LaserJamming: Controlling the curve of laser cut lattice patterns

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ABSTRACT

Rapid prototyping often comes with drawbacks in fidelity, a laser cutter is very fast but limited in fabricable shapes. LaserJamming offers an approach to increase the integration of curves in the laser cutter production environment. This is achieved by laser cutting lattice hinges and displacing these hinges with wedges, which forces an angle at each wedge insertion point. Creating a polyline curve. These curves are self-contained glue-less and require no mold or specialized machinery to assemble. To make the process streamlined a digital design editor supported by a regression model is created in congestion with a streamlined assembly workflow. We believe that this method can contribute to the design opportunities of laser cut production and can increase the fidelity of parts while maintaining the speed of production.

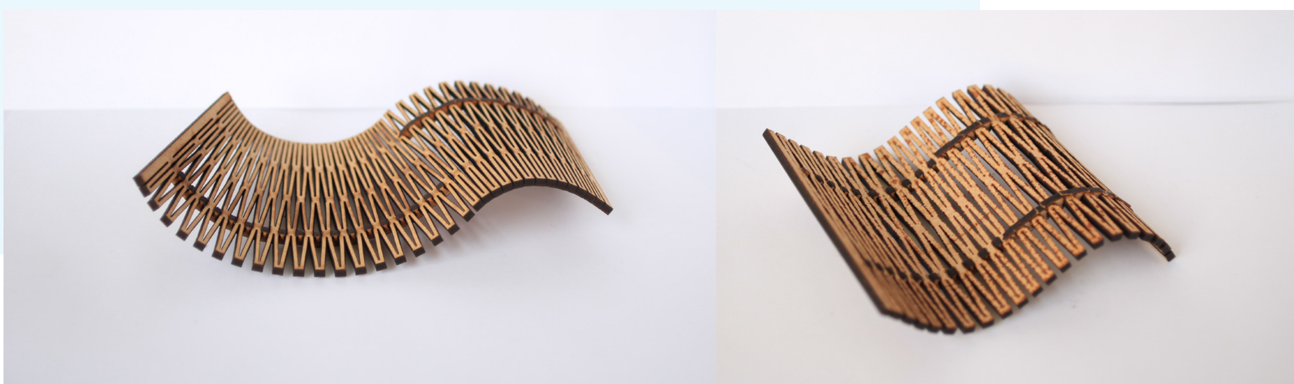


Figure 1, LaserJamming, self containing laser cut curves

PROLOGUE

I am a designer who really likes to investigate the core mechanics behind production and realization, researching through making is the approach I truly enjoy. For my masters I am considering the Industrial Design CDR track (Constructive Design Research).

During my bachelors there were two main projects which sparked my passion for design and more specifically research through design. These two projects were my B2.1 and Internship, the first was a project in the Crafting Everyday Soft Things squad and resulted in a publication of FabriClick (Goudswaard et al., 2020). The second was my internship at Signify 3D printing, where I researched Multi-Material printing.

These two projects motivated the choice for my final bachelor project. In both projects I had adopted a research through design approach and by making gained a lot of knowledge about the subject I had been working on. Both these projects were however not very guided by literature and expertise. The FabriClick publication was more of an afterthought instead of a true research integration into the process.

This motivated me to run a project more structured and close to what an academic project would be. I wanted to collaborate with external researchers and work with a technique I had no extensive experience or knowledge about. This motivated the choice for laser cutting and the Crafting Everyday Soft Things squad with Rong-Hao as coach, we collaborated for the FabriClick submission which was very pleasant. However I knew he would push me to continue working until we find something new. And as a very experienced researcher in the field he'd be able to highlight pitfalls of research design approach.

One of my main goals was to aim for a publication, and together with the external researchers I will pursue this after my graduation. This report is partly written in this narrative, however some process content was added. This report will form a basis of the submission and will be rewritten.

INTRODUCTION

Bending wood is a technique used a lot in the fabrication and design community, and there are ample techniques to do so. More recently with digital manufacturing laser-cut wood is something which is very often applied. These bending techniques however almost always need an external mold or fixture to keep the curve in place and this can often lead to a very time-intensive and expensive approach. (Peck & U.S. Forest Service, 2006)

With new digital manufacturing approaches the time from concept to prototype has been drastically improved, especially with the common availability of 3D printers. The laser Cutter being even faster it does however come with limitations in shape, as it consist of 2D sheets of material.

LaserJamming offers increased shape options with laser cut wood by enabling curvature of these 2D sheets. By jamming wedges between laser cut lattice hinges, the lattice pattern can be forced into an angle, which creates a self-locking, self-contained and flexible curve

To facilitate design with LaserJamming a parametric design editor has been created in GrassHopper. In order to create reliable results a large sample test has been executed and a regression model forms the base of angle prediction in the design software. This allows LaserJamming to create curvature without the necessity of a mould, glue, or time intensive 3D printing.

LaserJamming also provides an optimized workflow by placing the wedges on a strip, and adopts a pre-stretch approach for easy insertion of the pins.

The contribution of LaserJamming Is threefold;

- It proposes a new concept of jamming, where curves can be made from lasercut lattice hinges
- It supports designers with a design tool
- It provides a workflow of assembly.

RELATED WORKS

Bending wood
Bending wood is a technique which is done for hundreds of years, to bend wood often steam is introduced and the wood is then forced in position and dried. It is a very skillful and time-consuming process where breakage is not rare. Moreover it requires specialized equipment such as presses and molds to make the force the wood into shape (Peck & U.S. Forest Service, 2006). Utilising expansion of wood when absorbing moisture has been used to create bimetal like behavior. Where multiple layers of wood are glued and exposed to moisture, forcing the material to bend (Abdelmohsen et al., 2019)

Also mechanical solutions to bending wood is also not new, kerf bending either with a saw or with a milling machine has been used for multicurve bending of wood, and is associated with applications in furniture and architecture (Capone & Lanzara, 2019). Kerf cutting lattice hinges with a laser cutter is widely accepted in the maker community for making wood bend (Benchoff, 2017).

Rapid prototyping and speed
As 3D printers are often quite slow, printing medium size objects overnight limits the iterations that can be done. Researchers have identified this issues and resorted to compromises in fidelity and speed. Low-fidelity fabrication can be drawn to substitute materials such as legos (Mueller et al., 2014), or 3D printed faster by printing less material (Mueller, Im, et al., 2014) or modular (Sun et al., 2021). Another approach is substituting parts of the prototype by laser-cut parts, as the laser cutter is a 2D plotter it is quite a bit faster in building larger 3D shapes. Platener provides a time-scale where you can select between speed and fidelity where laser-cut parts, where when increasing speed more and more is laser-cut (Beyer et al., 2015).

Enhancing laser cutter capability
Research into increased mechanical capability by stacking has resulted in sophisticated mechanisms which can increase the mechanical fidelity, which however does take time in the machine (Leen et al., 2020; Umapathi et al., 2015). Automated assembly by selectively melting has led to increased speed in laser cutter prototyping (Mueller et al., 2013). And in Laser factory a complete assembly robot attached to the print head is implemented to allow electronic assembly within the laser cutter (Nisser et al., 2021).

Digital enhancements
For most previously mentioned works, the implementation is highly technical and the time-saving with increased functionality would be completely mitigated by the increase design considerations and thus time. Which is the reason that a design plugin is necessary to reap the benefits of these techniques, these plugins are often made in GrassHopper and provide guiding in designing and made all the complex calculations in the backend (Mueller et al., 2014; Mueller, Im, et al., 2014; Sun et al., 2021; Beyer et al., 2015; Leen et al., 2020; Umapathi et al., 2015).

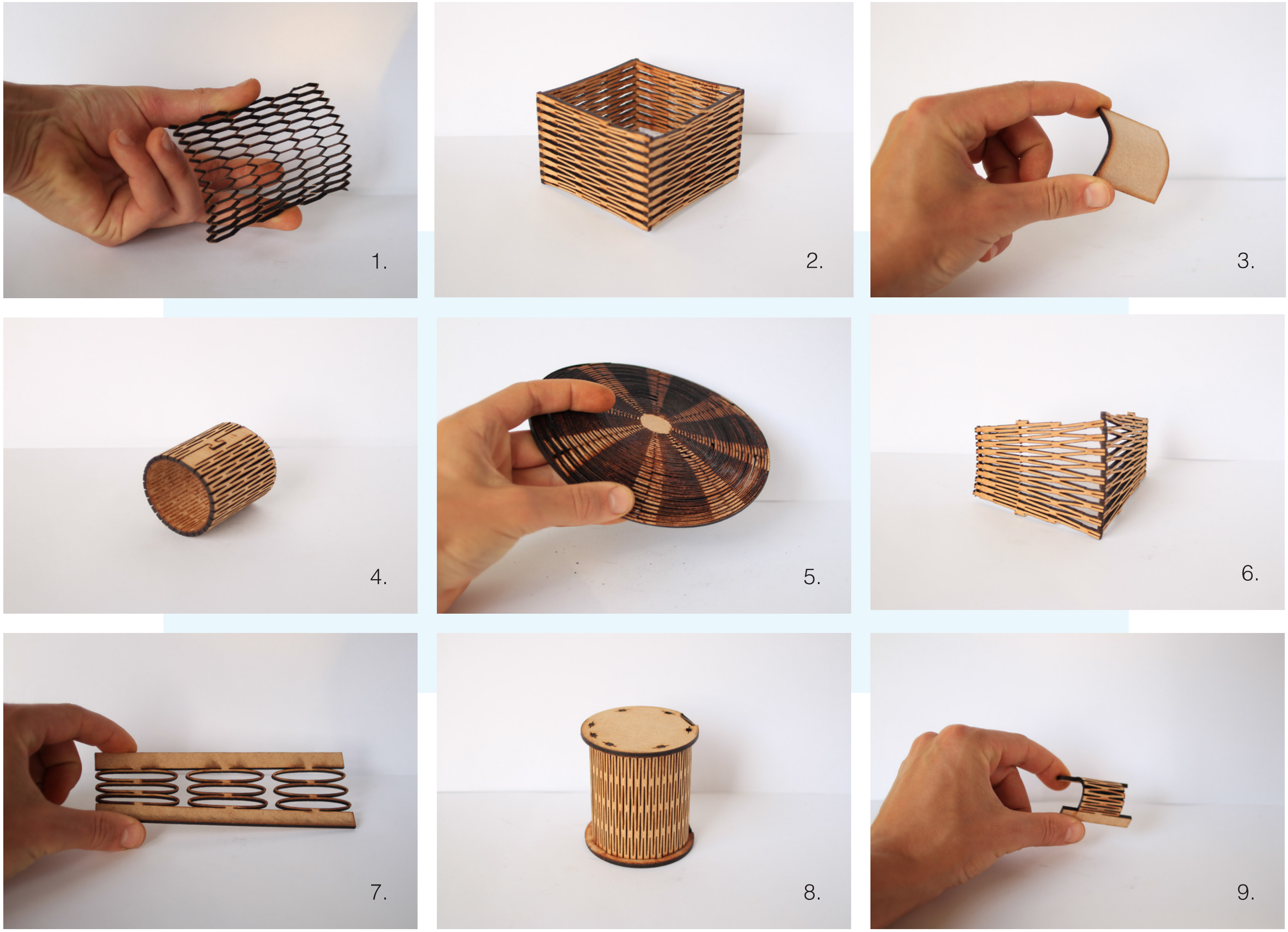


Figure 2, 1 Lattice pattern exploring minimal thickness, 2 Jammed box structure, 3 Invsible kerf, 4 small connection between two edges, 5 lattice disk, 6 Jammed double curve corner, 7 spring sample, 8 single plate assembly, 9 lattice pattern exploration

THE PATTERN

Initial explorations
Lattice hinges
In the first phase of the project a lot of ideation and exploration was executed to find a heading for the project. This started with ideas and was developed into a few different concepts. This initial phase focused on getting familiar with the design space, reading in on related works and involving external experts in the process. For the first meeting a poster was made that outlined the main interests and formed the base of further conversation (appendix 2).

Different additional techniques were used to speed up the process with limited access to laser cutters, such as sketching as well as physical modelling with cardboard and paper (appendix 2).

After gaining access to a cutter immediately the prototyping began, and initial explorations were in the following directions:

- one panel assembly using lattice hinges and multilayer panels (fig 2)
- Optimizing curve integration of corners (fig 3)
- And the third our of invisible kerf cut curvature (fig 3)

From these three explorations were made and in an informal conversation with the external experts the exploration continued, which turned into shape optimization, of bending and cornering (fig 3). However during the explorations it often came down to the limitation of the patterns, and that corners always had to be equipped with some kind of joinery to keep the parts in place. The conclusion was that controlling the a curve without external fixture would be very interesting. Eventually this led to the first iterations of LaserJamming which will be highlighted in the next paragraphs.

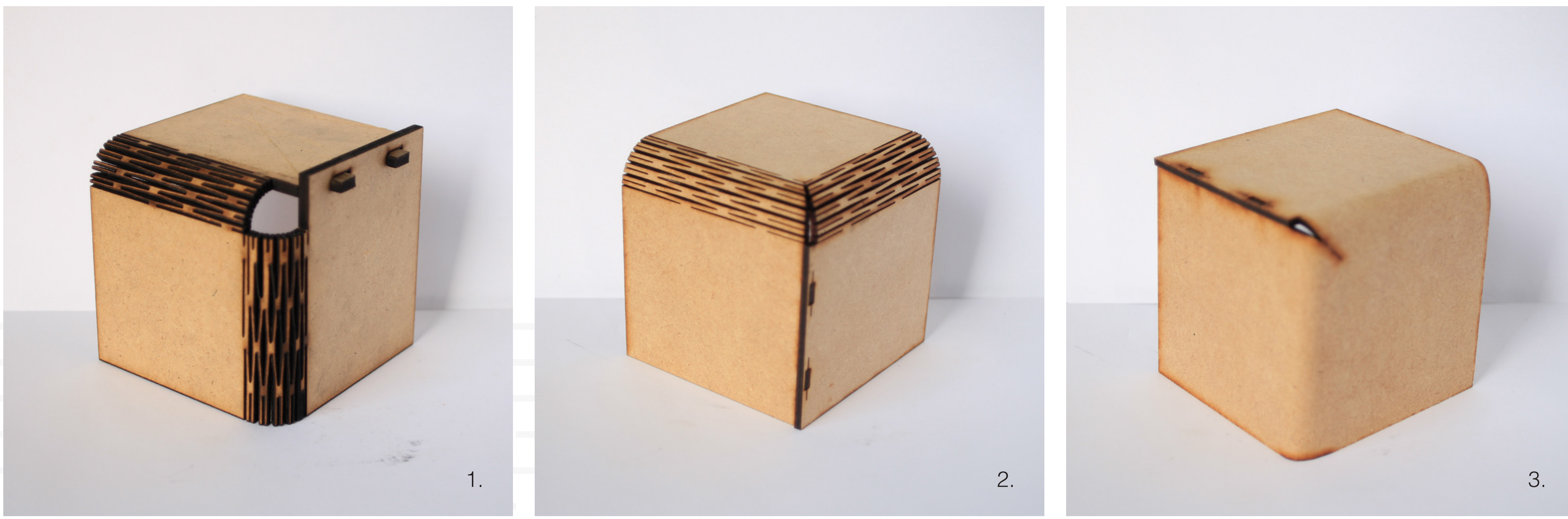


Figure 3, 1 first iteration box corners, 2 second iteration press fit joints, 3 final iteration invisible kerf bend

LASERJAMMING

LaserJamming consists of two parts, the lattice hinge pattern and small wedge inserts. These small wedges are introduced into the lattice hinge and because of their wedge shape introduce a different displacement between the top and the bottom of the pattern (figure). This introduces a curve into the pattern and locks the wedge in by friction.

Lattice hinge pattern

The initial pattern was based on the most simple lattice hinge pattern (Benchoff, 2017), and was adapted throughout the iterations. The lattice hinge pattern consists out of two basic elements, passive and active elements (fig 7). The Active zones act like torsional springs when the pattern is bent. One of the main advantages of this pattern is the high density of active zone's in a certain width, while retaining strength. And because the pattern can bend only so much per active zone this results in most versatility and strength when creating patterns.

After a while experimenting with the lattice hinge pattern, it became evident that an optimization could be made, small insertion slots were created where the wedges should be inserted. This had two main advantages, the first is that the wedges could become a little bit thicker while remaining the same bend curve, thus increasing strength. And secondly it became a lot easier to place the wedges homogenously along the pattern, as the wedges "slotted" in quite well.

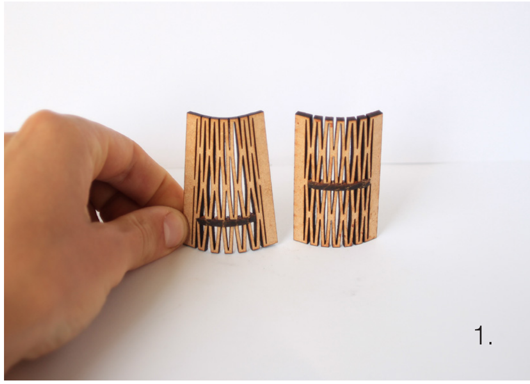


Figure 4, 1 small intitial samples, 2 iteration 1 bridge

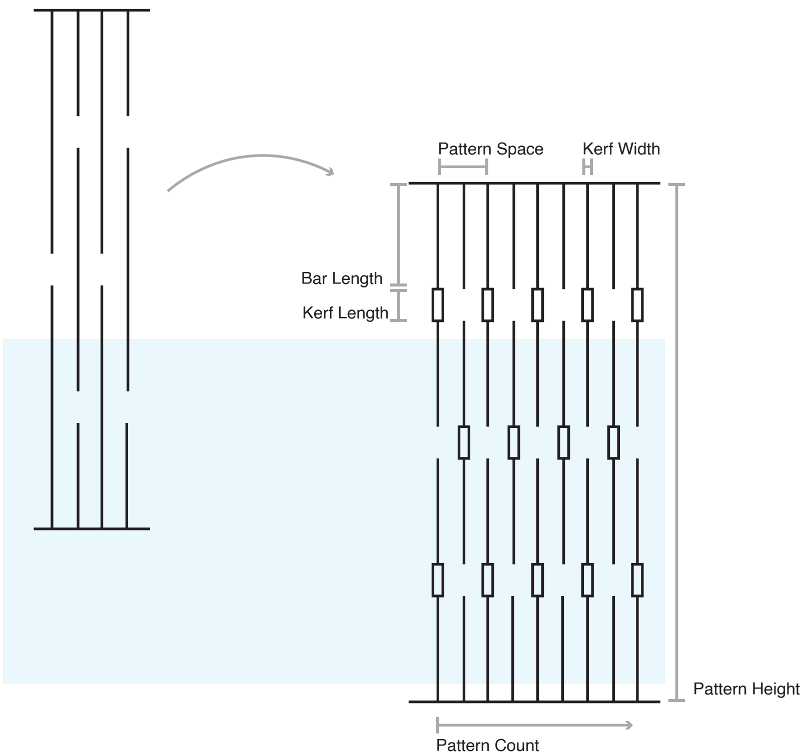


Figure 5, The optimisation of the Lattice Hinge pattern pattern

Wedge design

The wedges are the component that were experimented with the most. The initial behavior was discover with a small leftover piece of wood, however quickly purpose crafted wedges were made.

The first wedges were small pins that could be inserted into the pattern separately, just as a spacer for the top layer, this increased the width at the top, causing the pattern to bend. These initial pins were just held in by the elasticity of the wood, a big problem when the pattern was stretched and manipulated. The little spacers tended to fall out regularly. Another problem was that the wedges had contact with the wood at a very small surface, which sometimes led to delamination of the top layers of MDF.

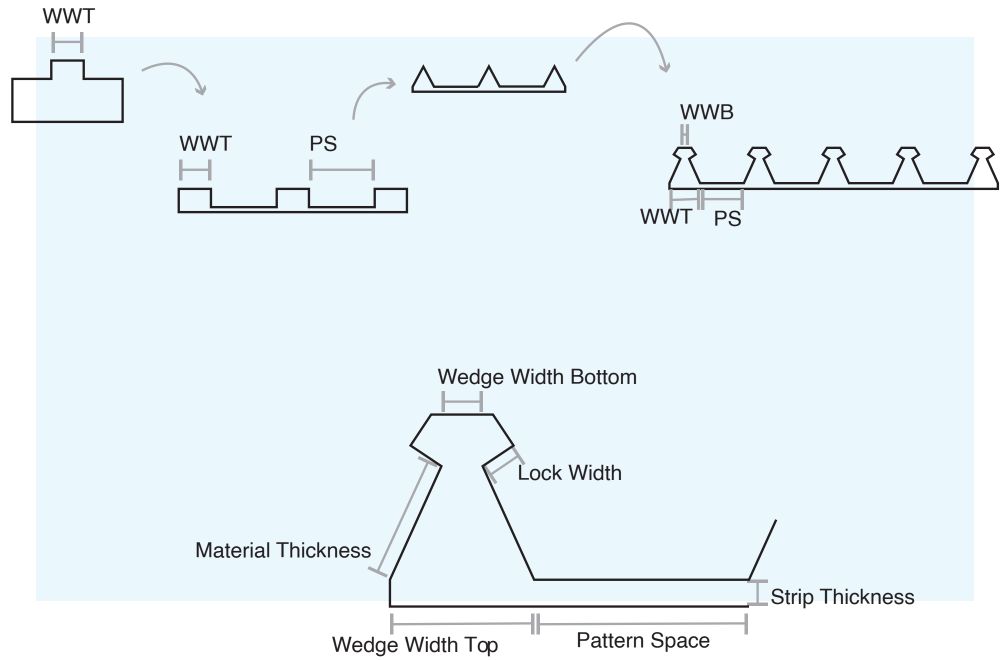


Figure 6, The optimisation and parameters of the wedge

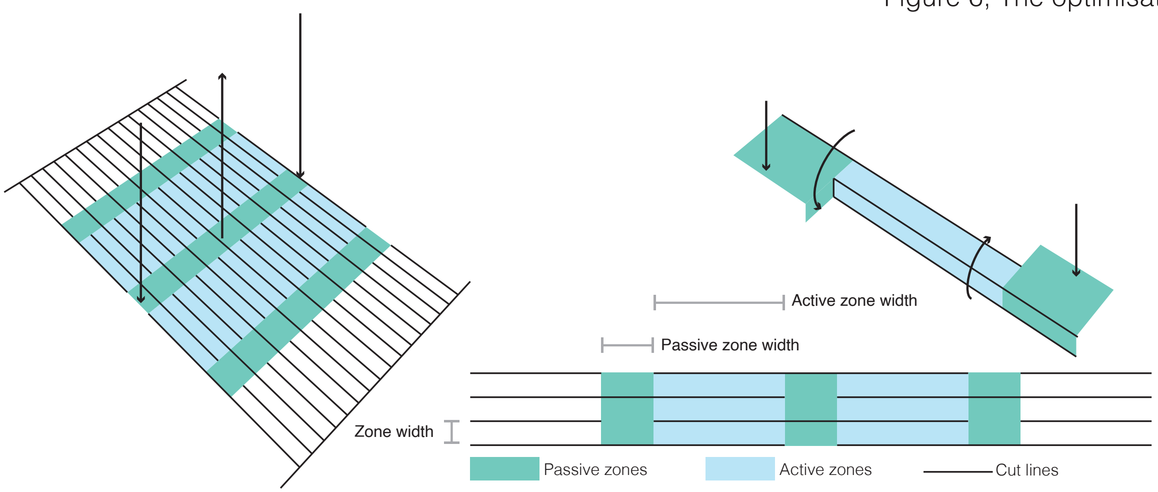


Figure 7, Lattice hinge pattern how it deflects under force

The drawbacks of the small spacer were solved by making pins that went completely through the lattice hinge pattern, which also allowed some external geometry at the other side of the pattern. To increase the reliability when manipulating the pattern a small physical lock was made that protruded on the other side of the pattern. This gave a lot more reliability with wedges staying in place. And also gave a small feedback click when the wedge was inserted completely. The complete insertion also offered more control over the bend characteristics. As the two sides could also remain parallel to just stretch out the pattern instead of curving it as well. And also decreased the minimum angle necessary to create a curve.

Assembly
From the initial exploration of inserting a scrap piece of wood, a lot of improvements have been made to the assembly process as well.

Initially the wedges were inserted one-by-one, which was doable for small patterns up to 10 wedges, however the scalability was severely limited. And also the position of the wedges was not very structured.

After which the pre-stretch technique was developed. Because of the regular intervals between the pins, the pattern could be stretched and inserted over top multiple wedges at the same time. This had implications for the wedges as they would be designed on a strip (fig 9.1), which could easily be broken or removed after assembly.

Stretching the pattern was done manually, however with larger patterns it became very important to be able to stretch the pattern a more precise amount. Thus a clamping and tensioning system was designed to be able to reliably stretch the pattern during assembly.

This clamping system was designed with flexibility in mind, to not complicate the assembly more in terms of requirements simplicity of production was a major focus. The eventual clamping system can be fabricated with a few pieces of string and a 3D printer with PETG, moreover during use only a table is required to operate the system (fig 8, 9.2).

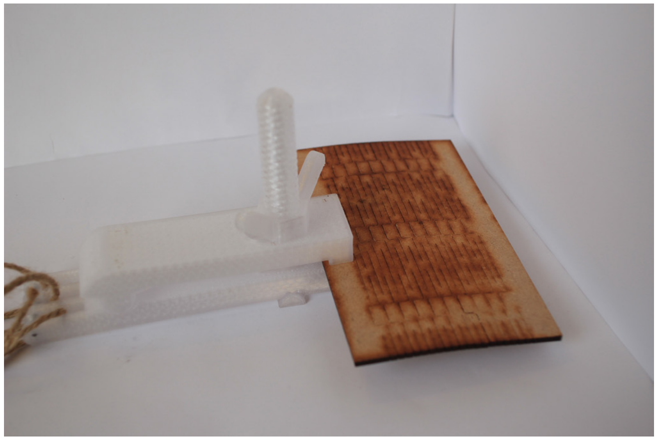


Figure 8, The 3D printed clamp of the tensioning system

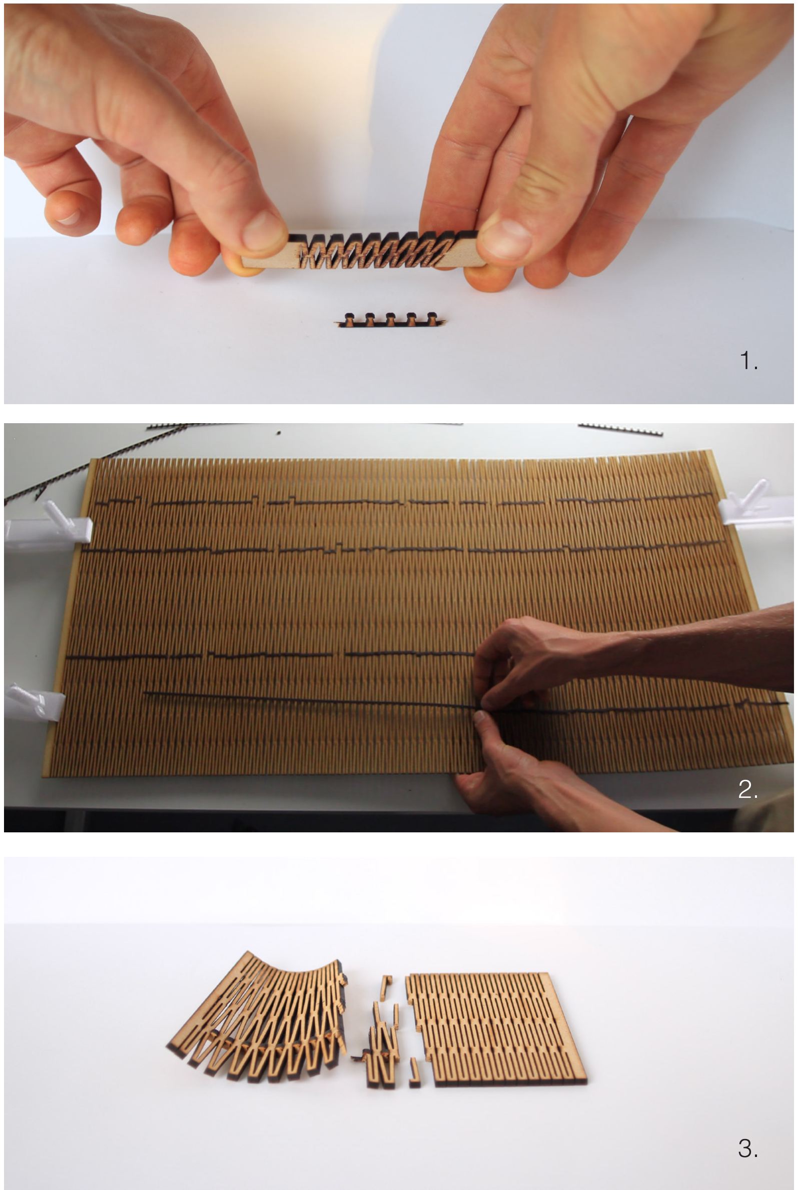


Figure 9, 1 hand stretching, 2 clamps in use to stretch a large pattern, 3 overstretching results in breakage

INCREASING RELIABILITY

Bend characteristics
When a wedge is inserted the pattern forms an angle at the wedge point. At first thought this angle could be calculated easily of the angle of the wedge. However the tension at the top of the pattern where it is stretched more is different than at the bottom (fig 16.5). This leads to non-linear interaction of the pattern and wedge, the same wedge would produce different angles in different patterns.

This factor made the production process focused on expertise and guesswork. Often a design had to be prototyped multiple times to create the end-result. In order to increase this guesswork a large data test has been performed to capture this relation between the parameters.

Initially a small exploratory sample test was done with the first iteration pins, to achieve the parameters to be considered, from this with the new wedges a second larger test was executed.

Initial test
In the initial design test, a few parameters were considered. Namely the bar length (BL), the pattern spacing (PS)(fig 11) and the wedge width top (WWT) . In this initial test the first iteration spacer were used (fig 6).

From this initial exploration it was evident that these factors did indeed play a large role, and that the deviation was quite significant. The parameters tested formed the basis for the larger scale test, and it also provided a lot insight into the workflow of the testing, tools and time it would take.

Setup
In order to create the most reliable data for the amount of datapoints that could be feasibly collected, the focus was put on the parameters that had the most influence on the bend angle, it was made sure that for each parameter at least three different datapoints were tested. This led to the following set of parameters and patterns. The material used for the test was the same as all the previous explorations, namely 3mm MDF.

A base pattern was chosen and from that base pattern 1 parameter would be changed, this led to the following set of designs:

1.1 Base Pattern: BL = 15; PS = 2,0

1.2 Base Pattern inserted from the top: BL = 15; PS = 2,0

1.3 Shorter BL: BL = 10; PS = 2,0

1.4 Longer BL: BL = 20; PS = 2,0

1.5 Smaller PS: BL = 15; PS = 1,5

1.6 Larger PS: BL = 15; PS = 2,5

For each of these designs the same amount of wedges and wedge size were inserted, this however did mean that some of the patterns were not stretched to their limit, and some were stretched very close to the breaking limit. The WWB was fixed at 1,0mm for this experiment.

2.1 Small wedge: WWT = 1,5

2.2 Medium wedge: WWT = 2,0

2.3 Large wedge: WWT = 2,5

Each pattern was bent with a few intervals of wedge amounts, starting out with 1 wedge, then 3, 5 and finally 7. Each pattern and wedge size was repeated five times. Thus every pattern design was cut 15 times and measured 60 times.

Figure 10, One of the measured samples

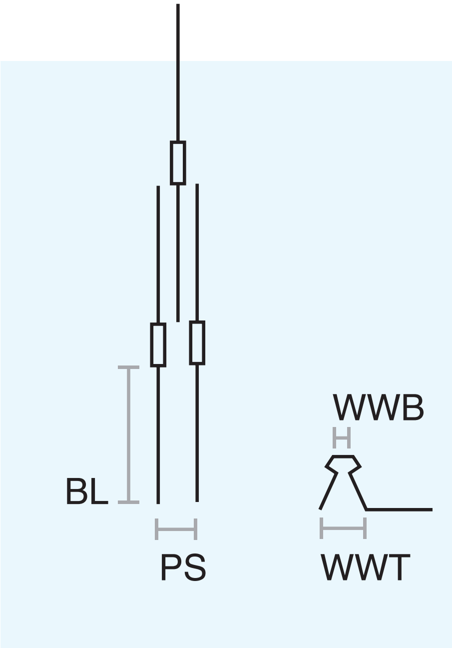


Figure 11, the parameters that were changed

Method
To keep the measurements consistent a digital angle protractor was used to measure the angle. The designs were measured in the following order;

A design cut 5 times was collected together with one size wedge. First 1 wedge was inserted into all five patterns, pressed down and flexed up and down. After which the angle measurements were taken, after which the wedge was removed and three wedges of the same size were inserted. When multiple wedges were inserted and additional step of breaking the strip was added, this because often while assembling it would break. The same measuring workflow was then repeated for 5 and 7 inserts. For every wedge size a new pattern was used.

During measuring if a pattern would break, this would be noted and a new pattern would substitute the broken pattern, to keep the minimum repetition 5.

Figure 12, part of the samples which were tested

Results

The execution of the test resulted in 360 datapoints, and this data was then first visually explored. And it was very clear that the different patterns produced different average angles. Especially when compensated for the amount of wedges (fig 13).

As is visible in fig 13, the data is grouped quite well, however there are quite some deviating outliers. As there is no apparent reason why some are deviating this much we can't remove any outliers.

Some deviations which were noticed seemed to have something to do with the location of the piece in the laser cutter, at some parts it seemed to cut a little less deep, and thus the kerf was a bit smaller, this meant that the slot in the pattern was a bit smaller and the wedge a bit bigger.

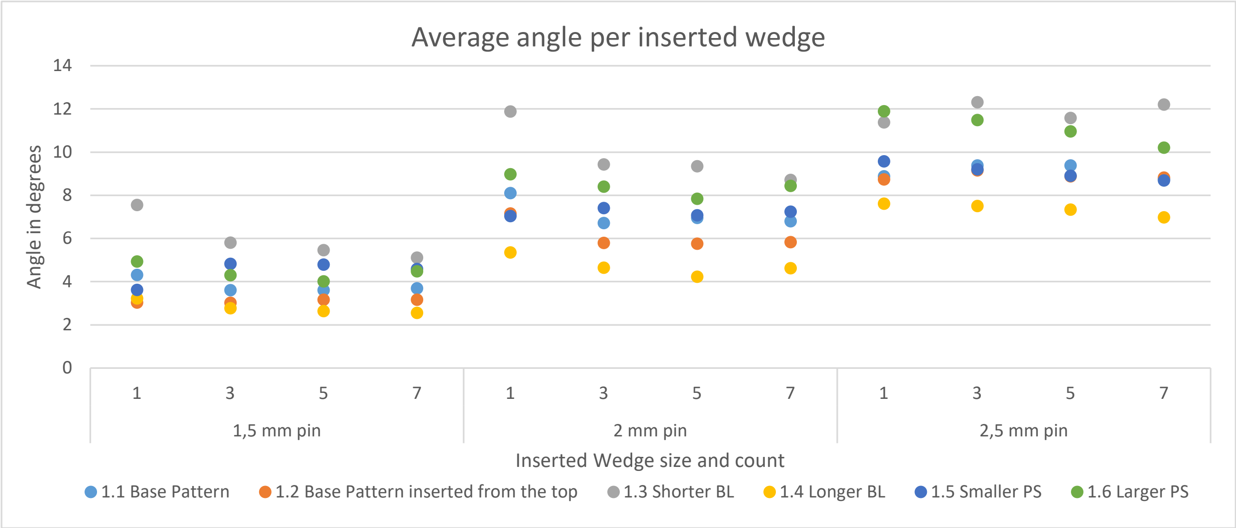


Figure 13, Results, average angle per wedge for each of the patterns

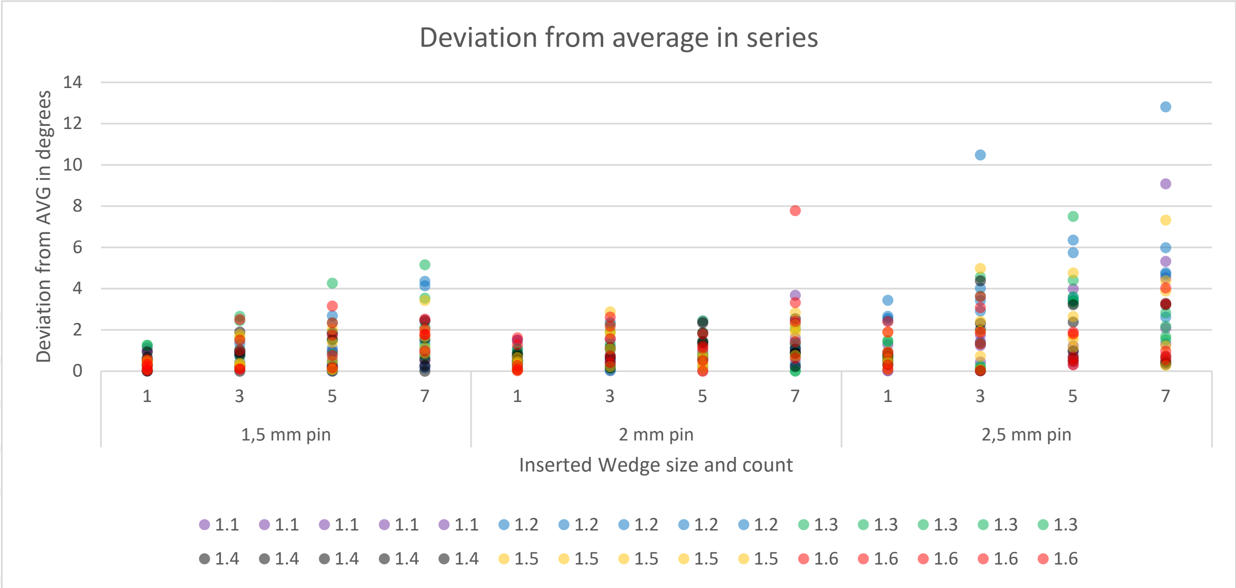


Figure 14, Deviation from group average, note the true angle becomes greater when wedge size and count increases

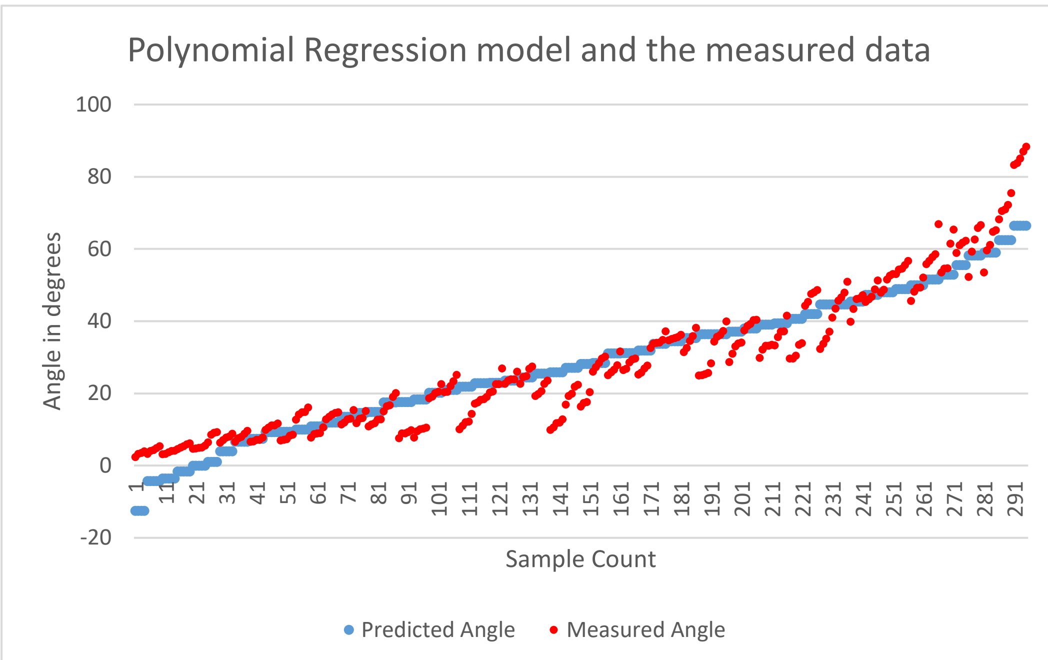


Figure 15, Polynomial Multi Regression result

Regression model

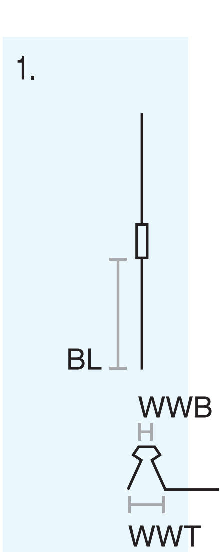
In order to make use of this dataset a regression model was trained. For this regression the insertion side was disregarded as it only provided 1 datapoint. At first a linear multi regression was trained, however a polynomial multi regression model proved to be the best fit, and thus became the final model, variables with an P value higher than 0,05 were disregarded as they did not alter the predictions.

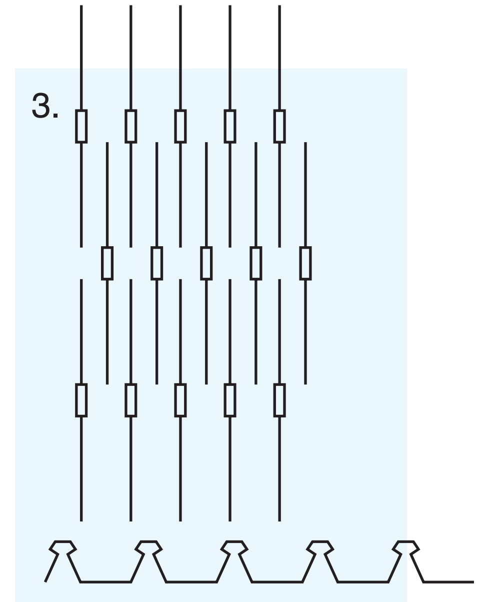
This resulted in the following regression model;

F(X) =13,6022 + BL*-1,648+ PS*-18,120 + PS^2*2,4853 + WWT*21,8423+ WC*6,7781

With an R2 value of 0,891922 and a RMSE of 6,358388

This is a reasonable fit for a physical model at this scale. However when reflecting on the Predicted values and the measured values there is a limitation at the bottom end. Where the predicted angles actually go below 0, which is physically not possible.





COMPUTER AIDED DESIGN

In order to streamline the process and increase reliability a digital design tool was made using GrassHopper (Robert McNeel & Associates, n.d.). In the first iteration it could be used to speed up the design process, where in the last iteration it has implemented the regression model to create the most reliable solutions.

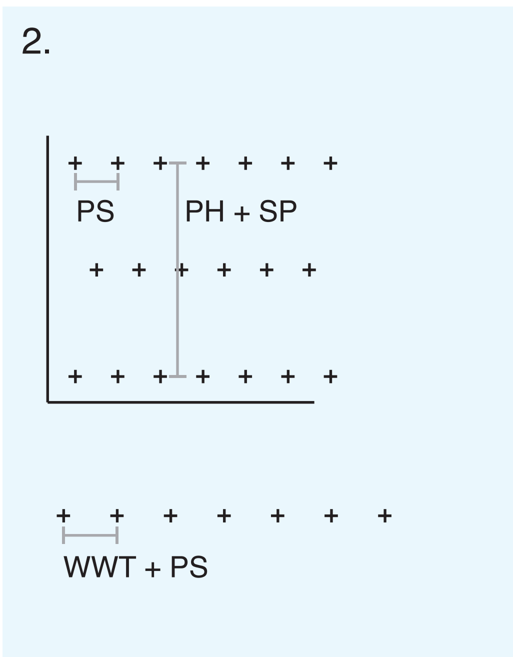
Iteration 1
The grasshopper model is based on two main functions, for the pattern and the wedge single primitives of the shape are constructed with parameters. These patterns are thus customizable at every single intersection however most of the values should remain fixed as they either have little effect on the curve or are detrimental to strength. (1)

A second function determines base coordinates of the complete pattern, the coordinates are dependent on values derived from the pattern primitives however it also adds on top of this, Pattern Spacing being the most important. (2)

The generated coordinates are used as an input to the pattern primitives, and thus the primitives are patterned. (3)

And finally some additional geometry is generated to bring the pattern to its final shape. It can then either be directly cut and assembled, or other geometry can be added. (4)

The first iteration thus was a modeler for the pattern, where by the maker every variable could be altered and changes. However the user has no feedback about the expected curve with the corresponding pattern.



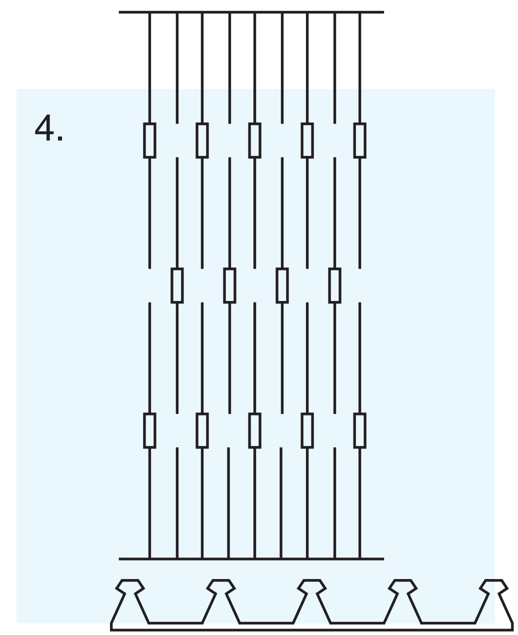


Figure 16.1/2/3/4, Visualising the design edditor iteration 1

Iteration 2
The second iteration was created to increase the reliability and user friendliness. It namely integrated a new range of input values, from all these specific parameters now the user could supply an angle and a radius into the program to generate the pattern.

This function is based on the principle that the wedge forces an angle between the two interfacing sides. And when multiple wedges are used this angle is then added onto a total pattern angle. This angle is calculated by a few values, the Wedge Width Bottom, Wedge Width Top and the material thickness. However because of the way that the wedges push against the wood this theoretical angle is not accurate to the Actual Wedge angle, the wood pushes against the WWT harder, and often does not directly touch the WWB. In order to compensate for this a compensation factor was used, this factor was derived from the dataset by comparing the actual measured angle to the theoretical angle. (5)

When this Actual Wedge angle prediction is calculated, the amount of wedges (e.g. Pattern Count) can be determined by:

Pa/AWa = PC

After this calculation the Pattern Space is determined, the total length of the pattern is determined by PC * (PS + WWT) and this formula can be used to determine the PS from the desired radius. (6).

These calculated parameters are then inserted into the iteration 1 file and the final pattern is created.

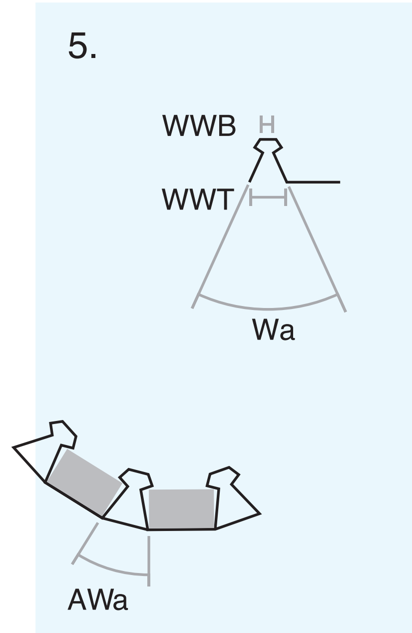
This iteration allowed the user to reliably generate patterns that were relatively accurate. However as mentioned before it had a fixed compensation derived from the data. Which meant that the differences between the patterns were not accounted for. And realistically the compensation factor should be changed when the different pattern parameters changed.

After the creation of the pattern a few test cuts were made, and are highlighted in the following table. Where MA is the measured angle.

Input parameters

BL	WWT	WWB	A	R	MA
25	2	1	90	50	76.6
25	2	1	90	50	79.8
20	2	1	90	50	95.3
20	2	1	90	50	91.7

The input variables are displayed on the left, while the actual measured values are displayed on the right. Through this example It is clearly visible that there is no recognition of BL shape on the pattern.



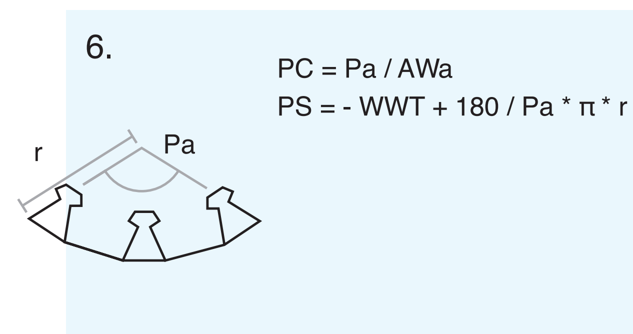


Figure 16.5/6, Visualising the design edditor iteration 2

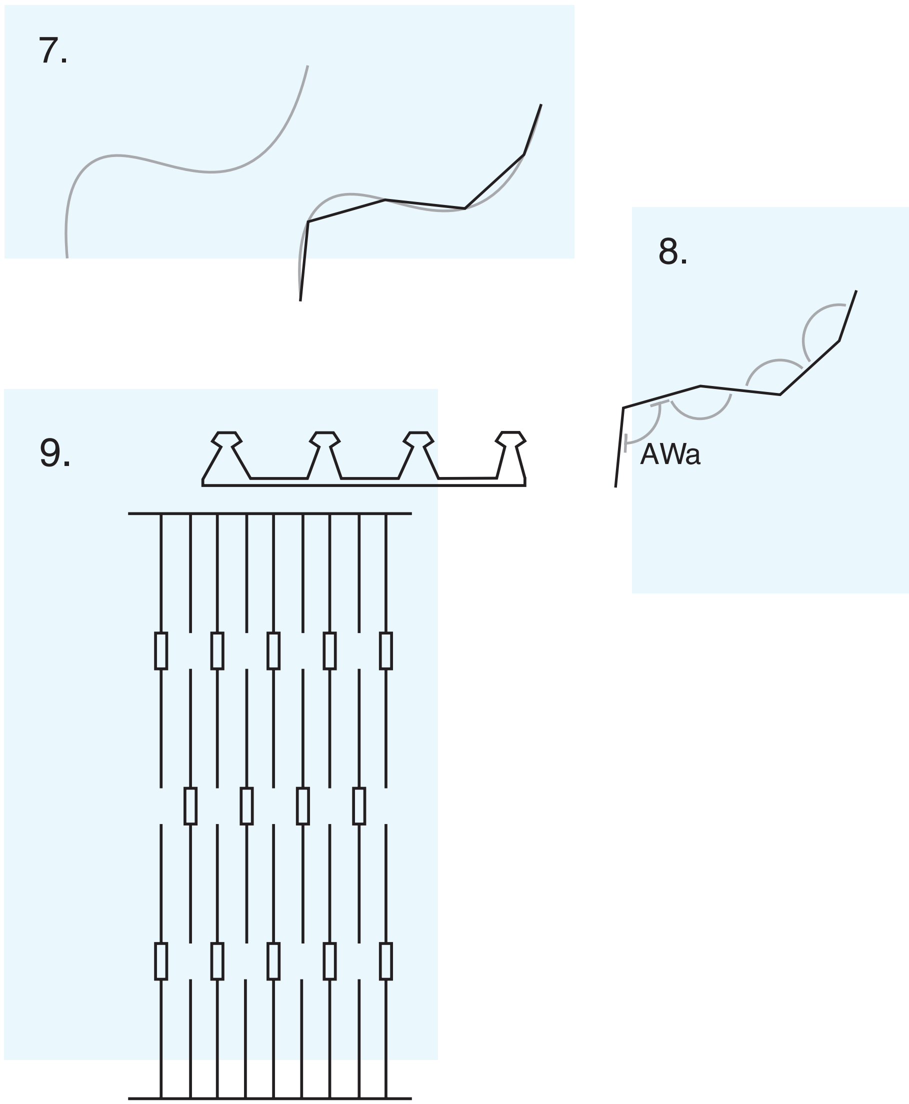


Figure 16.7/8/9, Visualising the design edditor iteration 3

Iteration 3
In order to increase the reliability and integrate all the parameters from the data sample, the regression formula was integrated into the design editor, this meant that the relevant factors would all be weighed in to a prediction. Besides this a feature was added which helped the design of multi curve parts, a spline processor.

Integration of the regression model
The regression model trained by the dataset was implemented as the base of calculating the angle the complete pattern would form.

PS, PL and Pa formed the input parameters which were translated into a WWT value, this means that the Pattern Spacing, the Wedge Width Top and the Bar Length remained constant throughout the pattern. The only changing part in the pattern was the Wedge Width Top. (5)

Integration of splines
In order to produce a multicurved surface with iteration 2, a few different patterns had to be generated and stitched together manually. In order to increase the usability and possibilities of the design editor a spline converter was added. This feature first loaded the spline drawn in Rhinoceros into GrassHopper and converted it into a polyline. (7)

Then for each of the polyline control points the angle was calculated (8).

With the regression formula this angle was translated into a Wedge Width Top and these were drawn together with he pattern. Note that the WWT of the wedge pattern changes throughout. (9)

This last step significantly increased the usability of the software, as it not only allowed more complex curves to be created. It also allows the user to visibly work and piece together a design, just loading in specific curves to be transformed into a LaserJamming pattern.

Overview of the grasshopper functionality

1. Draw the desired curve in Rhinoceros
2. Import the curve in Grasshopper
3. Split the curve and asses the angle at each wedge point
4. Apply the polynomial regression model to determine the wedge width
5. Generate the pattern coordinates
6. Draw the pattern and wedges

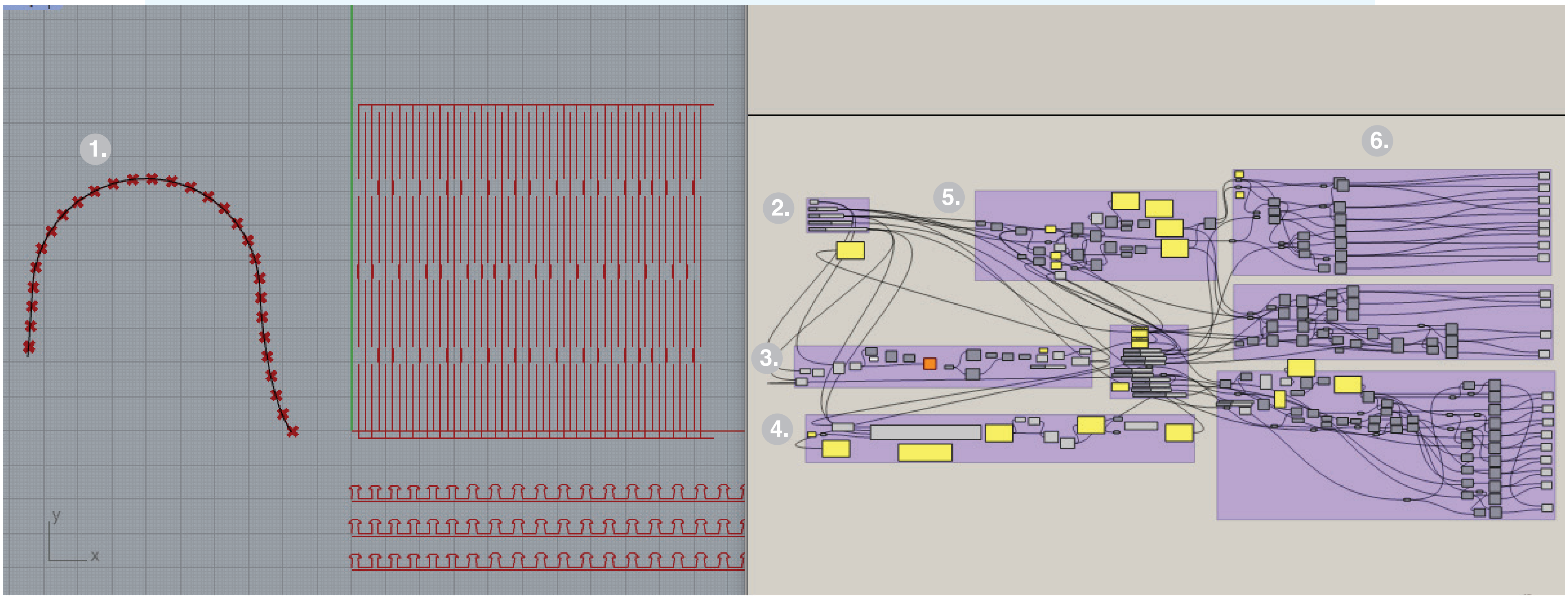


Figure 17, The GrassHopper design edditor overview

EVALUATION

Accuracy
The accuracy was tested with a few example designs. A spline was drawn and then cut and assembled, after which the drawn file was printed at true scale on a piece of paper. The patterns were then visually compared on accuracy.

Overall the patterns matched quite well, the radius of the circles was almost identical to the desired radius, however the end pieces were not completely curved in which was to be expected.

The s curve and the L curve however do have some improvement points.

At the L curve the pattern is not completely straight at the right end, as well as the curve being a bit shallower. The non-straightness is because of the necessary angle being very low, in the program a function is added that when the angle gets very small, the WWT is equal to the WWB, however because the pattern has a slight difference between the top and bottom kerf width a small angle can be expected. The curve being a bit more shallow has to do with the size of the polyline parts; Because they are quite significant on this size of pattern the curve gets flattened a bit.

For the S-curve the failure lies partly in the polyline conversion, however possibly the most prevalent issue is that the angle some wedges must force are just too high, this led the wedges to be very steep and the accuracy to drop. (fig 18.6)

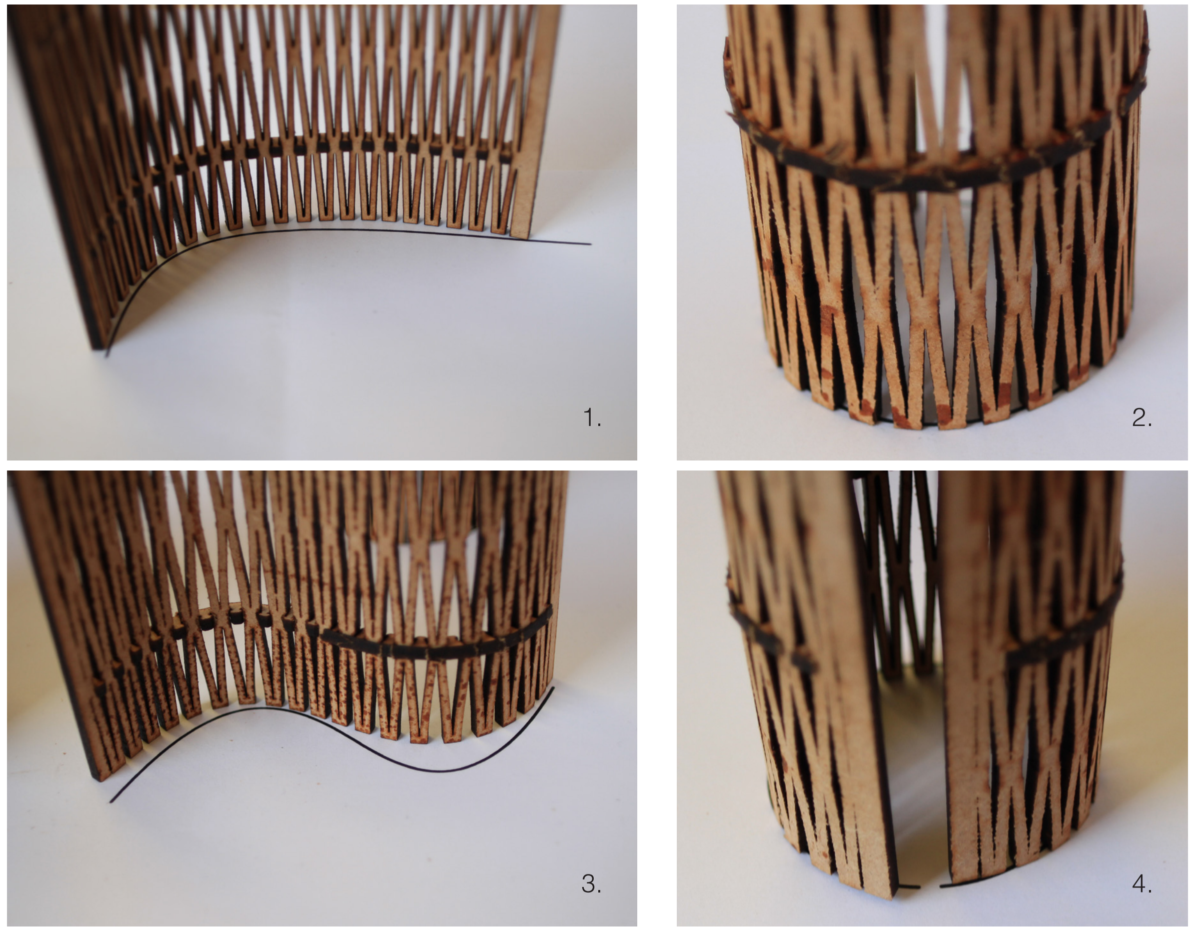
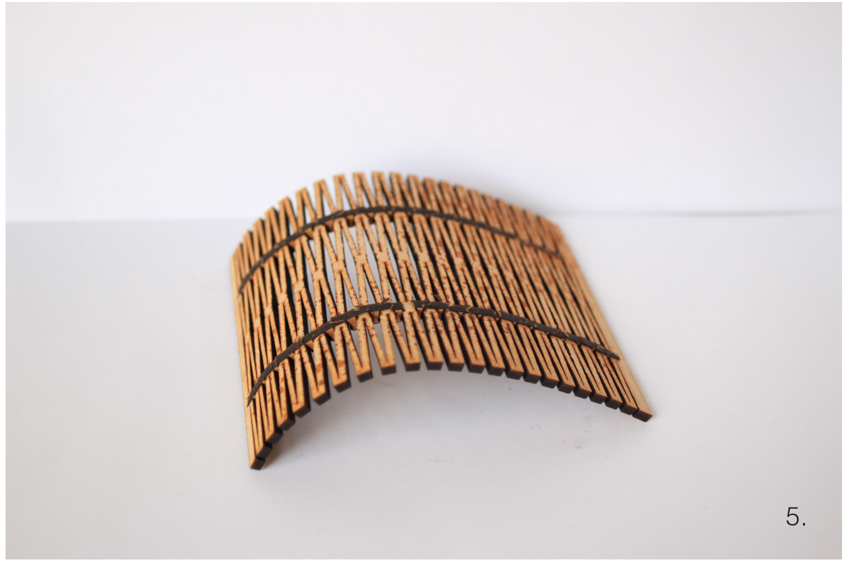


Figure 18, The evaluation samples, 1 L shaped sample, 2 circular 50mm radius sample, 3 S shaped sample, 4 circular 60mm radius sample



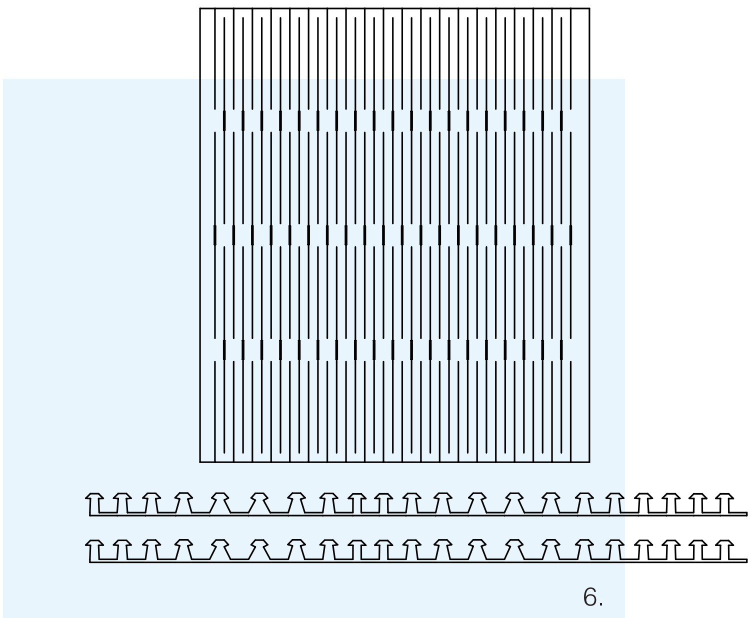


Figure 18, The evaluation samples, 5 L shapes sample, 6 S shaped sample pattern, 7 S shaped sample

Speed of making

In order to evaluate the speed a comparison was made with a main other high fidelity prototyping technique; 3D printing. To evaluate the speed we timed the production of the samples from the moment the machine was turned on, as the design time is comparable between the techniques. The end time includes assembly and hand work to bring the prototype to the final quality.

As an example a small cup holder was designed in SolidWorks and sliced using Cura for the 3D printer and printed on an ender 3 with PLA, the LaserJamming pattern was made using the design editor and laser cut using Lightburn with 3mm MDF.

LaserJamming: 27 minutes, 17 minutes cutting time, 2 passes 15mm/s (fig 20.1)

3D printer: 6 hours 45 minutes, 30mm/s, 0.3 layer height, 0.5 line width (fig 20.2)

Figure 20, 1 LaserJamming cup holder, 2 3D printed cup holder

CREATING A LASERJAMMING DESIGN

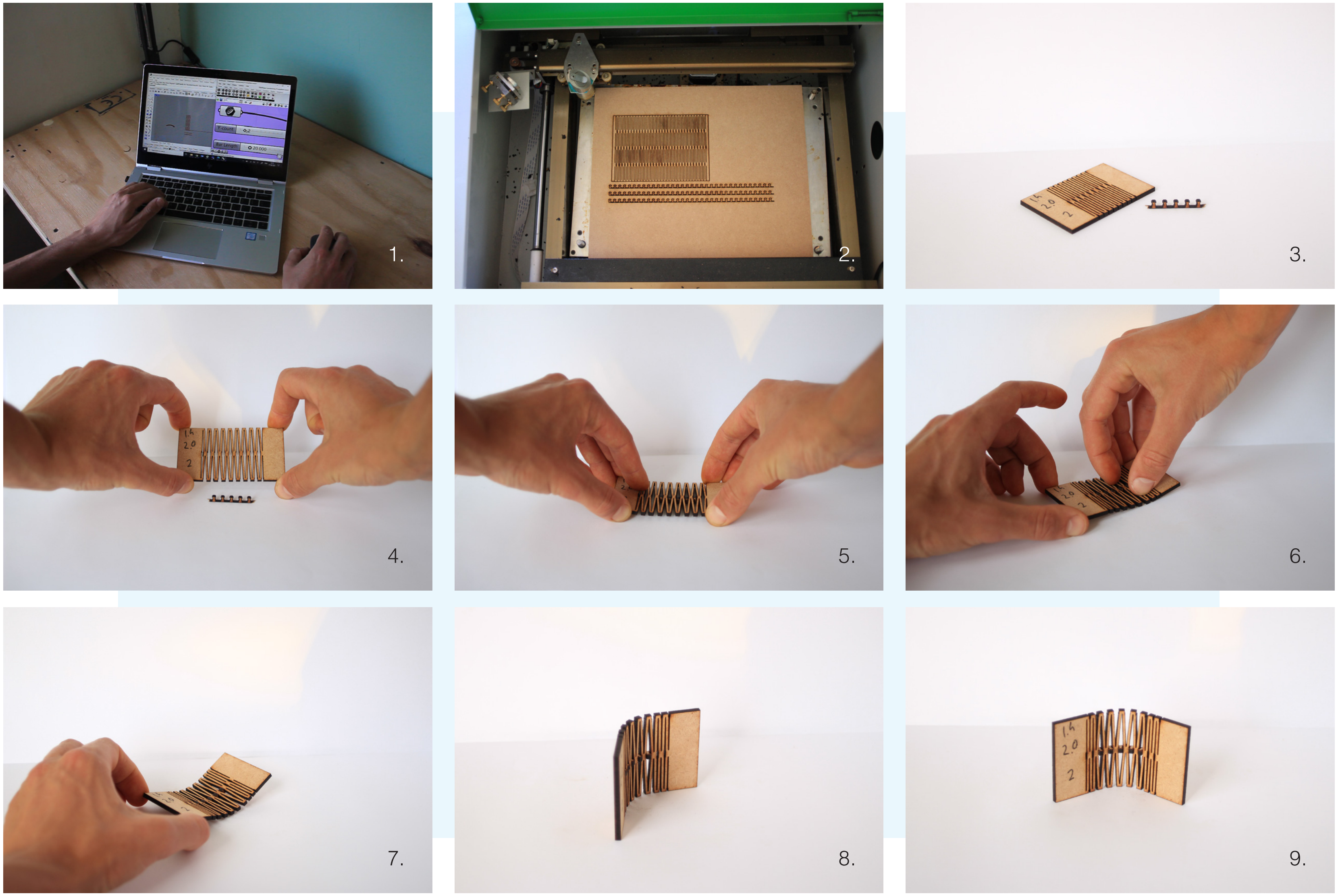


Figure 21, Workflow of creating a laserjamming design, 1 first the pattern is made using GrassHopper, 2 it is then lasercut, 3 and extracted, 4 after which it can be assembled by stretching, 5, 6 and placing the pins, 7, 8, 9 And finally the curve is achieved

PROPERTIES AND APPLICATION

The pattern

Shape

The patterns created by LaserJamming have in principle two degrees of freedom, they can bend forward and backward, and they can bend upward or downward and any combination of the two. (fig 23)

Strength

The patterns are semi rigid, because the pattern has to be flexed elastically in order to assemble it, it remains rather flexible. This is a feature which could be taken advantage off when for instance clamping something (fig 22.2), or simply compliant when impacted.

Fixture

The pattern is completely glue-less, meaning that everything is held together by friction and a clamping force. This means that it is possible to completely disassemble the end product.

Texture

Secondly the pattern allows light to be passed through, this property can be used to the designers advantage, by playing with the source of light. And more to the width of the slots can be altered as well by changing the wedge shapes, however when large patterns are made this play with light and curves could create very interesting effects (fig 22.1).

Moreover the patterns have small wedges which protrude on both sides, this could also be used for other purposes, the wedges could be extended to create a small ledge that could be used to join other patterns. Or the wedges could be extended and used to stitch multiple patterns together.

The designer

Another aspect of the LaserJamming at the moment is the designer influence, there are still some parts in the software which are up to the designer to asses, this allows for some freedom for experimentation, one of the most important parameters is the placement of the wedges. In order to gain the earlier discussed double curvature the placement of the wedges is the crucial factor, this location is not yet fixed in the software and the eventual assembly is completely up to the designer. This means that unlike 3D printing there is a mediation between the material and the final product. And the potential to remove the wedges again makes for a setup which can be experimented with. When prototyping one might generate a few different wedge strips which all fit the same pattern, this makes exploration fast and material-efficient.

Figure 22, 1 large LaserJamming pattern, 2 making use of the flexibility as a clamp

Figure 23, Possible curves, 1 bending backward and bottom out, 2 bending forward and top out, 3 bending linear and bottom out

LaserJamming as a business
Separately to the research project, the application area was thoroughly researched in combination with a separate course, Design Innovation Methods. LaserJamming was approached from a business perspective, a few aspects will be highlighted, the full reports can be found in the reference list. (Goudswaard, 2021a/b/c/d)

Value proposition
To find out what the actual value is for the user a value proposition canvas was used (Strategyzer AG, n.d.), this gave valuable insight into what areas the product could focus on to solve a user need. (fig 24)

Service blueprint
In order to assess the aspects the service would need a service blueprint was made (Kruitwagen, 2021), notably is the inclusion of makerspaces in the service. In order for the service to generate a user base, it is necessary for laser cutters to be available to a lot of people. Makerspaces do have the capability to allow this access. (fig 25)

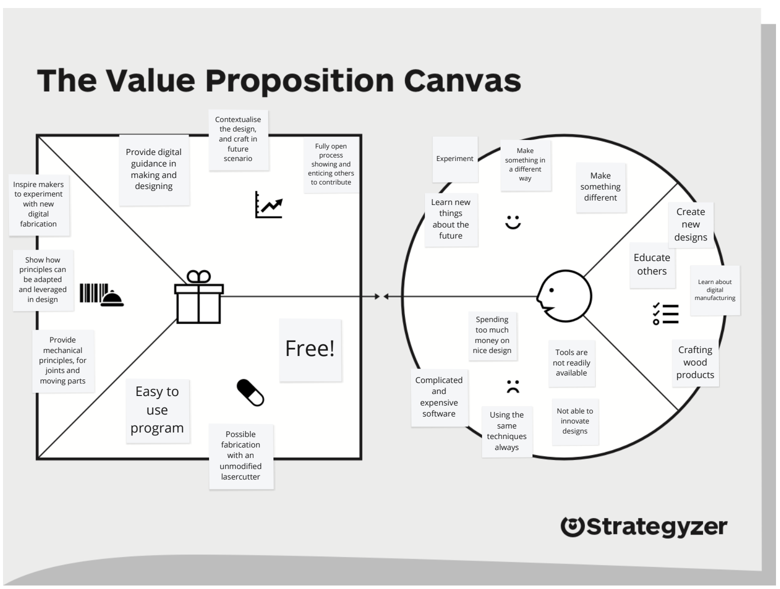


Figure 24, Value proposition canvas (Goudswaard, 2021-a)

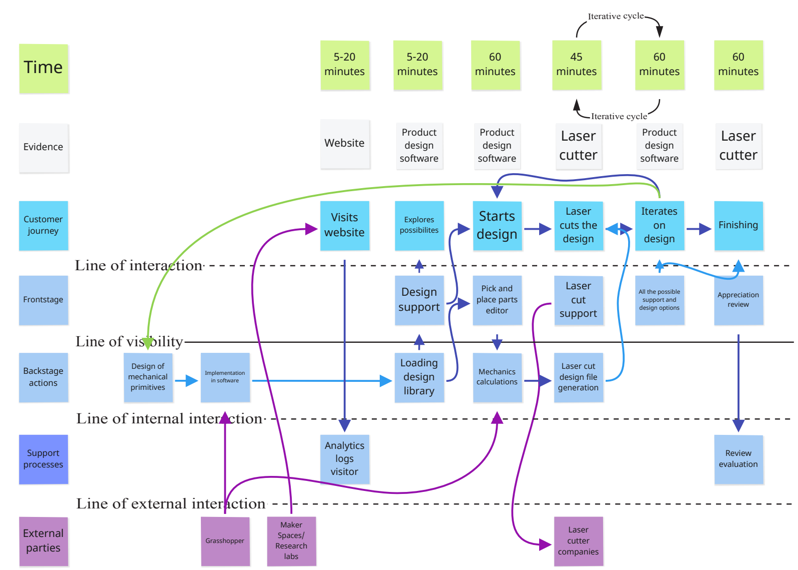


Figure 25, Service blueprint (Goudswaard, 2021-b)

Sustainable business model canvas

In order to assess the sustainability and sustainability of the business a sustainable business model canvas was used (CASE Knowledge Alliance, n.d.). From the exercise it could be concluded that LaserJamming has some serious potential to increase sustainability in production. Because of the materials being glueless and from one material, and also very material efficient, the curves are made from flat plates and are extended to even span a larger area. However more so, there are no sacrificial molds and or other parts to this technique. Lastly the use of a laser cutter could allow for a lot more local manufacturing, as it is a very general tool that is widely available. (fig 26)

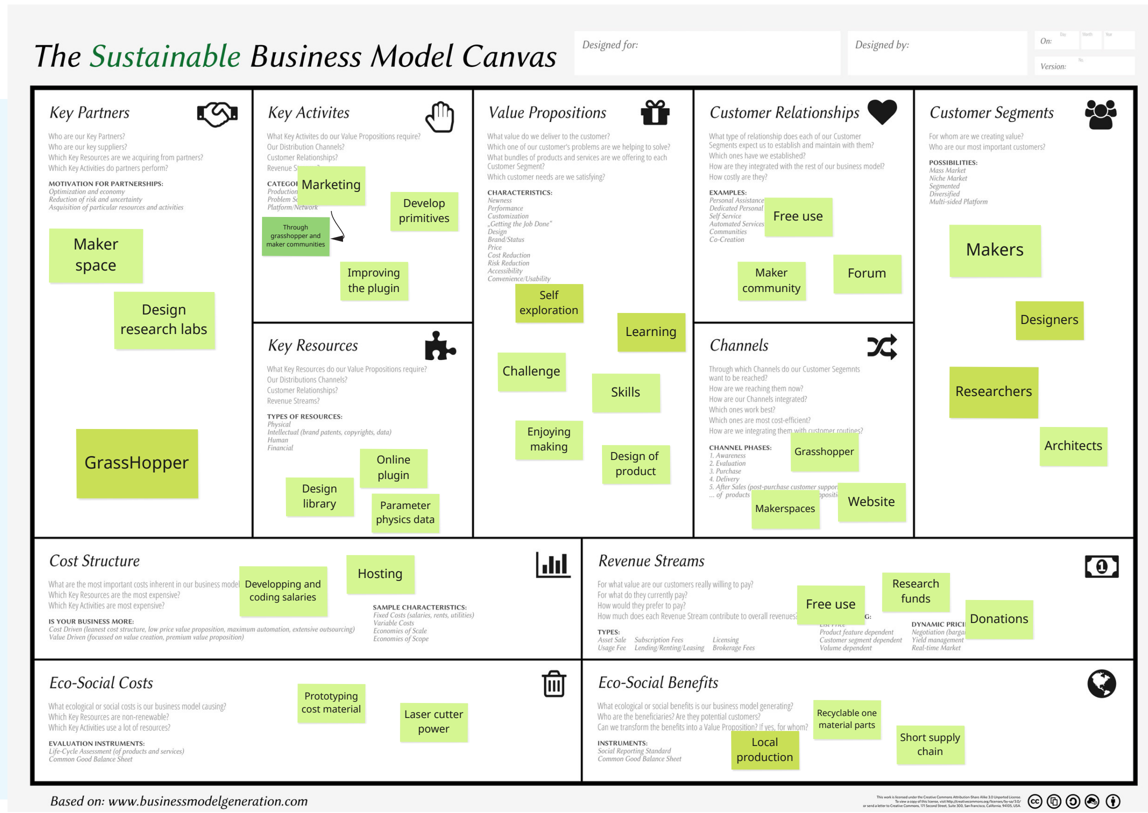


Figure 26, The sustainable business model canvas(Goudswaard, 2021-d)

DISCUSSION

Future work

Reliability and versatility

One of the main pitfalls of the current LaserJamming project is the reliability, despite the implemented regression model. There are still parameters which need to be assessed by the designer, for instance the maximum wedge angle which is possible, or if the pattern is flexible enough to allow the insertion of the designed wedge. These factors are up to the designer to asses and evaluate. This should be improved, with for instance a feature which showcases which wedge create an impossible angle, or a small calculation which assesses the flexibility of the pattern. Features like these could really improve the user interaction and allow new designers to create a working pattern from the start. These features could also help the scalability significantly, a lot of experience is required however to asses the pattern parameters. And so when changing the scale the correct parameters change. With large patterns however it can take considerable time to gain this expertise as the cutting times are increased.

Secondly the coverage of the design editor should be increased. When working outside the range of tested values with the regression model, it can quickly become quite ineffective. As explained before at a certain range the model calculates a negative WWT, which is not feasible in production, similarly the editor can simply produce a pattern so stiff it can't be assembled. In order to increase the range of reliability tests with larger scale products should be executed. When I tried to make lasercut parts a factor 5 larger, I needed to make 10+ attempts before gaining the behavior that was wished (fig 22.1).

Materials can also play a big part, the editor now only considers 3mm MDF, however because of the elastic movement of the pattern other materials should work as well. Some initial tests were done with 4mm MDF which proved promising. In principle materials that are elastically flexible and can be cut on a 2D plotter are fabricable with this technique. Ideally some integration of material properties would be integrated into the editor as well, such as tensile strength and elastic modulus. This could increase the possibility of using materials not extensively tested.

Finally there are also quite some opportunities for additional integrations, as mentioned before the editor now only calculates the angle generated by the wedges. The second degree of freedom on manipulating the width of the pattern is is underutilized and up to the designer. This could also be an implemented feature. Similarly not geometric patterns could also be generated, these are however simply not yet integrated. Also some experiments were executed with 2.5 D shapes, where a flat sheet was morphed into 3D, these implementations are possible as well, however not yet accessible with the current technique and software (fig 27).

External recognition

In collaboration with external experts the project was guided and focused to a new technique, which is a very clear indication of a technology push (OpenLearn, n.d.), and this is very important to realize, especially when creating a design editor which should be used by individual designers. Informal conversations during a presentation with two manufacturing professionals and an architecture students highlighted the possibilities of the technique, but also mentioned the limited scale as an issue. Future work should focus on co-creation with external parties outside the research group, where the usability and applicability of the design properties can be tested. I think that one of the most promising applications is in architectural facades and ceiling suspended panels. Also the transparency of the panels could play a large role, with for instance light deflectors etc.

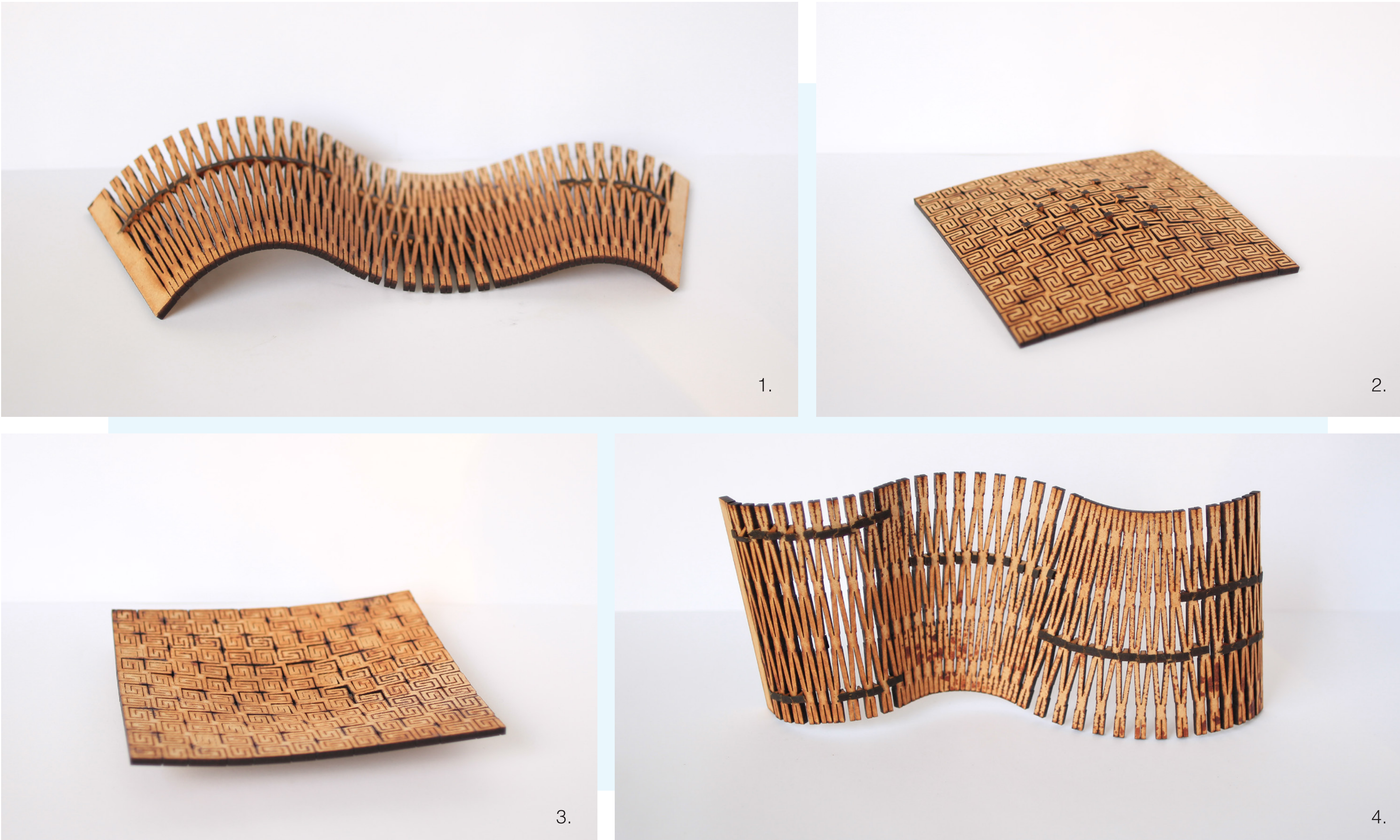


Figure 27, 1 Multicurved surface which cannot be directly calculated with the design editor, 2,3 Jammed 2.5D shape, strips of pins are not possible for assembly, 4 shape memory pins fall out after moving the pattern after a while

Limitations
As outlined in future work there are some limitations that can be solved, there are however also some other limitations which are inherent to the technique and thus will be imminent.

Assembly time
LaserJamming clearly has a significant assembly time. This assembly time can clearly mitigate the speed increase for larger parts, because the wedge count might be high and the pattern must be stretched under a lot of pressure.

Strength
The strength of the part is dependent on the spring type bars, however because the pattern needs to be stretched to be assembled limited strength can be expected for a LaserJamming design. Thus load bearing in the bent direction is very limited. The strength perpendicular to the curve is mostly unchanged. At least when supported from the bottom, similar to rolling up a piece of paper.

Accuracy
As the laser cutting approach cuts from the top of the material, it can be very hard to create an exactly equal kerf width throughout the cut. This however will change the interaction with the laser cut wedges, as they are not completely straight.

Post-processing
Because of the nature of laser cutting there will always be burn marks when working with wood. These burn marks are possible to sand away however the shape of the LaserJamming pattern really mitigates the possibilities for this. The surfaces are possible to sand, however the insertion of the pins which are quite unstable makes it evident that sanding should be done before the insertion.

Shape memory
The MDF used had an interesting tendency to after a while remember the shape it was in for a while, this meant that once lodged wedges suddenly became a bit loser. This initially indicates on plastic deformation of the material, however more reasonable would be the loss of elasticity over a while. This feature however did limit the possibilities for disassembly and inserting new wedges for instance. (fig 27.4, fig 28.3)

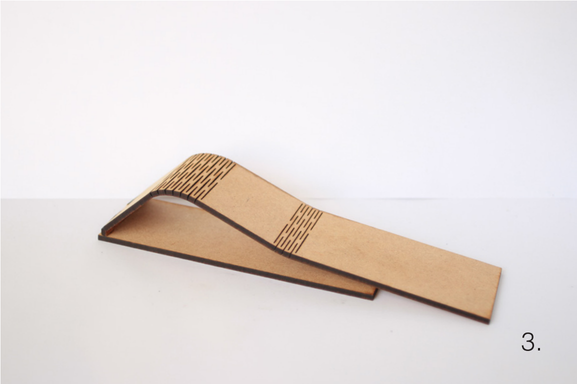


Figure 28, Variable seat exploration, 1 relax mode, 2 sturdy mode, 3 shape is memorised after a while

CONCLUSION

LaserJamming is a technique which can increase the integration of curved objects within the Laser cutter workflow. By jamming wedges in between a lattice hinge pattern the technique can force a curve into flat sheets. The amount of curvature generated has been researched by a large data sampling test, a polynomial multi-regression model has been trained to predict the behavior. This model has been implemented into a design editor which empowers the user to quickly make reliable patterns. The final result can be assembled without glue or other additives resulting in a self-contained semi-rigid pattern that holds it shape.

EPILOGUE

This project has really been a great personal learning experience. Especially the collaboration with external experts was great. I think my personal goal to do a research through design project, initiated from academia really was met. It was a joy to work together with people I admired 1,5 years ago, and collaborating and involving them in the process. Especially when they are enthusiastic about your progress as well! I hope they are motivated to continue this collaboration and help me with submitting a paper to an international conference.

Content wise, I think this project further cemented my devotion to digital crafting and finding new approaches to making and designing with digital machines. Especially learning to work with GrassHopper for the first time was a really fun experience. I think that parametric design is really something I'd like to pursue further in upcoming projects.

Moreover I am very content with the challenges I've had and overcome during this project. It has not always been easy working from home, and especially having to explain how things feel and interact was not easy, I think that I've shown quite some flexibility in my communication and that I really improved on that end as well.

As a final bachelor, I am very aware that some areas were under highlighted in my project, especially in user and society. As the design of the software took more time than expected there was just too consider this in depth, especially when researching through design during COVID-19 like this it is sometimes extra hard to put yourself out there.

Lastly I would like to thank Rong-Hao, my coach for sticking with me during this project and especially for taking the time to meet with me this often during the project. It has been a pleasure.

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Appendix 1 PDP

Personal Development Plan

Final Bachelor Project

By Maas Goudswaard; 1337149

VISION

Whether we all like it or not, the world is changing. The way we, as a society and as individuals, cope with this change is our challenge. CO2 emissions are rising and government restrictions are failing. Global problems require global solutions but a governing function on that scale is still unimaginable.

It thus falls upon us as individuals and communities to make better for the future and improve the way that we interact with the world. This starts by mindset; we should all aim to contribute by choosing sustainably. And I think that designers can make a real significant impact by not only on an individual level change, but they can exert force by designing and configuring towards more sustainable products and processes, allowing others to choose sustainably as well.

This choice can only be provided by business and industry. The global rise of wealth is paired with bad practice, but it doesn't have to be this way. Through business tremendous achievements have been made, the time is now to go through a second iteration. Companies can funnel efforts in gaining on climate change instead of slowing. I think that in our world capital is the only accelerator faster than the environment.

Designers have an important position in our consumer market, which they can leverage within their current companies to give consumers the choice. The designers are the mediators between technology and product, process and production and thus they bear the responsibility to the outcomes of their designs especially on a global scale.

IDENTITY

Driving innovation through business can start with the beginning, production. Especially our global production industry is extremely damaging to the planet. For example: designing a part, to then make a mould, fabricate it 1.000.000 times, then store it, sell 500.000 and discard/store the other half. These practices make no sense in our current age of digitalization.

I believe that local, on demand, digital manufacturing is the key to more sustainable production practices. And I see it is my responsibility to spread my knowledge and expertise in exploring and exploiting these practices. This goal can only be met with expertise in the industry, contacts and most of all collaboration. I hope to be able to provide companies or other institutions with tools or knowledge that they can appropriate to improve their impact on the environment. This can be done both through academics and business.

Collaboration is of utmost importance to be able to bring change, and I would love to work with a team who is driven by contributing to this global cause. On an individual level but also on a professional level.

My goal is to grow towards a designer who is an expert in digital manufacturing and who can investigate potential new applications of these new production techniques in different contexts. By working on new challenges providing either tools, or knowledge I believe my impact can be most widespread.

PAST

From my education before ID, I've always known that I like making and designing, and that I like project based learning. During my education at industrial design I've had a very broad development within the areas of expertise, however as I've always been motivated by making my joy in design always lied within the Technology and Realization as well as the Math Data and Computing aspect. The challenge of making something which you haven't done yet is one I am intrigued by.

One of my major self-discoveries during my bachelors is that I like research, more specifically research through design. I've experienced how physical prototypes can give deep insight and experience, hard to accomplish through words. When I have made samples I can see and feel the changes in quality, and I can see what work I've put in to get to this point. This works as a real motivator and truly is what makes me happy.

FUTURE

In my immediate future, my FBP I've set myself two main challenges, for one I want to explore my approach in research. And secondly I want to expand my toolbox as a digital crafter.

After my bachelor I am planning for something different, I've rushed very fast through my studies and learned a lot. However in order to give myself some time to reflect I am planning to take a year off to do two things, first I want to work. Preferably to explore future opportunities in a business, thus at an R&D department for instance. And secondly I want to start a sailing adventure, my girlfriend and I are going to buy a sailboat and fix it up and then sail to the Mediterranean.

After this year off school I am planning to do a master's degree, momentarily I think my choice would be to continue my studies at TU/e. The goals in my FBP are partly set up to give me insight into what track I want to choose, either RRD or CDR.

My future after my masters is yet unclear, as mentioned in my Identity I hope to be able to continue researching in digital manufacturing and digital craft. However if that is going to be by doing an PHD, or if it will be working in a company, that I will need to determine after my masters.

GOALS;

ACADEMIA

For my FBP I want to explore the academic side of research. Because I have experienced working in an R&D department, I would like to investigate whether it would be fitting for me to approach it from an academic side. I've actually published a paper already in DIS2020 called FabriClick, however in this project we did not approach it as a research project. And I thus did not experience how it would be to work from an academic approach in the research through design field.

In order to achieve this I have approached two external researchers, Lining Yao (CMU) and Clement Zheng (NUS). They are experienced researchers as well as my coach Rong-Hao Liang. With these two external researchers I want to have at least a BI-weekly information update and or meeting, to communicate my results and gain guidance. As a result I will make a paper submission to an international conference.

This will allow me to learn more about academic research and research through design, growing me in Design and Research Processes. The main outcome however is the experience and hopefully insight for my masters choice.

Design and Research Processes

Professional Skills

EXPAND TOOLBOX

As a digital crafter I've worked a lot with manufacturing machines, such as 3D printers and Embroidery machine. However one very major approach is missing; Laser Cutting. In order to explore and become more versatile as a designer, I want to explicitly learn about laser-cutting and the mechanics that are paired with the technique.

My goal is to work with the laser cutter and produce a lot of samples/prototypes. My goal is to make at least 50 different laser cut samples during the course of the project. Moreover I want to make 3 physical laser cut prototypes at the midterm demo day and at the final demo day.

If achieved I will have gained a lot of experience working with a laser cutter, and I hope it will guide my future application area. Moreover I will challenge myself to continue improving and creating new and innovative samples. It will require a lot of making, designing and prototyping, evolving mostly arround Technology and Realization.

Creativity and Aesthetics

Technology and Realization

DOCUMENTATION

As mentioned before my FabriClick project was not meant as a research project, and thus documentation was done quite sloppy. Samples unaccounted for and insights not captured. Moreover, we had very little pre-knowledge about the subject and this left us finding related works only when writing the pictorial.

During my FBP I will do two things to develop myself, for one I will make a template for sample accounting. Where I cover what files I used, machine settings, but most importantly interesting behavior and potential headings. I will use this template for every sample that I make with the laser cutter.

Secondly I want to investigate and research during the process of making. In order to achieve this I will read a paper every week related to my research, to start getting to know the area I am working in, and form a base of my related works. On every paper I will write a very short abstract of 50-100 words on why it is relevant for my project. Moreover, I will attend all the paper reading groups organized by the CEST squad.

I hope this will increase my productivity, however I hope that it allows me to truly add something to the existing academic knowledge, to really do something new. This goal is not directly in line with an area of expertise but it will really grow me as a designer and as a professional.

Professional Skills

Design and Research Processes

COMMUNICATION

During the COVID-19 crisis it is becoming more and more important to be able to express yourself well digitally. You can't simply bring your samples and tell the story. Moreover in an international collaboration there is no way of actually showing your work physically. Personally I've often lacked the necessety to properly express myself digitally or in 2D for that matter.

What I want to do is to prepare presentations for meetings every time I have a collaborative meeting, to develop a communication which is efficient and useful. As a tool I would like to apply my exploratory sketching to tell the story. Thus for every meeting I will make a page where the new insights and the future plans are being shown.

This assignment will allow me to personally improve my communication/ digital collaboration. However more importantly it forces me to get out of my head, and onto paper, training my Creativity and Aesthetics.

Creativity and Aesthetics

Professional Skills

EXTERNAL LEARNING

During my Final Bachelor Project I also have other activities planned that will allow me to develop my expertise areas and professional skills. For these extra activities I've not set specific goals, as I've plenty goals to worry about in my FBP.

Firstly I will continue gaining experience working in the private sector, Signify has given me the opportunity to continue my work with a parttime job. I will work on developing different concepts, and principles in the context of Signify's luminaires

The job I have is very diverse, one day I can be working on a machine that need's to have new functionality, and the other day I can be designing an new luminaire concept. This diversity really allows me to grow a lot in the areas of Technology and Realization, Math Data and Computing, Creativity and Aesthetics and Business and Entrepreneurship

Creativity and Aesthetics

Math Data and Computing

Technology and Realization

Business and Entrepreneurship

Digital Craftmanship is an elective I am going to take in Q4, in this course will offer me even more experience in digital manufacturing. Again to increase my toolbox I am to work with another digital manufacturing technique, for instance sublimation printing.

The course aims to challenge student by making a bag or pocket with a digital manufacturing approach. Which will allow me to grow within Math Data and Computing, Technology and Realization and Creativity and Aesthetics.

Math Data and Computing

Technology and Realization

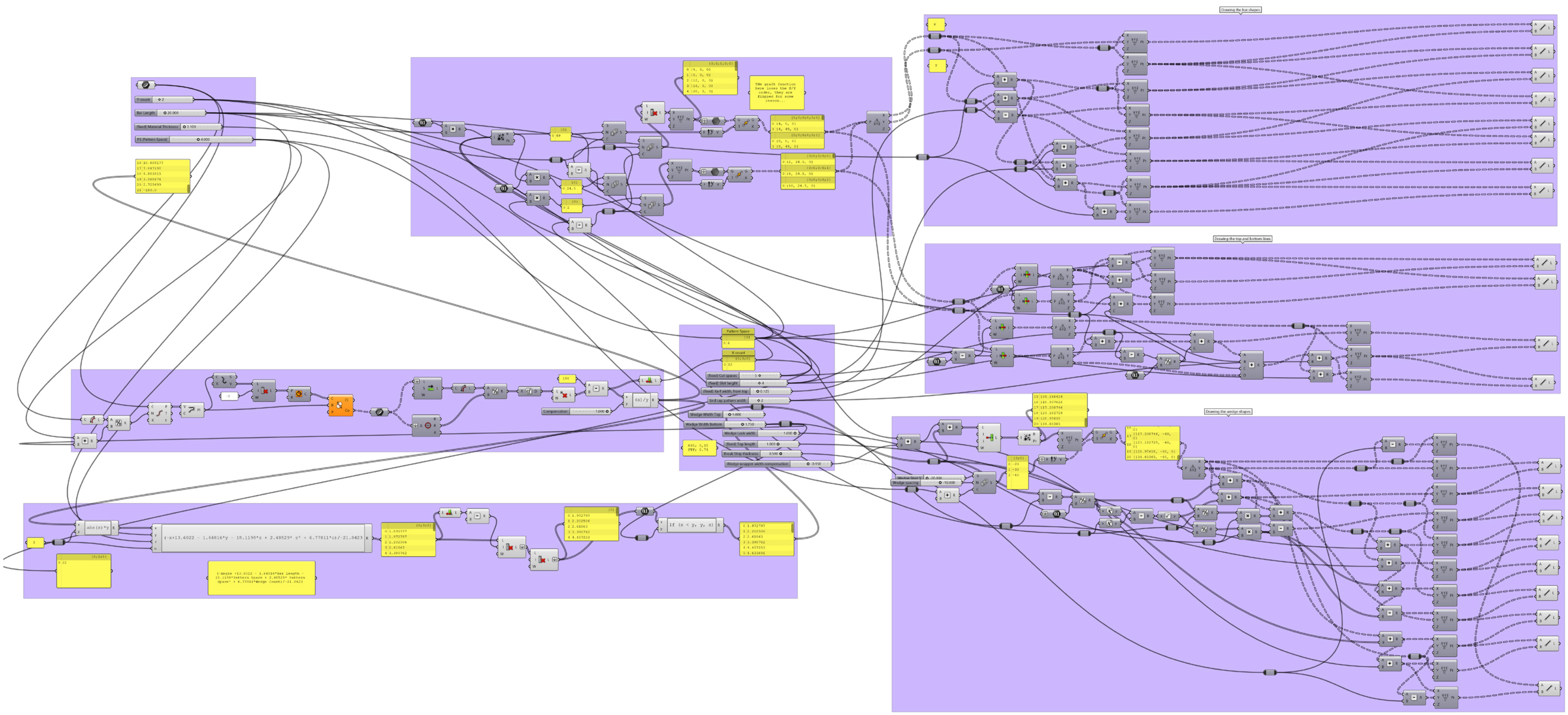
Creativity and Aesthetics

Lastly I am following the elective Design Innovation Methods, a course focussed on business application of concepts and products in business. This course allows you to analyse a project of your own. I am going to analyse my FBP as if it was a business, this will force me to see my own project from a different perspective. This approach will challenge me from an Business as well as a User perspective. This course really allows me to cover these aspects which I wouldn't have covered in my FBP.

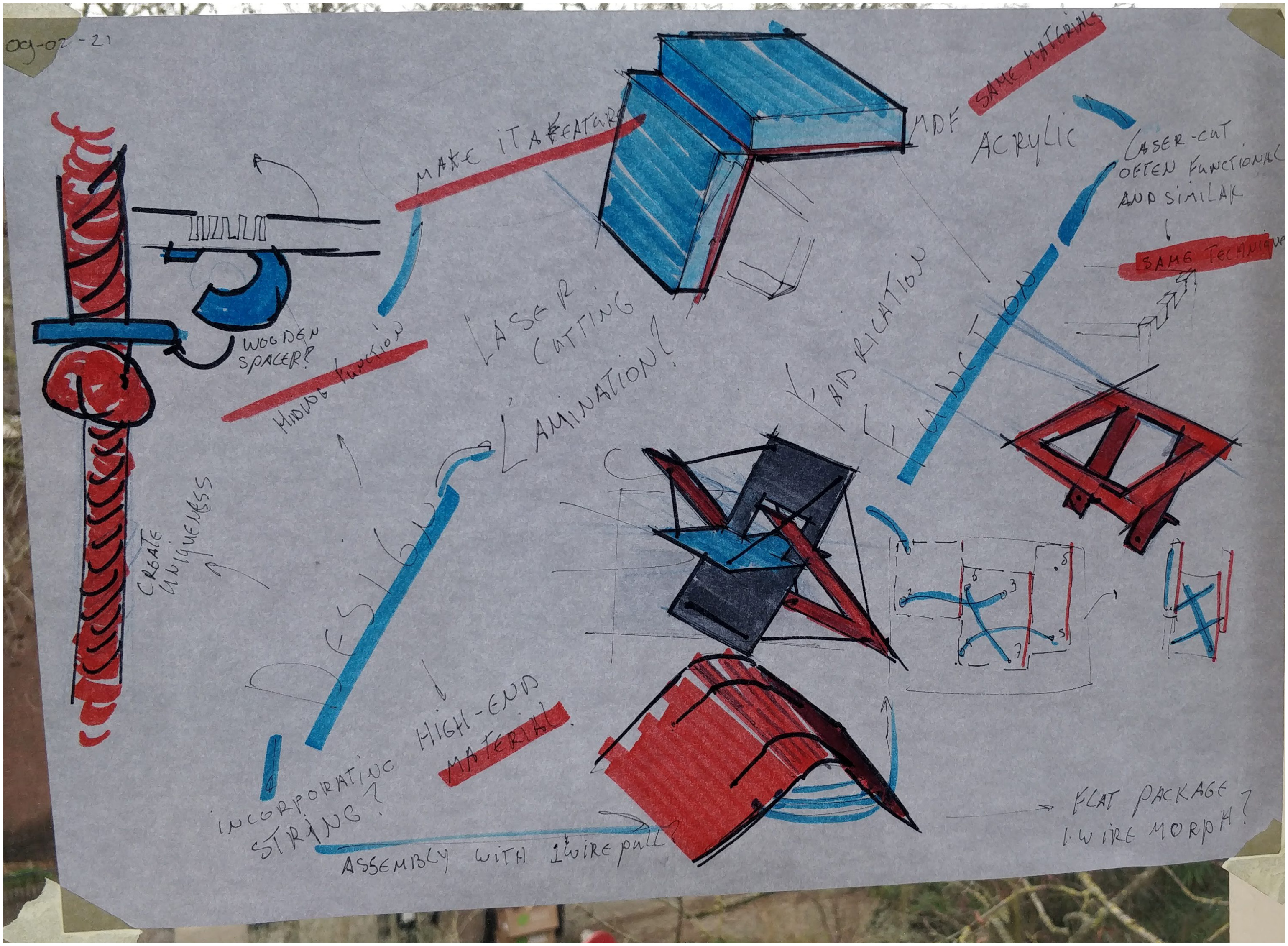
Business and Entrepreneurship

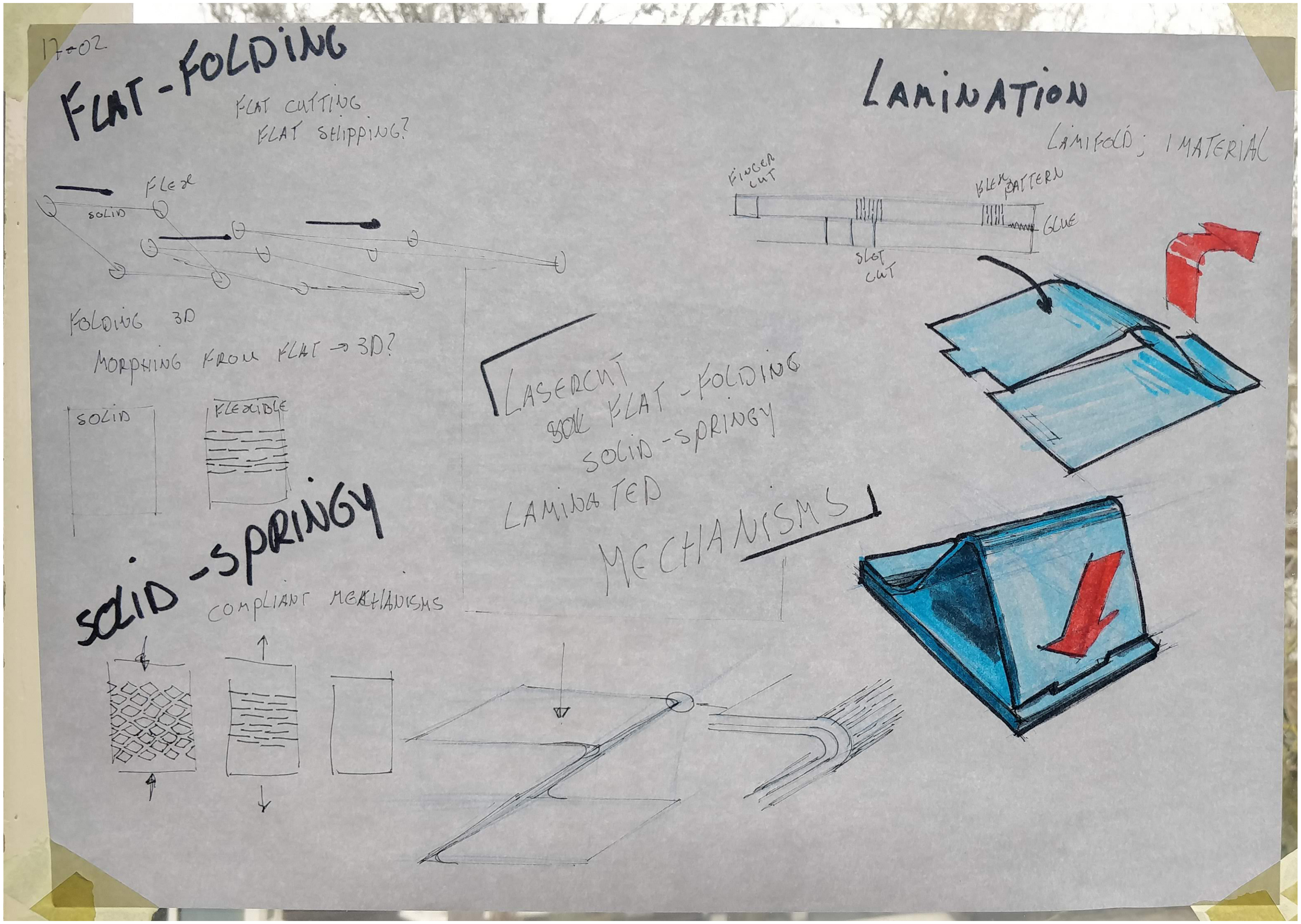
User and Society

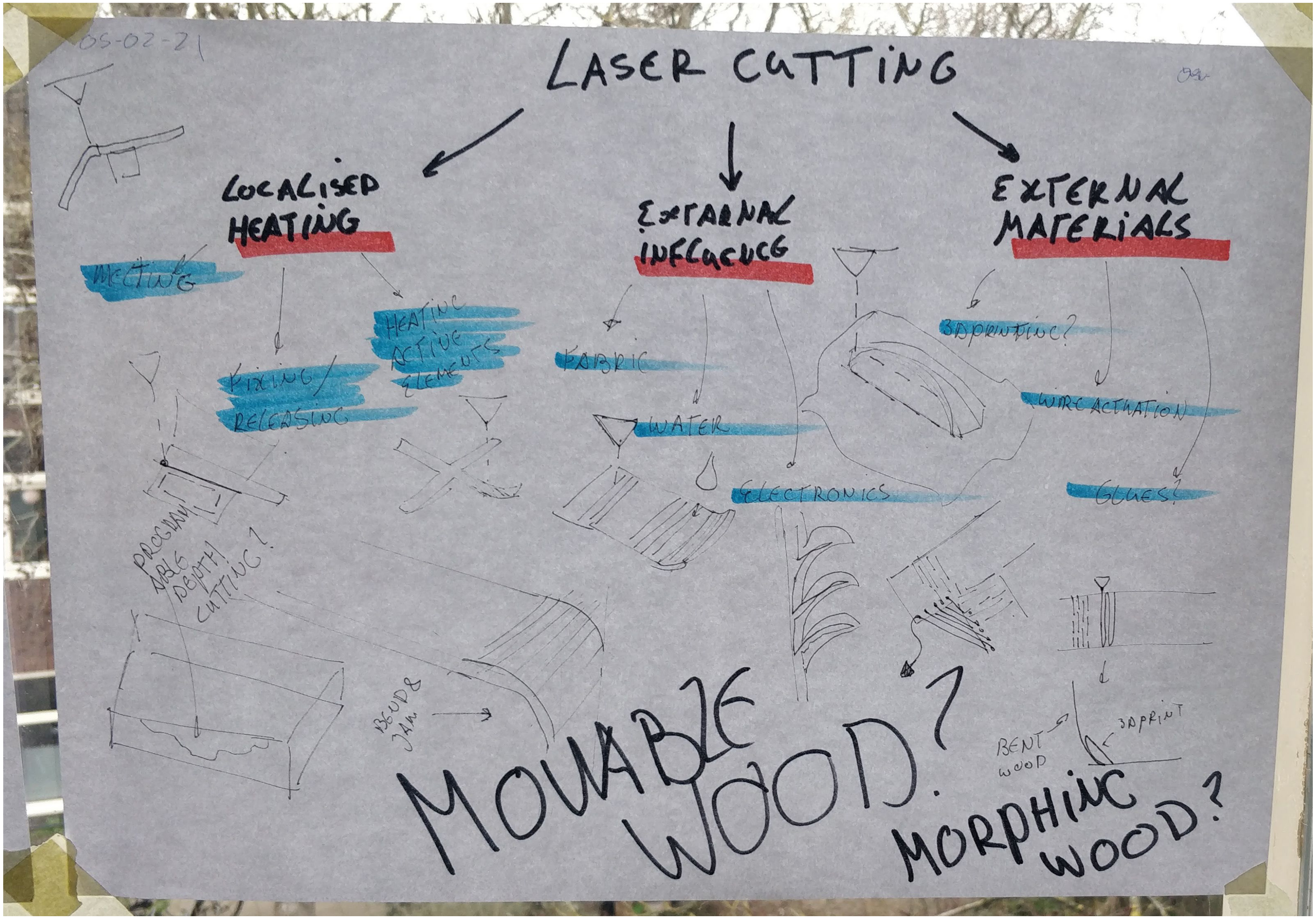
Appendix 2 GrassHopper file

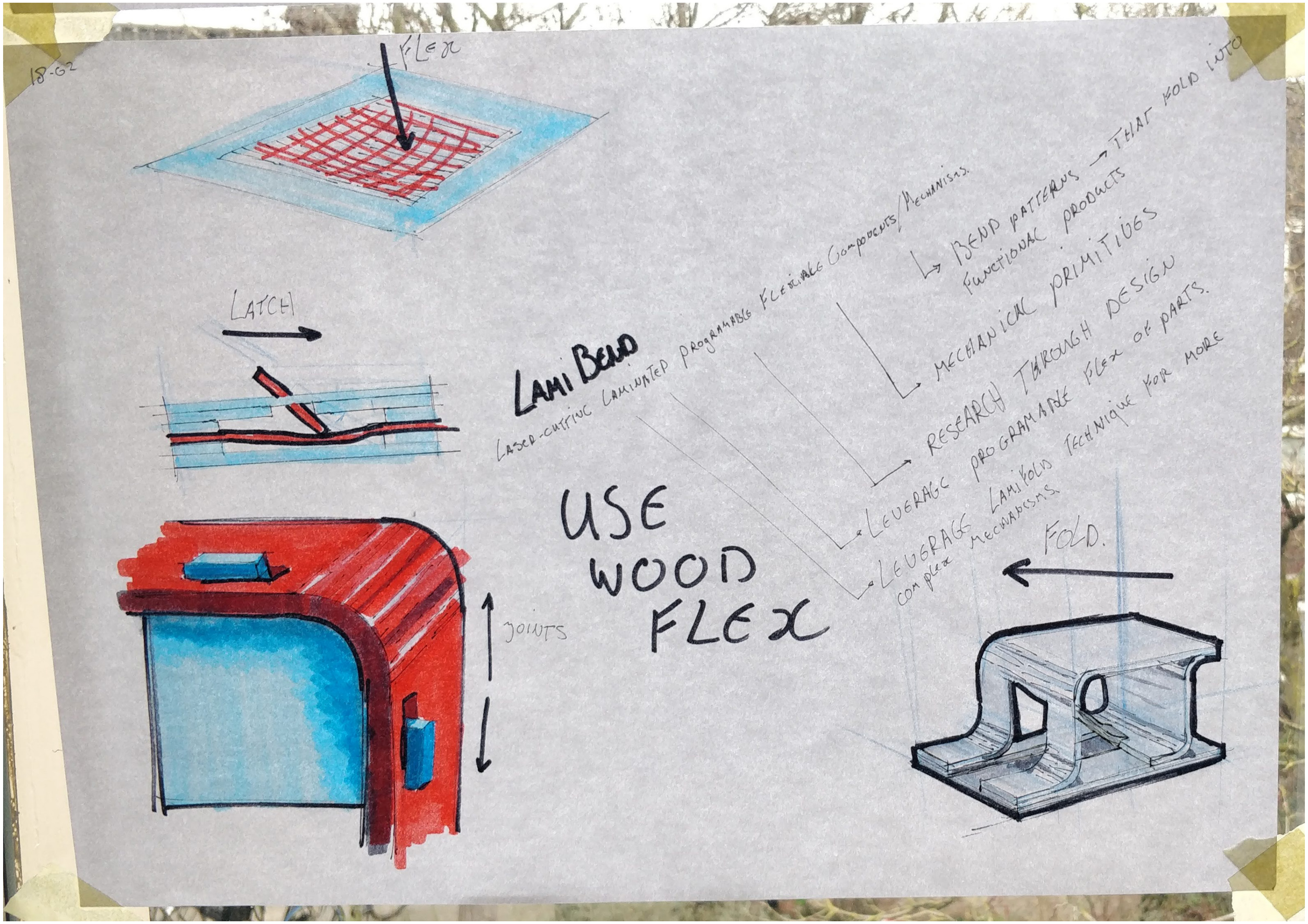


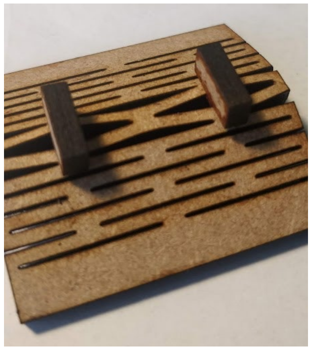
Appendix 2, additional sketches and presentations for collaboration with external experts

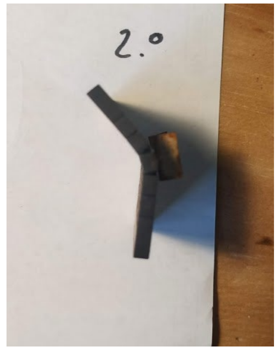



17-02
FLAT-FOLDING
FLAT CUTTING
FLAT SHIPPING?
FLEX
SOLID
FOLDING 3D
MORPHING FROM FLAT → 3D?
SOLID
FLEXIBLE
SOLID-SPRINGY
COMPLIANT MECHANISMS
LASERCUT
FLAT-FOLDING
SOLID-SPRINGY
LAMINATED
MECHANISMS
LAMINATION
LAMIFOLD; 1 MATERIAL
FINGER CUT
FLEX PATTERN
GLUE
SLOT CUT


05-02-21
LASER CUTTING
LOCALISED HEATING
EXTERNAL INFLUENCES
EXTERNAL MATERIALS
MELTING
FIXING/ RELEASING
HEATING ACTIVE ELEMENTS
FABRIC
WATER
ELECTRONICS
3D PRINTING?
WIRE ACTUATION
GLUES?
PROGRAMMABLE DEPTH CUTTING?
BENT WOOD
3D PRINT
MOVABLE WOOD?
MORPHING WOOD?


18-02
FLEX
LATCH
LAMI BEND
LASER-CUTTING LAMINATED PROGRAMABLE FLEXIBLE COMPONENTS/MECHANISMS.
BEND PATTERNS → THAT FOLD INTO FUNCTIONAL PRODUCTS
MECHANICAL PRIMITIVES
RESEARCH THROUGH DESIGN
LEVERAGE PROGRAMABLE FLEX OF PARTS.
LEVERAGE LAMIFOLD TECHNIQUE FOR MORE COMPLEX MECHANISMS.
USE WOOD FLEX
JOINTS
FOLD.

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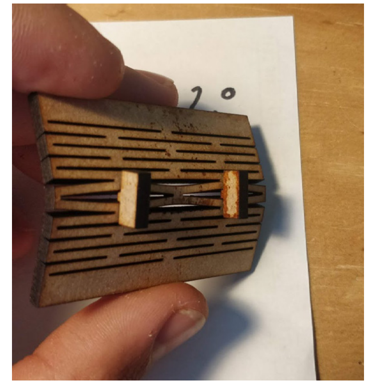

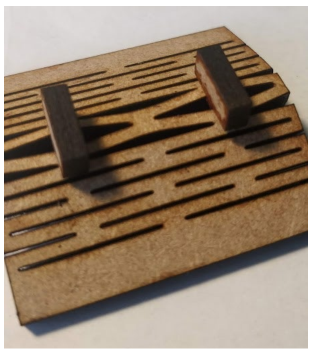

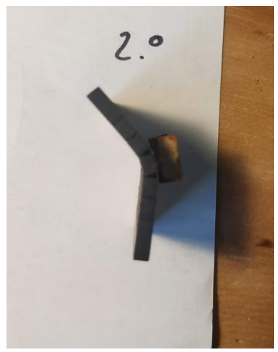
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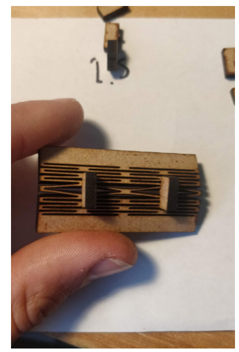
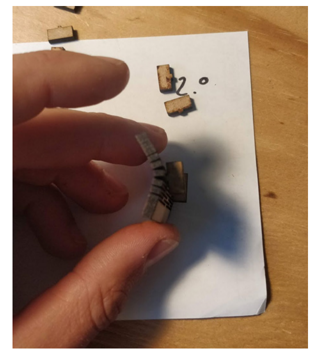
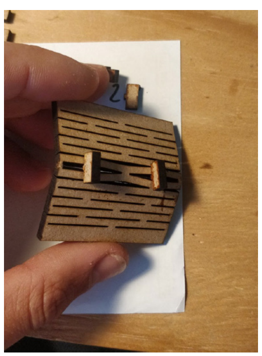
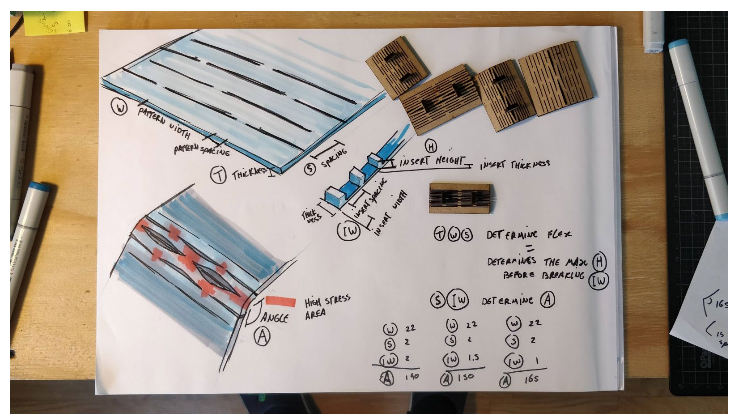






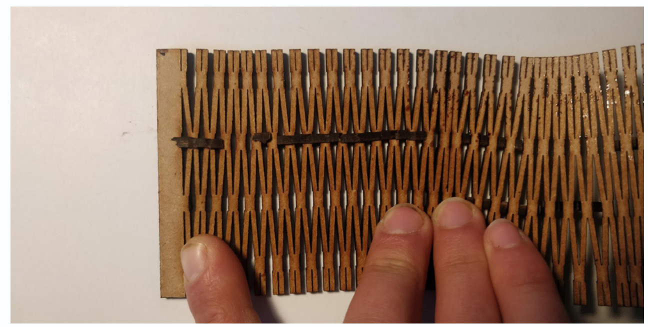

W PATTERN WIDTH
PATTERN SPACING
T THICKNESS
S SPACING
H
INSERT HEIGHT
INSERT THICKNESS
THICKNESS
INSERT SPACING
IW INSERT WIDTH
T W S DETERMINE FLEX
=
DETERMINES THE MAX H
BEFORE BREAKING IW
S IW DETERMINE A
HIGH STRESS AREA
ANGLE A
W 22
S 2
IW 2
A 140
W 22
S 2
IW 1.5
A 150
W 22
S 2
IW 1
A 165

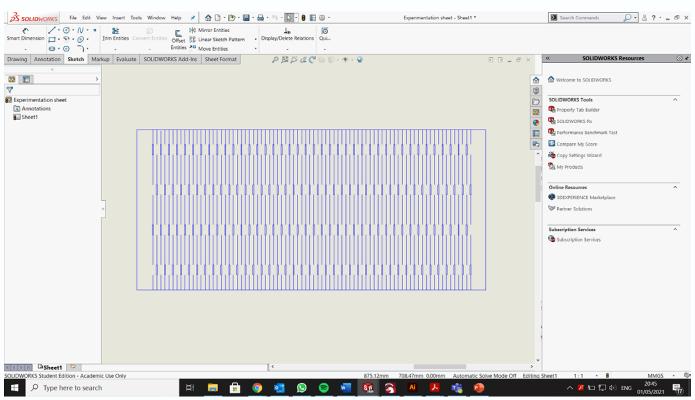
LaserJamming

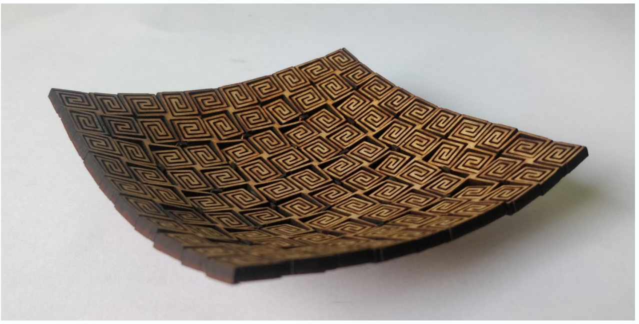
Increasing laser-cut fidelity by 2.5D laser cutting.

The technique

- Design
- Cutting
- Pre-Stretch assembly
- Results!







What will we present

- Design on the patterns
- Workflow; optimized pre-stretch technique
- Design tool; grasshopper plugin supported by DATA
- Example designs; Jewelry, architecture panels, chair

Questions

- What example designs?
- How could we strengthen the reliability aspect?
- How can we decrease the manual assembly
- Thoughts? Novelty? Relevance?