.Lock the structure with the secondary dowel joint.

Three members

This corner connection connects three members, through two primary mortise and tenon joints and a secondary dowel joint giving the corner rigidity. As we see the tenons gets smaller when multiple members are used in the same joints, decreasing the structural capabilities. The 45° angeled beam also has a secondary waved surface, preventing horizontal movement.

Oblique joint

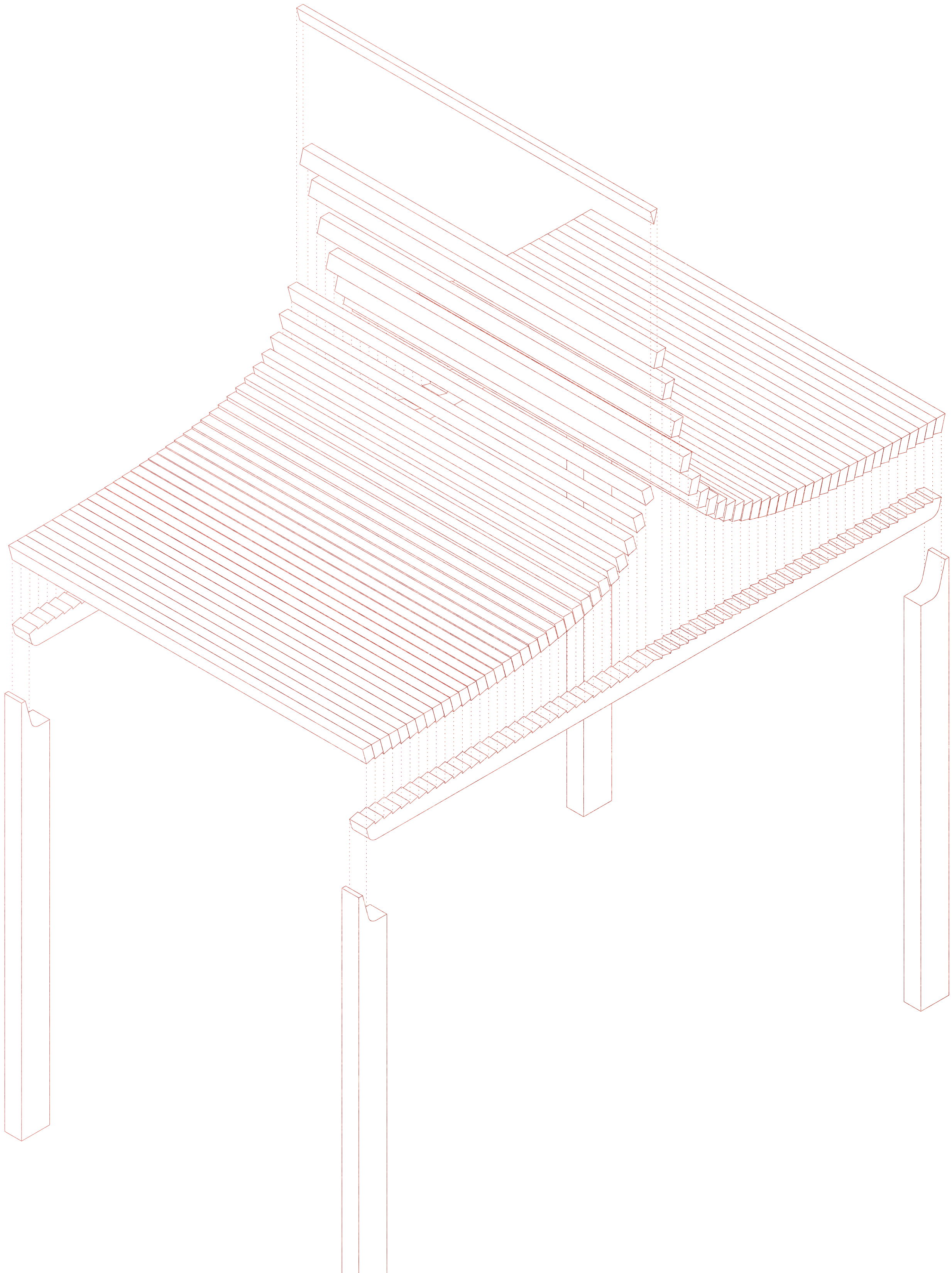
Axis required	Locking method	Milling time
4 axis	Geometry	27 minutes

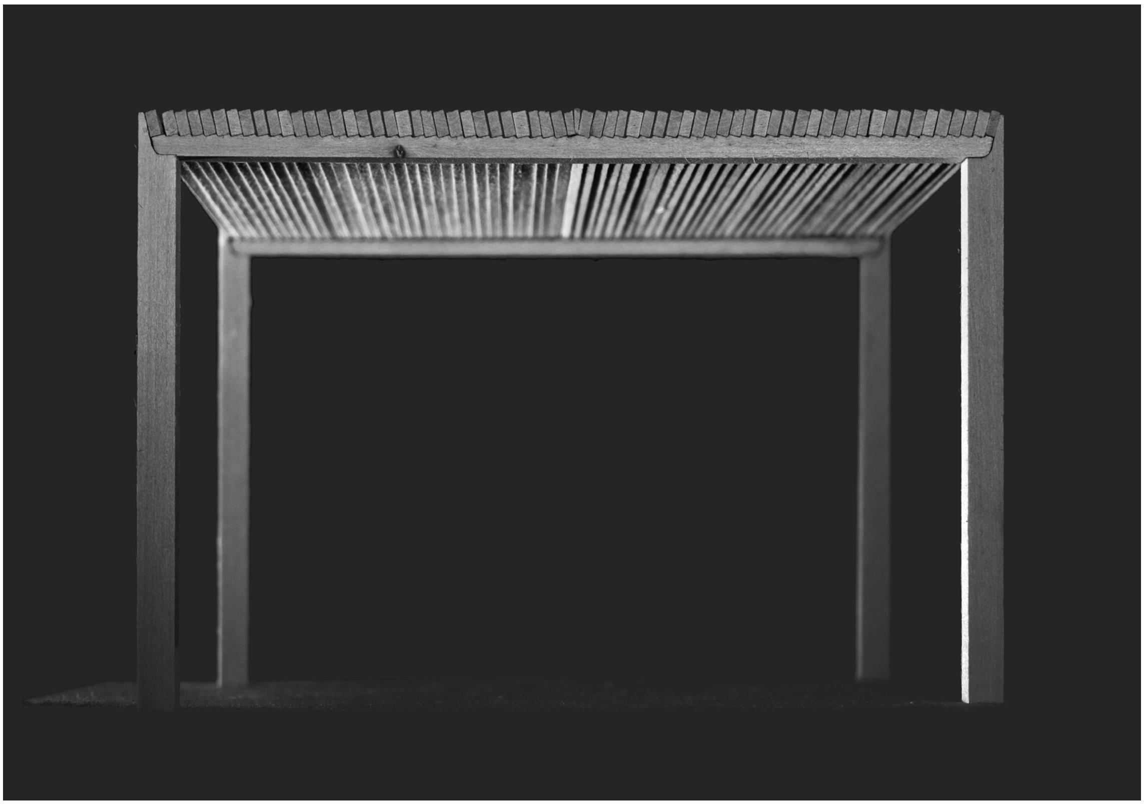
Figure 42. Diagram of T.M. joint (L.P.)

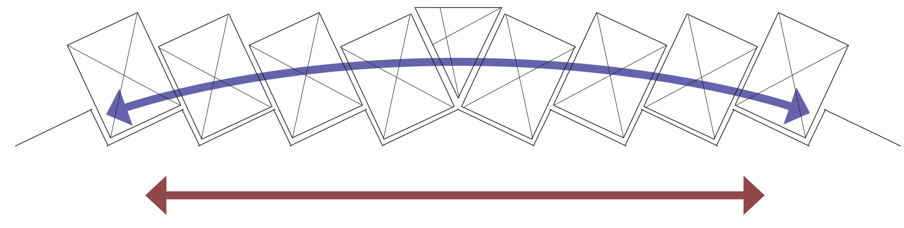
Figure 43. T.M. joint, personal photo (R.P.)

Applications

Chapter Three







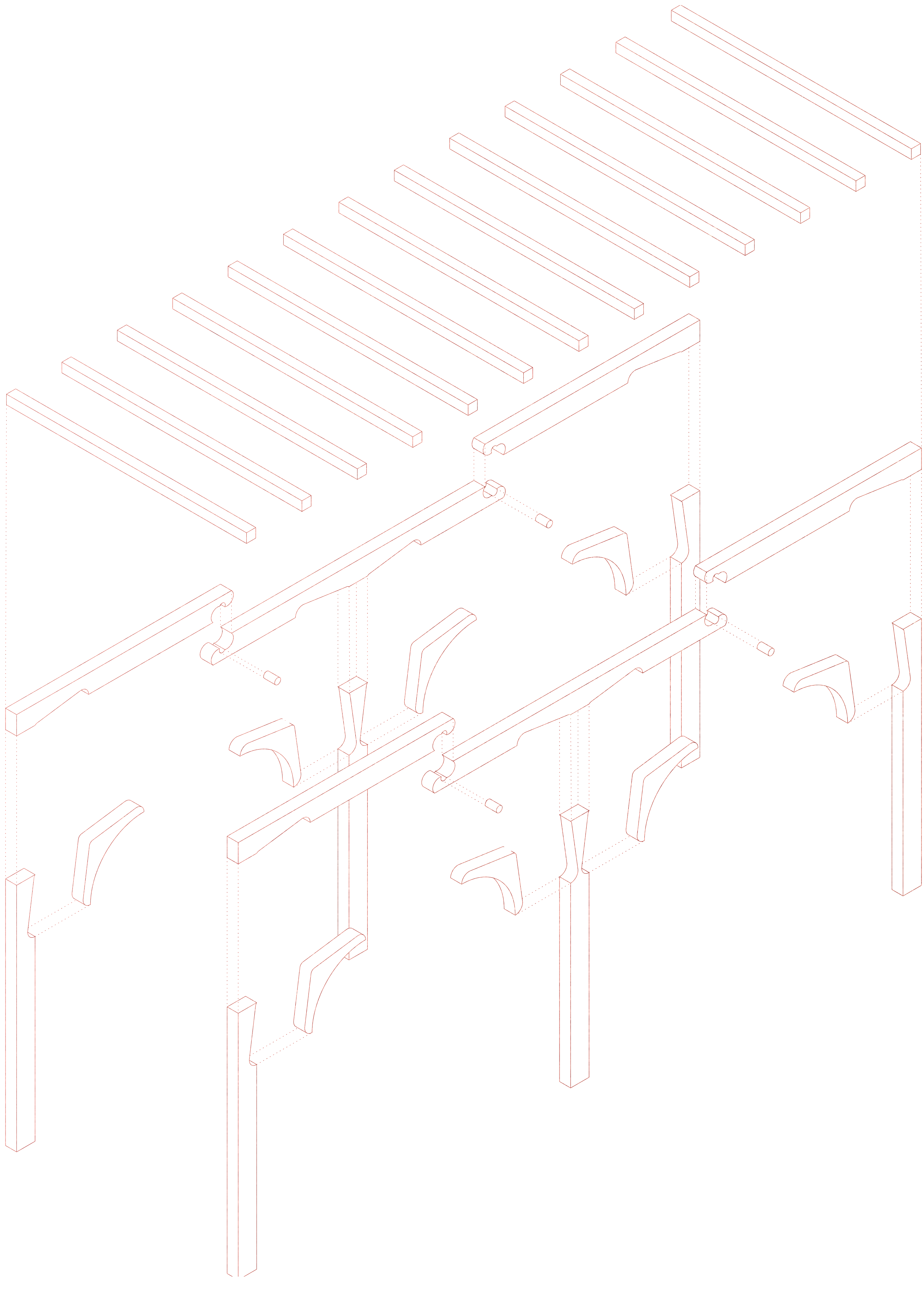
Structural concept

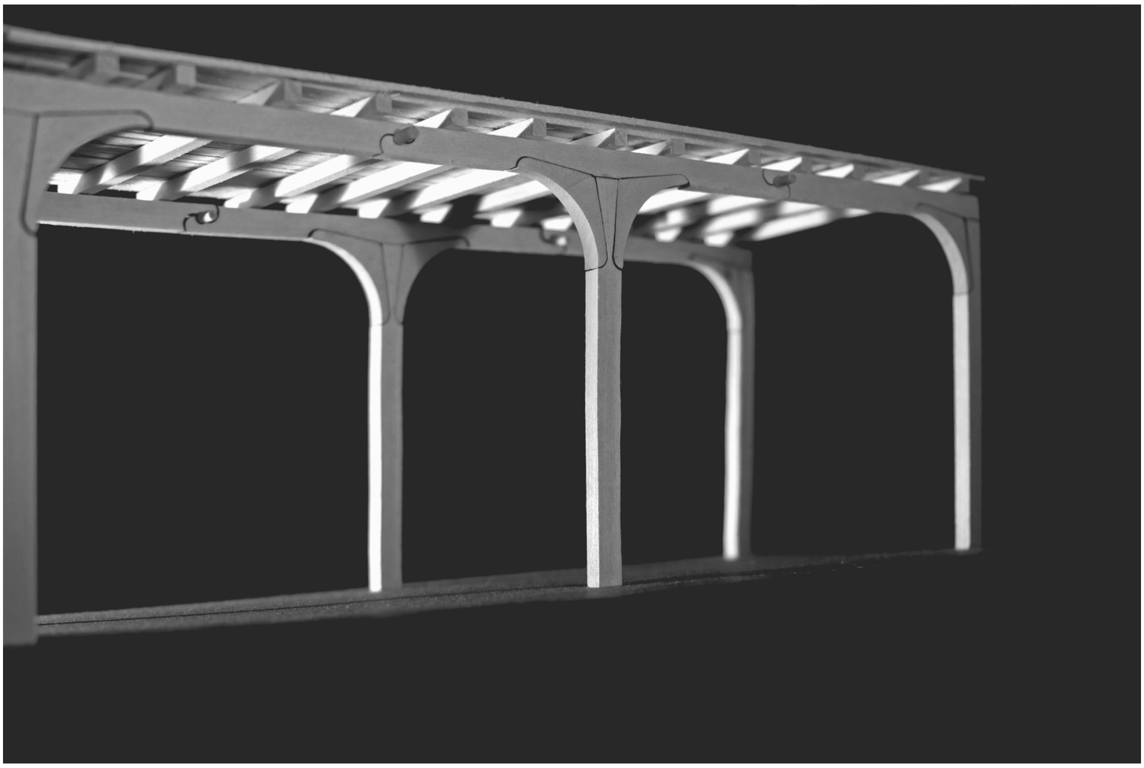
Sawtooth roof

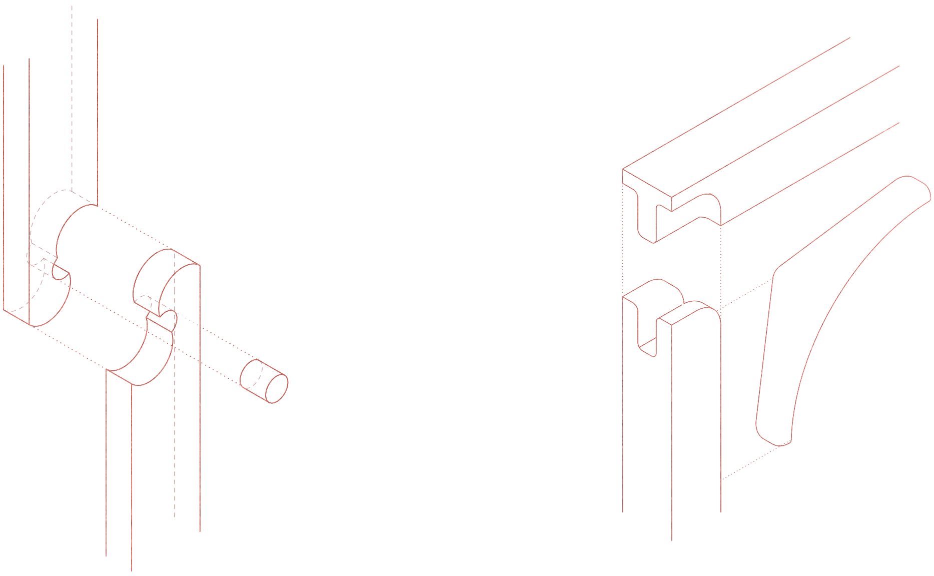
The sawtooth roof conceptually uses the entire slab as a beam, where the floor-planks work in pressure and the visual beam works in tension, although it might be exposed to local structural failures due to the planks utalization perpendicular to the fibers. Visually the slab underneath gets an very interesting texture which is mirrored at the centre of the beam, where one of the sides planks catches the light and the other looks more smooth.

Figure 44. Exp. iso. of Sawtooth roof (L.P.)

Figure 45. Sawtooth roof, personal photo (R.P.)





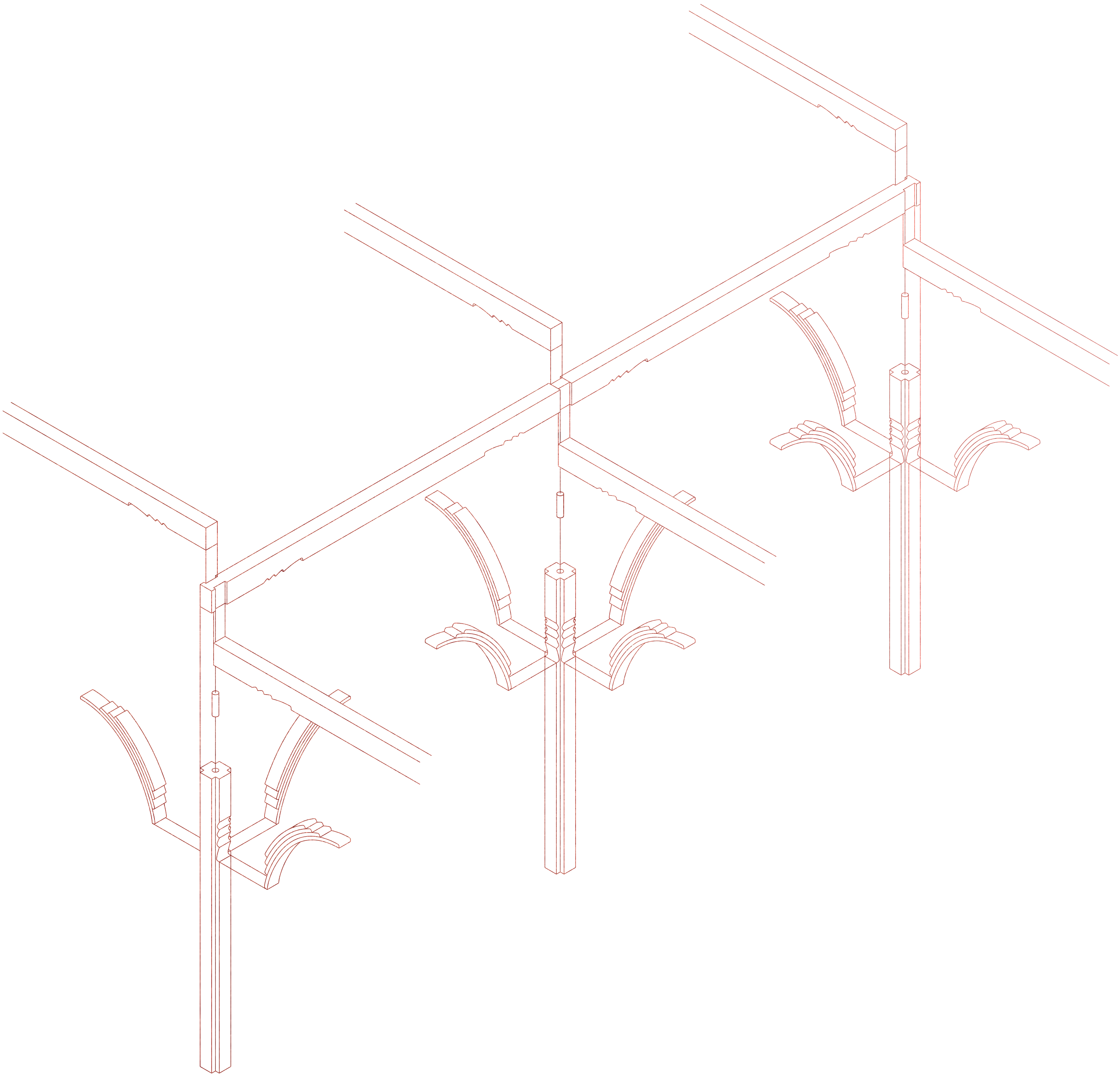


Krusidull structure

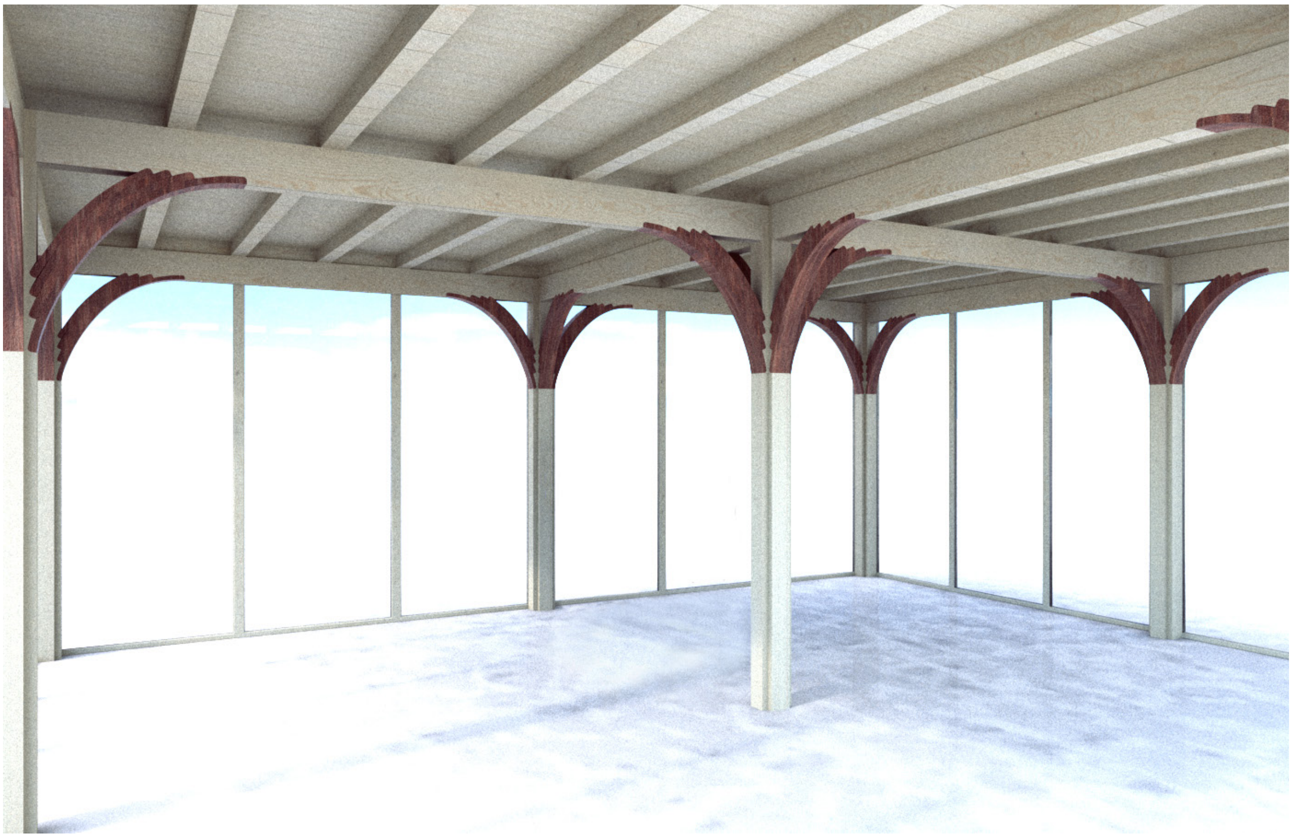
In this structure the yin yang joint is utilized to join the continuous beam together, where the structural utilization of the beam is low. The rounded corner is used in the pillar beam meetings, giving the corners rigidity. The connections are all clearly visible and expressed in the structure.

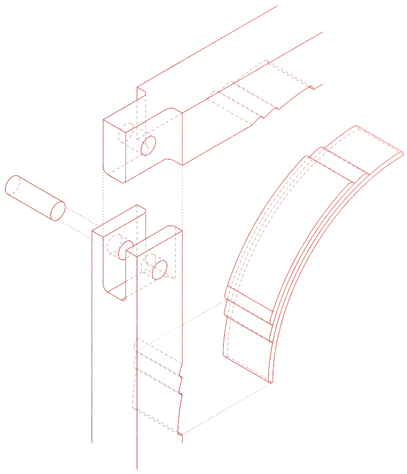
Figure46. Exp. iso. of Krusidull structure (L.P.)

Figure47. K. structure, personal photo (R.P.)



Exploded isometric axo of load
bearing structure





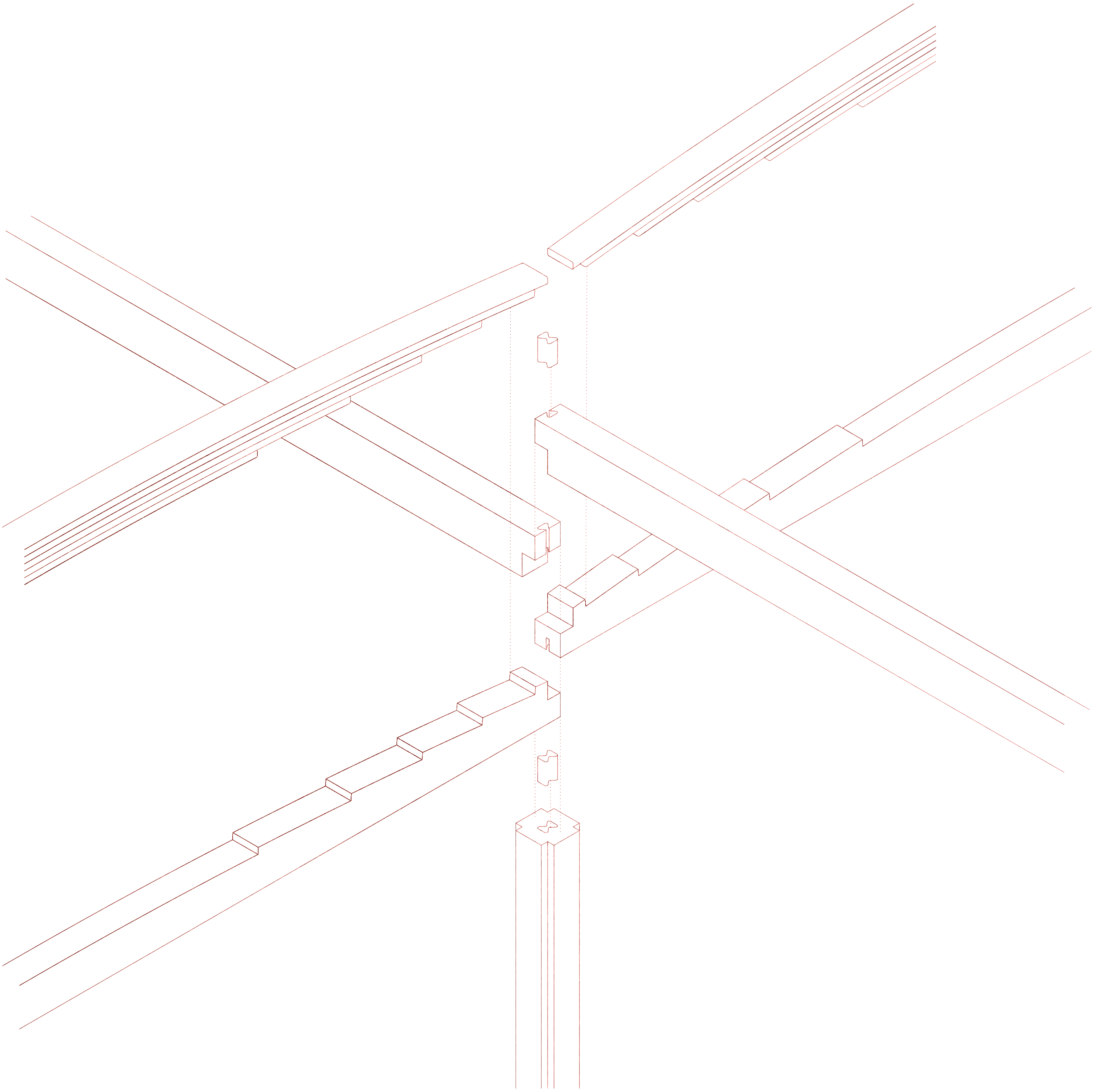
bended planks corner

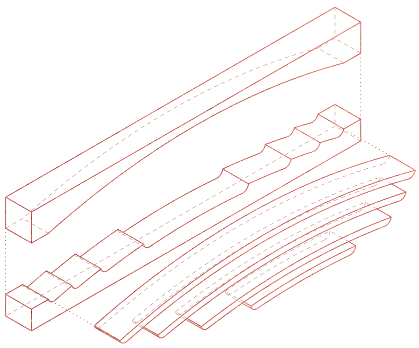
Bended planks

The bended planks joint is in this scenario is utilized in an dual direction pillar beam system. The ambition in this exploration is show the connection in an more public atmosphere where the connections are accentuated.

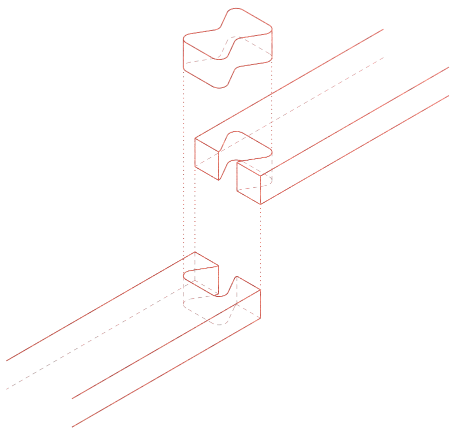
Figure48. Exp. iso. of bended planks (L.P.)

Figure49. B.P. structure, personal photo (R.P.)





Arch beam



Dove tail connection is
used between beams

Arch roof

This is anexample of an large scale implementation where the arch beam is utilized in an large span structure. The planks are accentuated in an darker colour. The connection quickly gets more complex with higher number of members.

Figure50. Exp. iso. of central column of A.R (L.P.) Figure51. B.P. structure, personal photo (R.P.)

Reflection

Discussion

Summary

This projected aimed to answer the relevance ond posibility of the milled answer of the handcrafted wooden joint. This through research, structural, manufacturing, material and design material investigations.

The general critique to the wooden joint is the fabrication cost and its weekness in comparision with steel and adhesive solutions. The milledcrafted joint mitigate the fabrication cost but the structural capabilities remains. Where this thesis has found the relevance of the joints is suitable for less structural intensive connections.

The result of the design interations is rooms with structural clarity where the structure and connection is clearly a part of the whole and very present in the rooms. Where my belif is that architecture with the precision, design and quality of these joints will give structural ensurance and an sense of care to its residers.

This thesis has found that the milledcrafted reinterpreted handcrafted joint is possible and relevant for contemporary architecture, although with some structural restrictions.

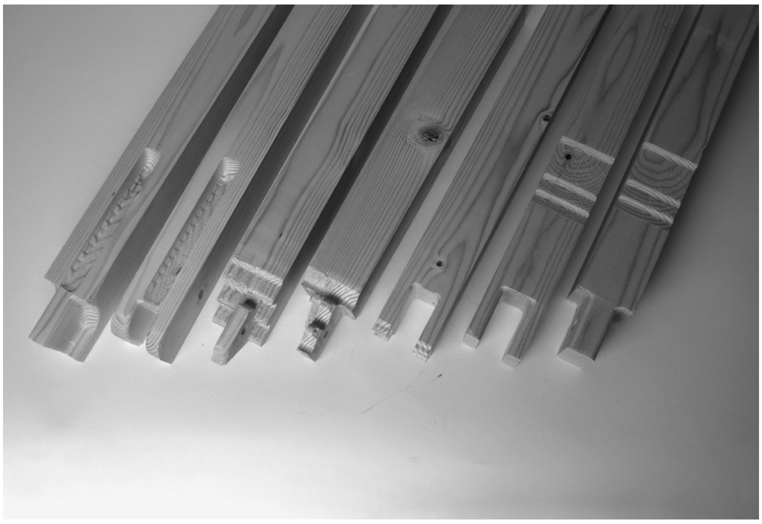
Reflection

This research is very much the tip of the iceberg in terms of design, implementation and structural evaluation with the milledcrafted joint. Where I feel the improvements and posibilites is vast. The joints presented in this thesis can all be iterated further and improved.

To continue on this work intresting topics would be further developed structural evaluation of the joints and investigation of the implementation of an system suitable for todays building industry, from the fabrication to the construction.

Bibliography

References



Litterature

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Robert Jockwer, Assistant Professor in Structural Engineering at Chalmers university of technology, personal communication, May 08, 2020
Geir Söderin, Structural engineer at Modvion, personal communication, May 08, 2020

Images

Figure 4. Diagram of cross section (L.P.)	- Inspirated by diagram in Timber Construction manual
Figure 5. Diagram of structures (L.P.)	- Information from Timber construction manual
Figure 7. Diagram of share and quanaties (L.P.)	- Information from skogsstatistik.slu.se
Figure 8. Timber floatiing, Björn Svensson (R.P.)	- Image by Björn Svensson

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