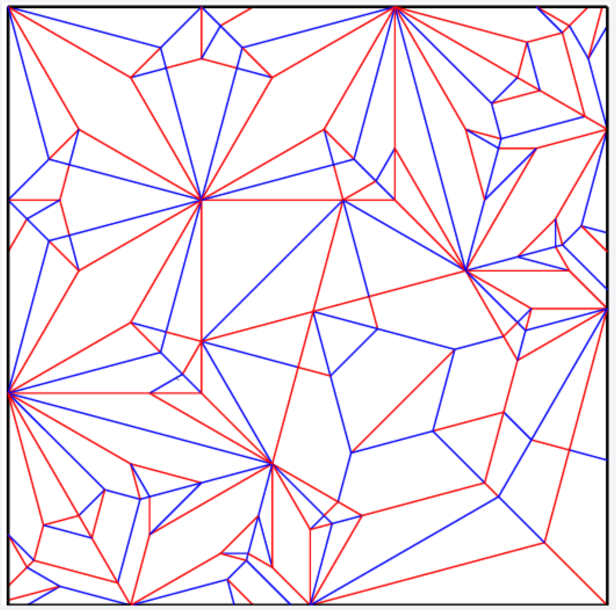
Origami Folds Printer

Major Project

Design Process Journal



B.Yasser Zeid
MSc PDE 2021

University of Glasgow

THE GLASGOW SCHOOL OF ART

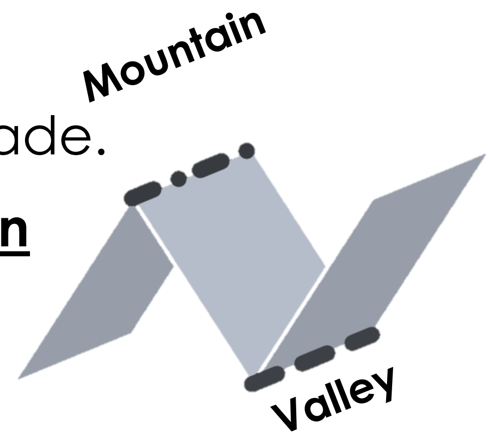
Origami is a Japanese words made out of 2 syllables;

Ori which means folding and **gami** (Kami) which means paper.

Through a series of simple folds according to the 4 rules of Origami design, a shape is made.

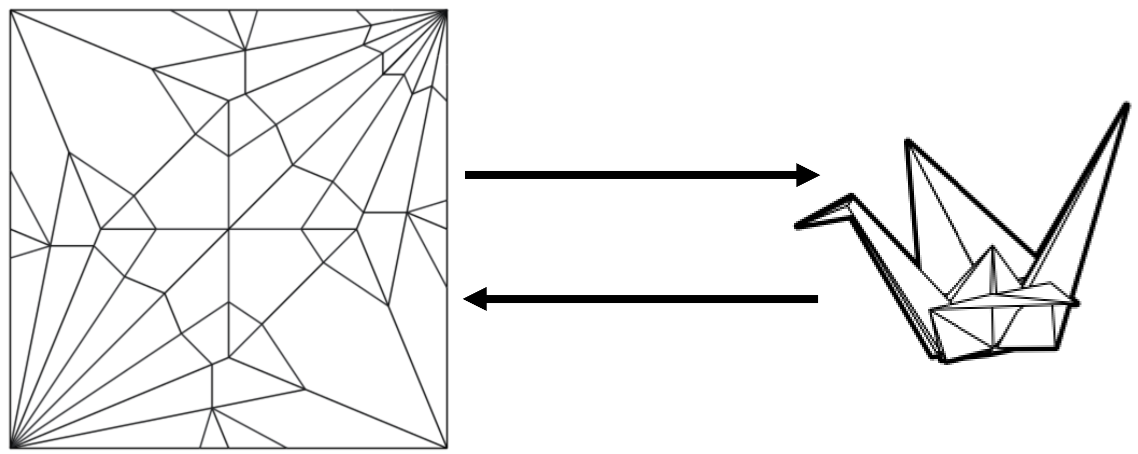
The combination of folds that create the base to the shape are called **Crease Pattern**

It consists of Valley Folds and Mountain folds



The Design thinking here came to reversing the basic idea of having the crease pattern after folding the shape, to having the crease pattern pre-creased and ready to be collapsed to shape and the extra folds added forming the final shape.

This would be a tremendous help for everyone working on **designing** new Origami models, or **amateur** origami enthusiasts longing to work with more complex shapes. It can also be a great aid to **architecture students** with their modelling, mock ups and prototyping and last but not least this could be a **rapid prototyping** method for anyone researching such structures and seeking applying them in engineering applications; such as the space industry and other fields.

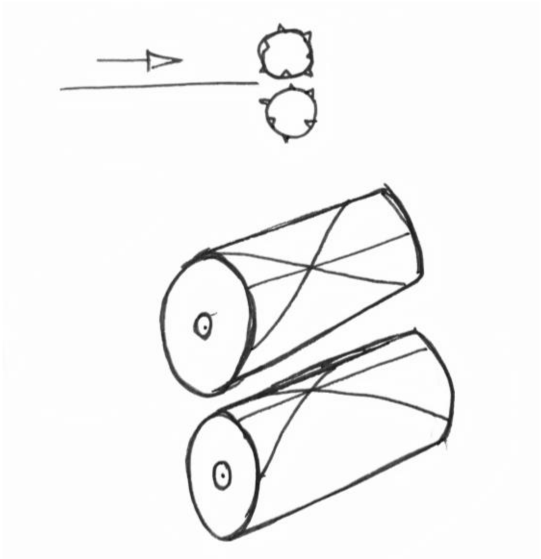


So, designing a product that would indent the crease pattern needed to cover several touchpoints that come with paper creasing;

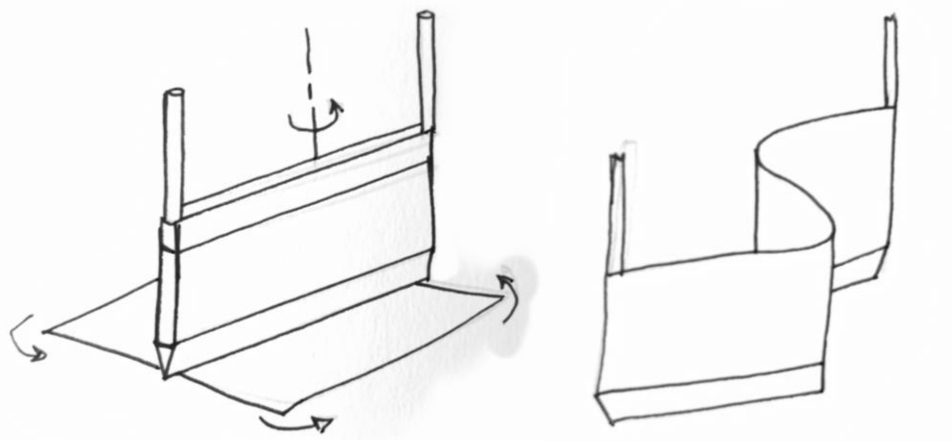
- General movement mechanism
- Indenting tip
- Indenting force
- Flooring material
- Turn-over mechanism

And started the research and iterations from here around these factors.

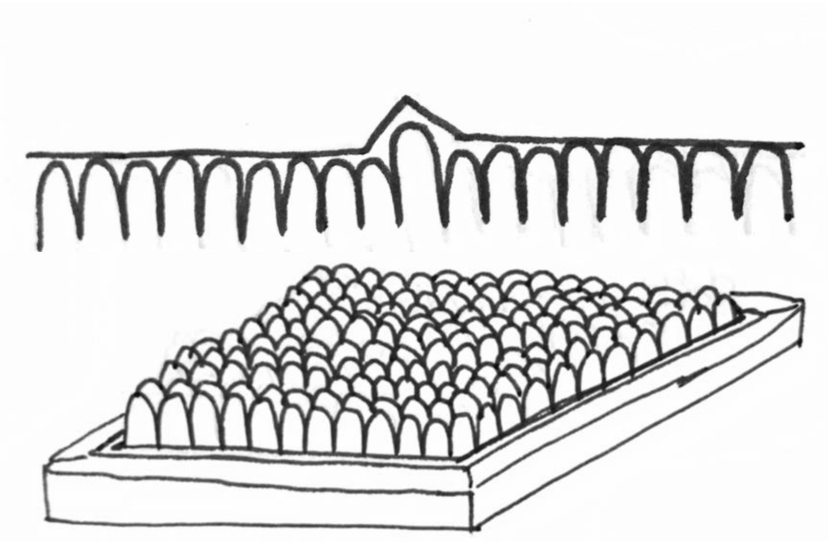
Determining the <u>moving mechanism</u> came through several idea and choosing the best fit idea.



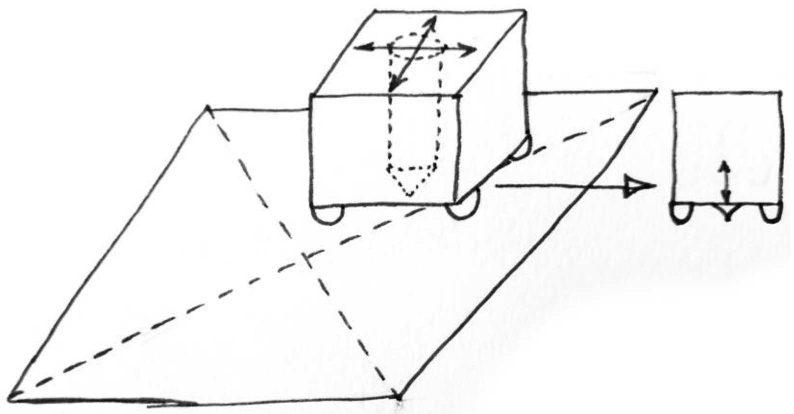
Rollers with changing topography through magnetic field control or constant topography for mass production.
Paper goes in the rolling and comes out with crease pattern engraved.



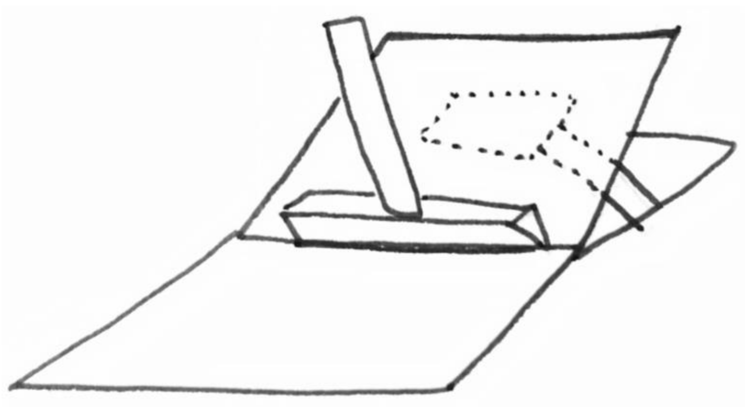
Using a **malleable sheet metal** to do the indenting for the paper with the control of the 2 pillars holding it to create the crease pattern.



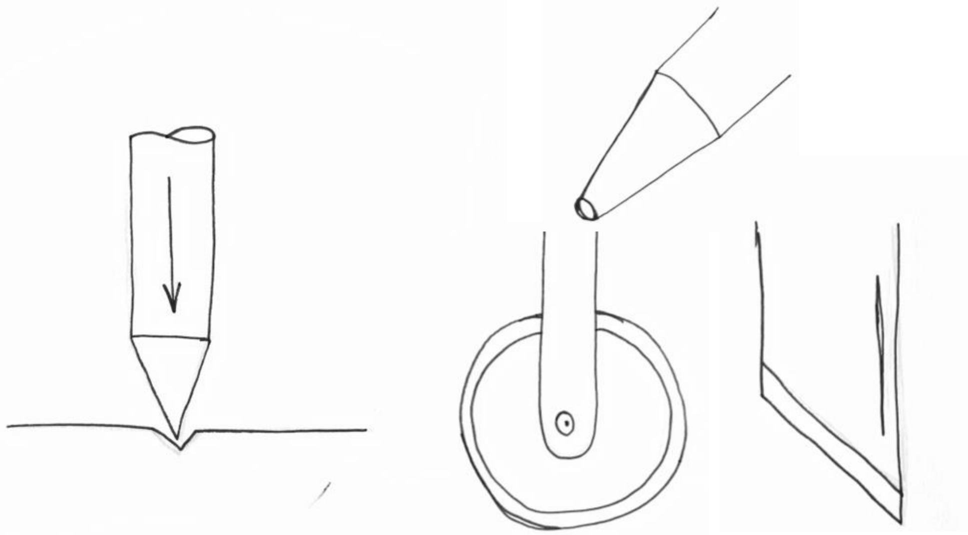
Using a **beads carpet** below the tensioned piece of paper where the beads elevate making the indentations in the paper.



Designing a **cube** that would run over the paper and make the indentations. The use of optic sensors would be necessary.



Using an **indenting pivot** with the aid of a **moving ground**, the relative motion between the 2 along the piece of paper would create the folds.



Using a **numerical control** machine to move over the paper and making the folds. Several options for the indenting tool can be used and even LASER which was feared to burn the paper

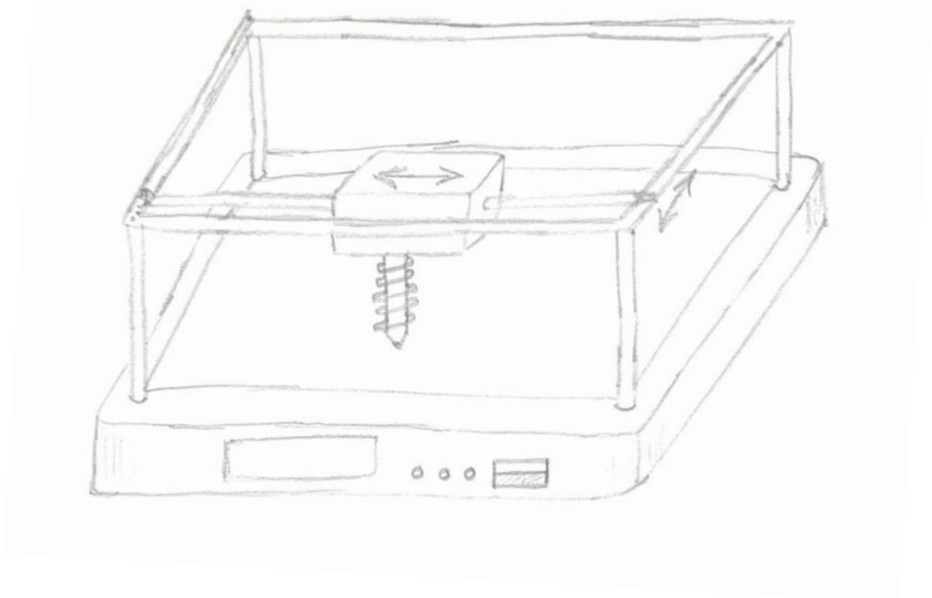
The choice in the end being the numerical control machine rooted from the aspiration of having an up and running system by the end of the project and with such narrow time window, I had to exclude some rather technically challenging ideas though, I really favored some as the indenting cube but time was of essence.

Moving on after the decision to have a numerical control machine, I researched into open source 3D printers and chose the HyperCube and had to alter the design to suit my needs;

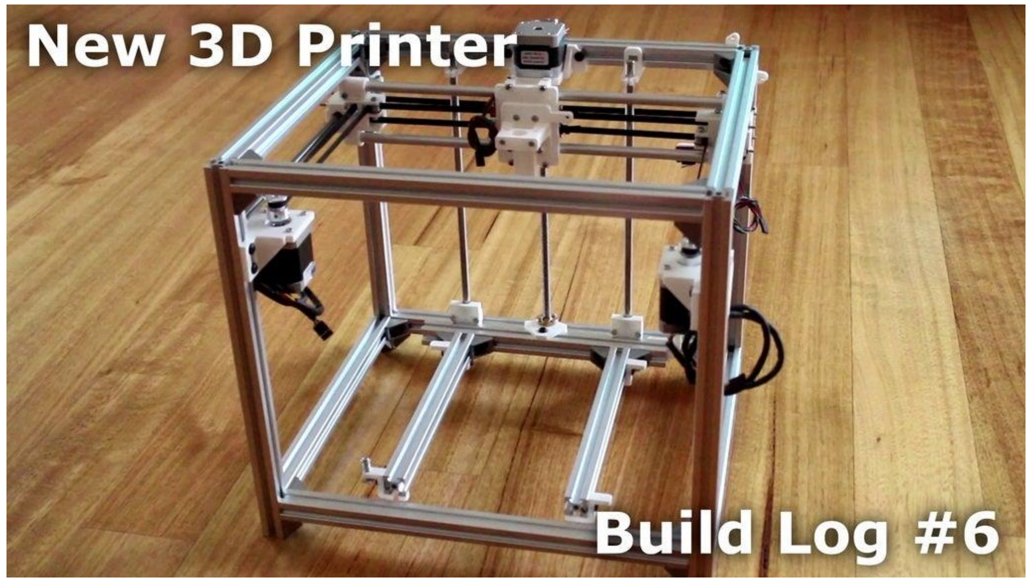
Shortening the pillars with no need for the Z-Axis as the Z movement would be the indenting pressure to be applied using a servo motor.

Removing all the heaters, feeder, extruder and unneeded parts.

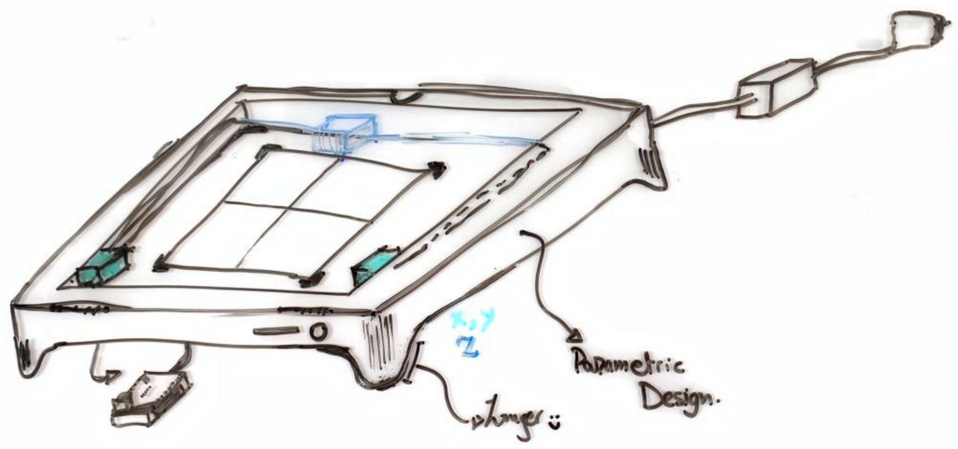
Adding the Origami indenting tip and its fixture.



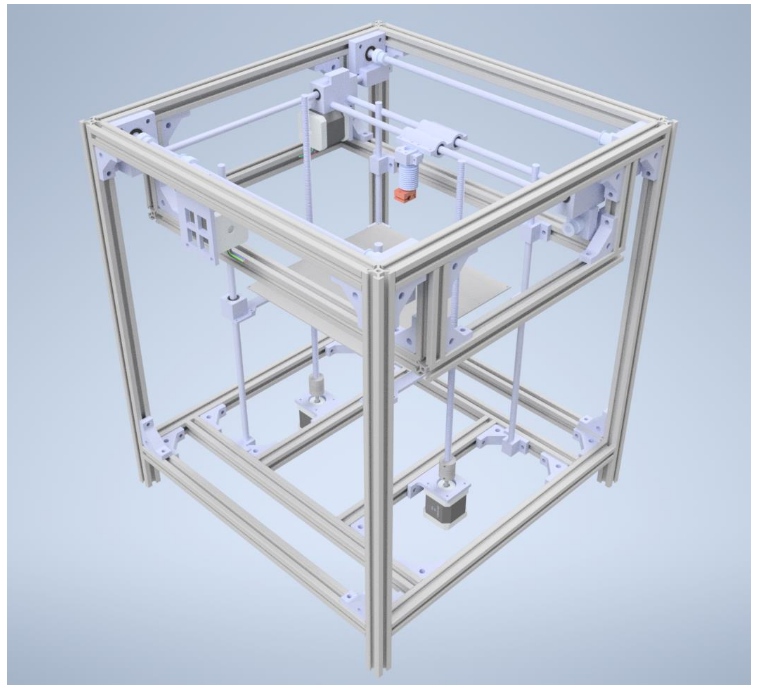
Initial Sketch inspired by the Mayku formbox



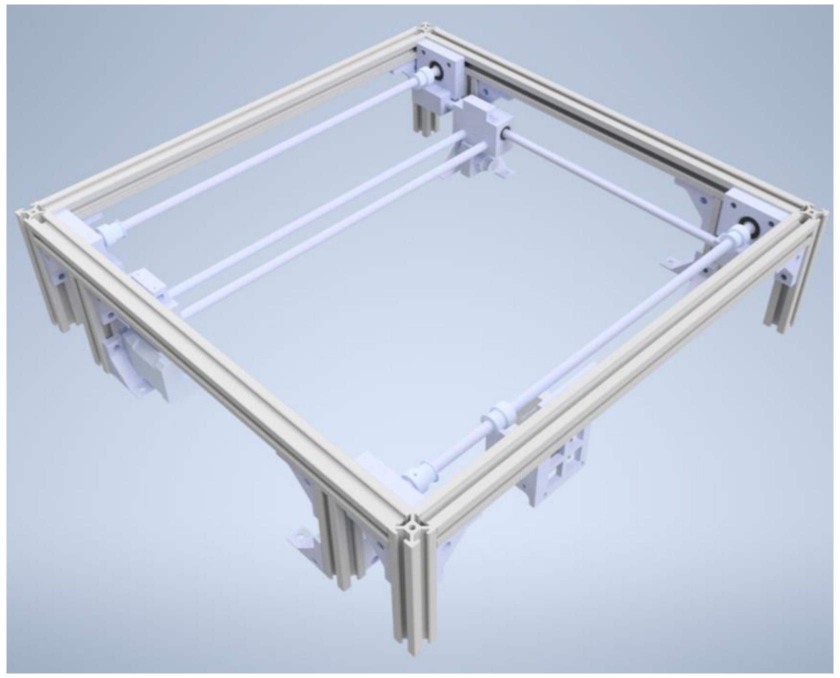
HyperCube open source 3D Printer chosen to be used



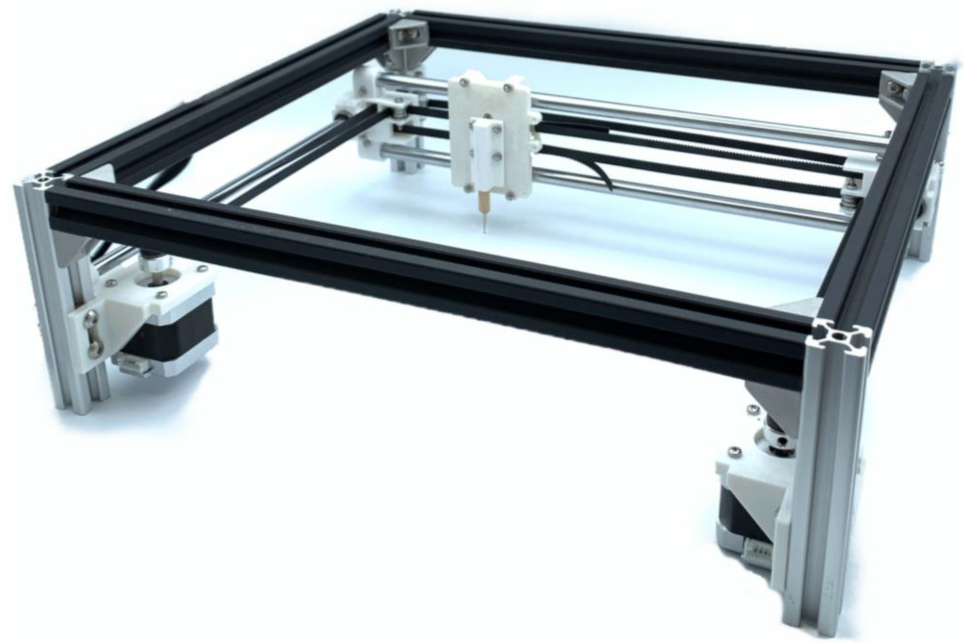
More mature vision sketch of the machine



HyperCube CAD render before altering



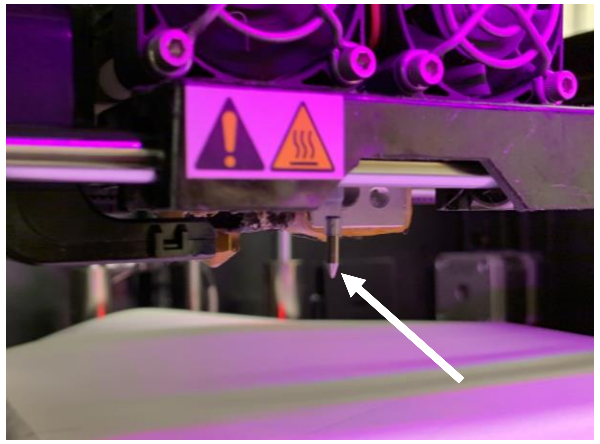
HyperCube CAD render after altering



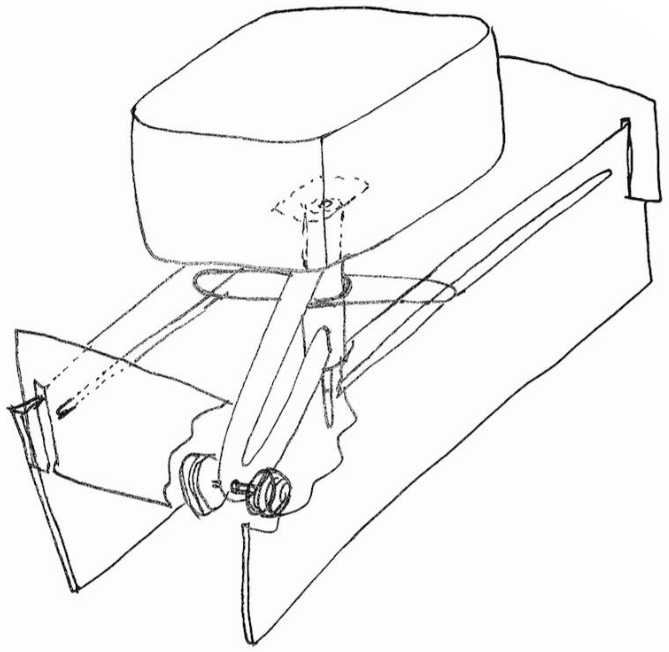
Up and Running Prototype

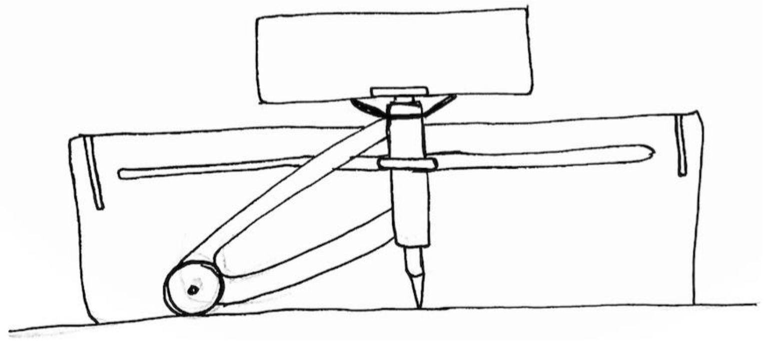
Seeking a proof of concept that the indentations can be made through applying the proper force to the paper I passed through several stages.

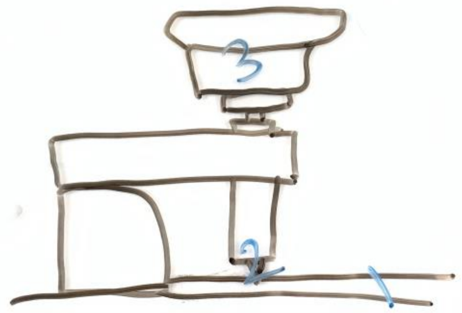
Firstly, Ran a trial with an existing 3D printer using an empty pen inserted in it to make the indentation

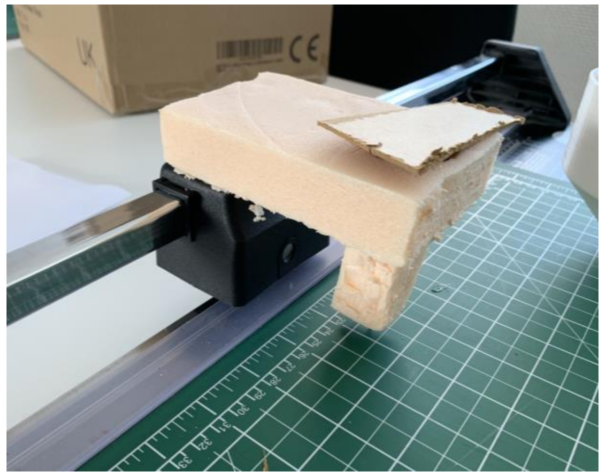


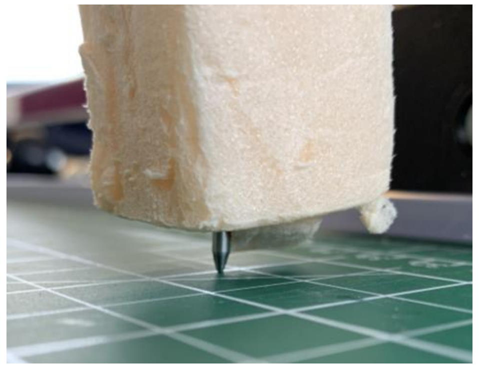
Unfortunately, it didn't give in a proper outcome that can be utilized in prospective work. So, I designed a set up to be used where the indenting tip is inserted to run along a straight-line while having loads added over it affecting directly the indenting force.
Then when came to applying it, I altered the design once again and used an existing paper cutter's beam as a straight-line moving guide.







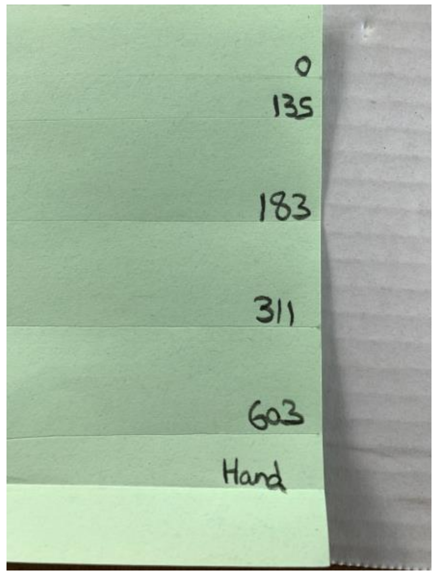


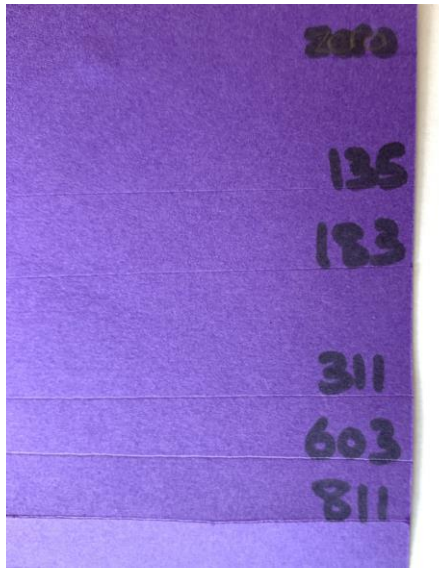


Initially used an empty pen tip as an indenting tool which I already use in my origami works to make certain creases. Along with a cutting mat as a flooring material as it was a middle ground material within hardness and softness, I ran several iterations varying the load using several items found around the studio, weighed them to know the applied load to help with the upcoming work.

- 3D Print: 135 gm
- Golf Ball: 48 gm
- Lock: 128 gm
- Stapler: 292 gm
- Water filled bottle: 500 gm

Ran several trial on two pieces of paper of different weights; 80 and 150 gsm and changing the load with every crease, it showed the different and gradation of crease intensity.





Afterwards, moved on to calculating the force equivalent to the proper load needed to make the crease and researching into Hooke's law of springs, I had the simple formula ready for application.

$F = k.x$

$F = 0.603 \text{ gm} \times 9.81 \text{ m/s}^2 = 5.91 \text{ N}$

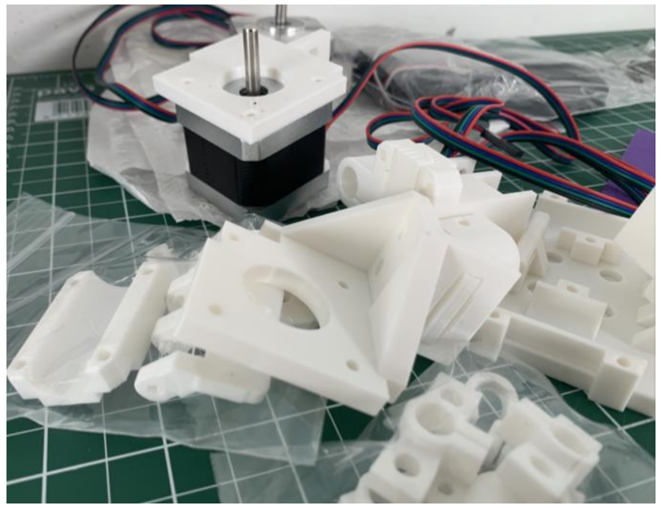
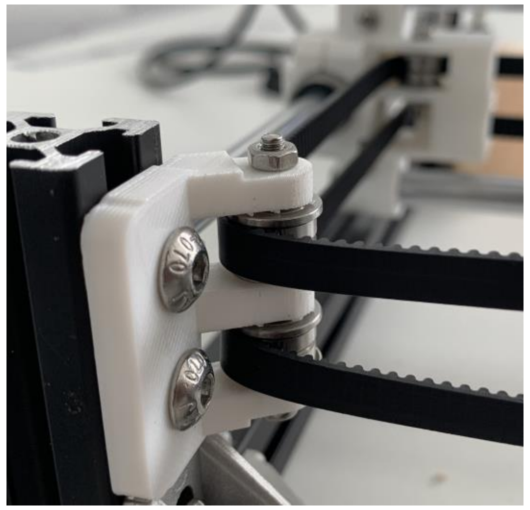
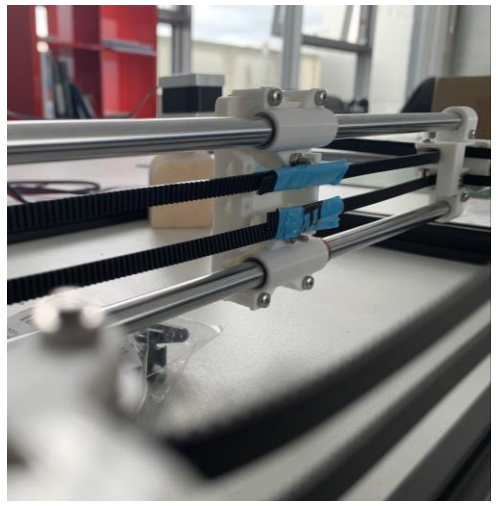
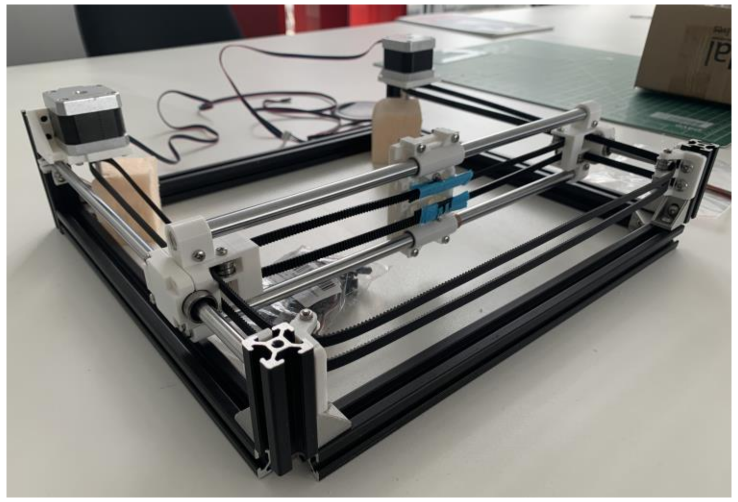
X: Servo motor and setup

k: Spring stiffness

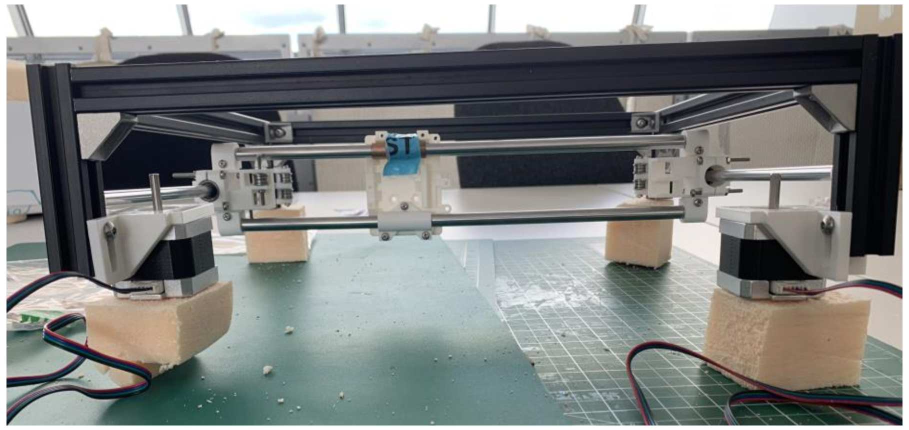
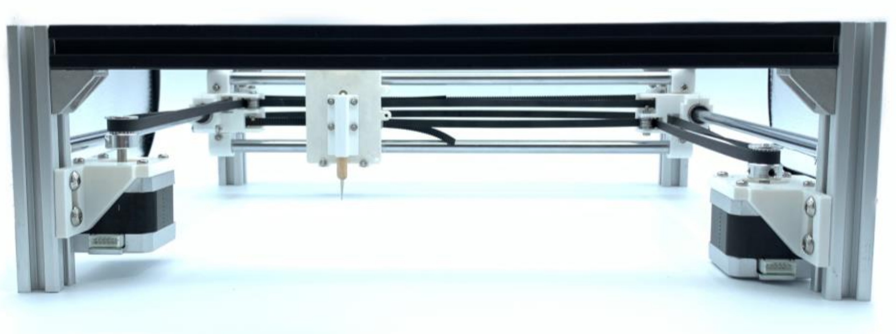
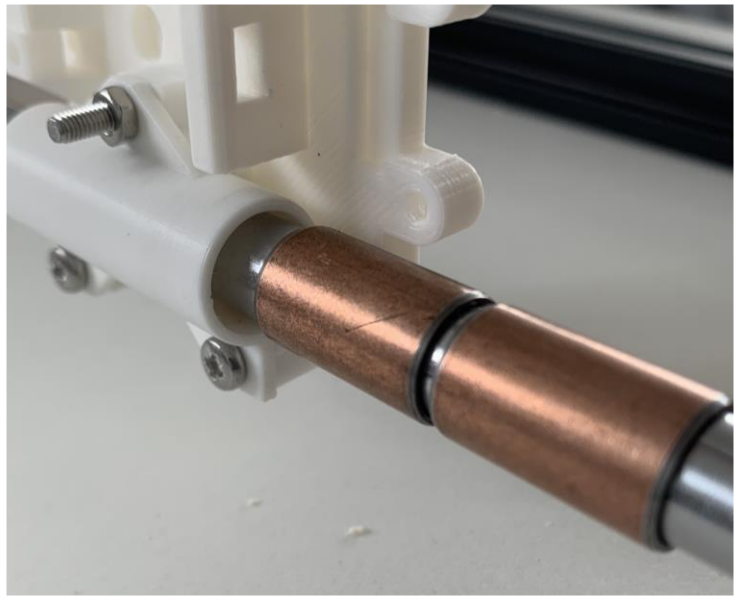
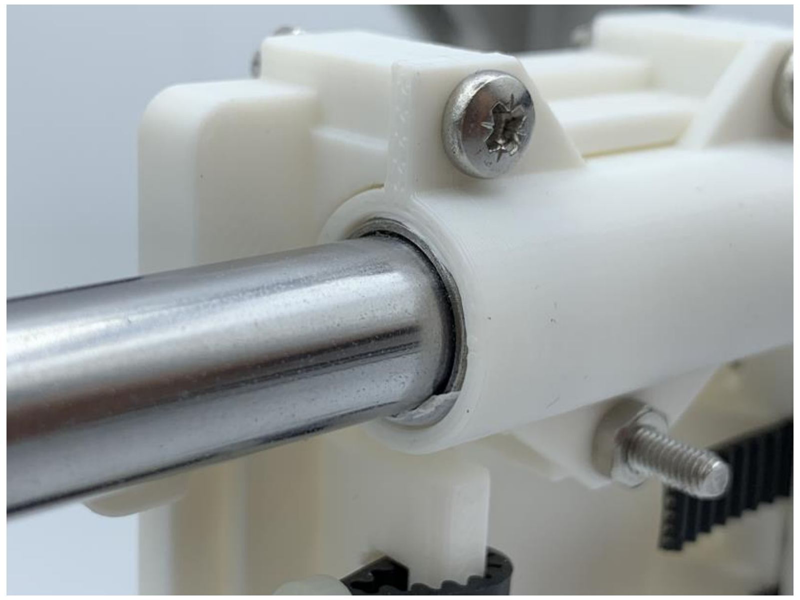
With settling upon the cutting mat as a flooring material, I looked more into crafts tools and reached to embossing styli to be used in engraving on paper so tried using it and gave in even better indentations than empty pens.

Having a proof of concept for the folding, it was time to start working on the product prototype:

Bought the needed parts and handed the workshop what needed some processing, ordered a 3D print for the brackets and main parts and within few days I had the whole system assembled and ready to go with some few minor issues to be tackled.

Had 2 issues while assembling the structure; The vertical columns were unequal and too short so had to compensate initially with foam then got proper extra extrusion beams. Also had a problem with one of the 3D prints going into a clearance fit with the bushes so got PTFE-Teflon tape and fixed it to interference fit.

Having a system up, needed to work on having it running. Came in with the electronics and programming part.

Started off with disabling /*Commenting*/ all the unnecessary parts of the code attached with the open source documents which was using Marlin; a firmware used to control numerical control machines.

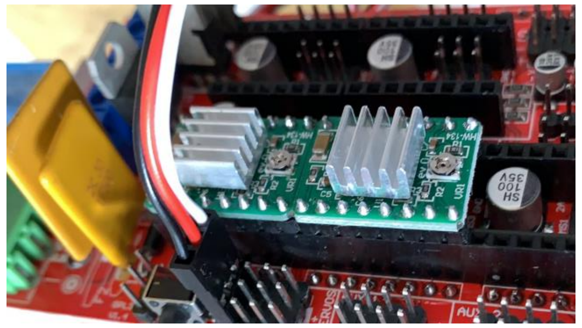
Marlin - Configuration.h | Arduino 1.8.15

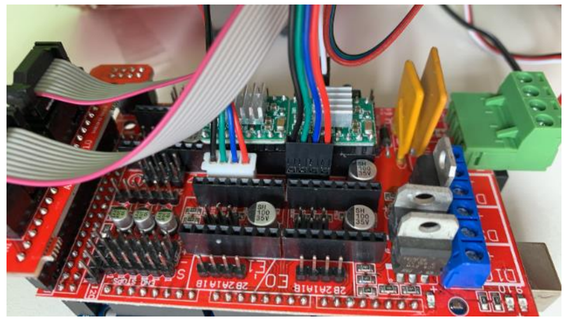
File Edit Sketch Tools Help

Marlin | Configuration.h | Configuration_adv.h | Version.h

```
// @section extruder

// This defines the number of extruders
// :[0, 1, 2, 3, 4, 5, 6, 7, 8]
#define EXTRUDERS 1

// Generally expected filament diameter (1.75, 2.85, 3.0, ...). Used for Volumetric, Filament Width Sensor, etc.
#define DEFAULT_NOMINAL_FILAMENT_DIA 1.75

// For Cyclops or any "multi-extruder" that shares a single nozzle.
//#define SINGLENOZZLE

// Save and restore temperature and fan speed on tool-change.
// Set standby for the unselected tool with M104/106/109 T...
#if ENABLED(SINGLENOZZLE)
  //#define SINGLENOZZLE_STANDBY_TEMP
  //#define SINGLENOZZLE_STANDBY_FAN
#endif
```

In parallel, assembled the electronics together and connected the motor drivers to the shield connected over the main board and all that connected to the power simply and the motors making the system fully ready to be operated

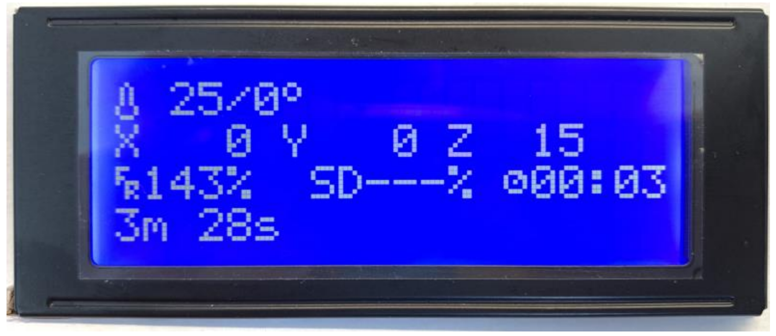


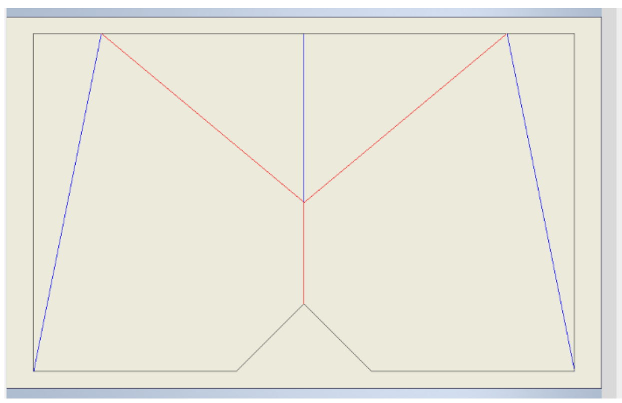


To start operating the machine, it was needed to have a Gcode file to be uploaded to the SD card, inserted in the machine and have it work.

Only issue was with the pause between the mountain and valley folds to turn over the paper which was decided to be manually just to fit the time window given for the product. So, had to try and see the normal flow of work and what it'd yield.
Found out that the DXF2GCode software already separates the fold types in the gcode

So I just needed to add a pause code; M125 between the 2 fold types and have a dry test run with no tool or paper mounted.





```
(*** LAYER: MountainLine ***)

(* SHAPE Nr: 1 *)
G0 X   4.000 Y   7.000
M3 M8
G0 Z   3.000
G1 Z  -1.500
F400
G1 X   5.875 Y   7.000
F150
G1 Z  -3.000
F400
G1 X   4.000 Y   7.000
F150
G1 Z   3.000
G0 Z  15.000
M9 M5

(* SHAPE Nr: 3 *)
G0 X   2.125 Y  10.000
M3 M8
G0 Z   3.000
G1 Z  -1.500
F400
```

```
(*** LAYER: ValleyLine ***)

(* SHAPE Nr: 2 *)
G0 X   5.875 Y   9.250
M3 M8
G0 Z   3.000
G1 Z  -1.500
F400
G1 X   4.000 Y   7.000
G1 X   2.875 Y   7.000
F150
G1 Z  -3.000
F400
G1 X   4.000 Y   7.000
G1 X   5.875 Y   9.250
F150
G1 Z   3.000
G0 Z  15.000
M9 M5

(* SHAPE Nr: 4 *)
G0 X   4.000 Y   7.000
M3 M8
```

File Edit Format View Help

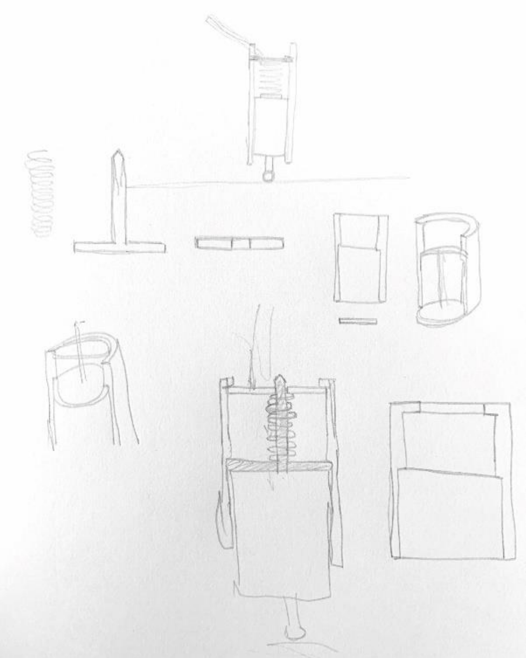
```
G0 X   2.125 Y   4.000
M3 M8
G0 Z   3.000
G1 Z  -1.500
F400
G1 X   5.875 Y   4.750
F150
G1 Z  -3.000
F400
G1 X   2.125 Y   4.000
F150
G1 Z   3.000
G0 Z  15.000
M9 M5

M125

(*** LAYER: ValleyLine ***)

(* SHAPE Nr: 2 *)
G0 X   5.875 Y   9.250
M3 M8
G0 Z   3.000
G1 Z  -1.500
F400
G1 X   4.000 Y   7.000
G1 X   2.875 Y   7.000
F150
G1 Z  -3.000
```

Getting back to the origin of the machine being a 3D printer, I needed to alter the design of the carriage to accommodate the indenting system.

Initially, I was working towards mounting the servo motor to the carriage. Then, got a feedback idea to have the indentation loading be manual! Which was a bright idea with only one problem not having the unloading of force when moving over the idle lines where there should be no indentations.

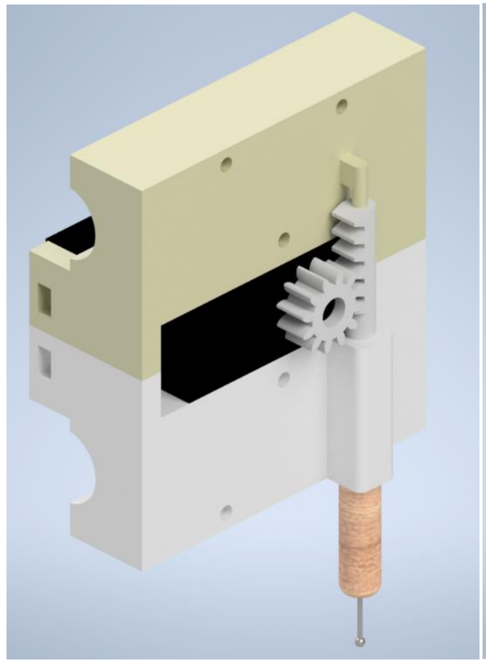
Anyways, I designed the manual fixture to be mounted on the existing carriage of the machine

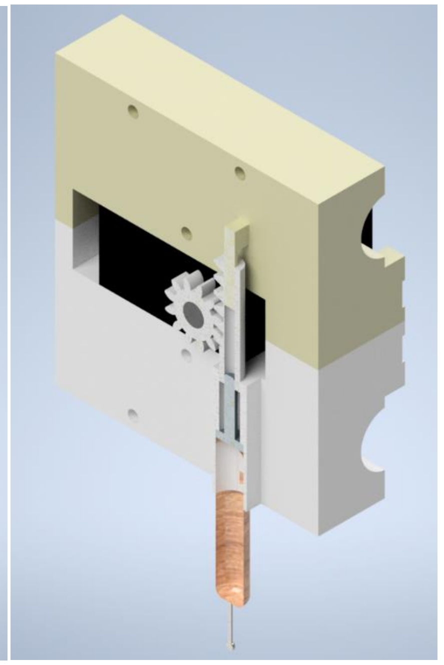
It was intended to have the loading done by a nut moving downwards compressing the spring inducing the force calculated by Hook's law.

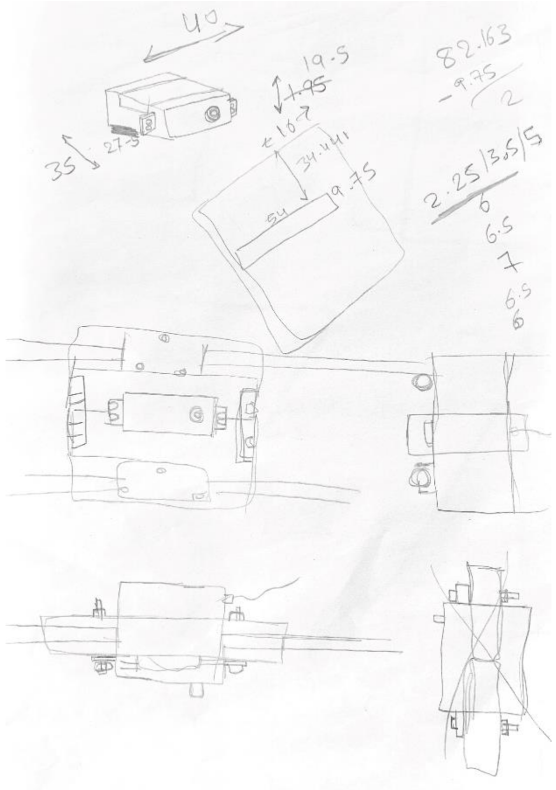


When came to designing the fixture for the servo motor, I found that it's too big for the existing carriage so I designed a whole new carriage divided into upper and lower halves to accommodate the servo within.

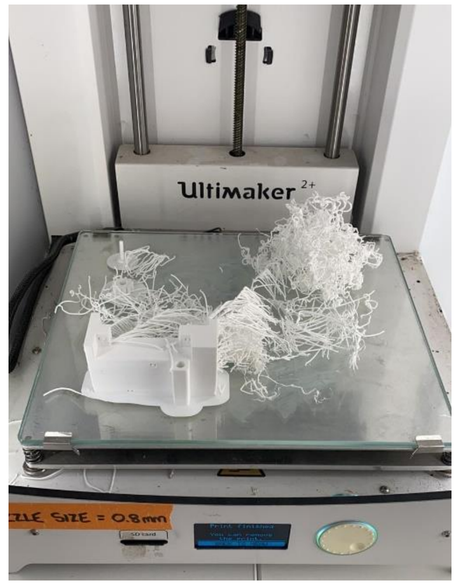
Decided to have a rack and pinion system to transmit the linear motion to compress the spring.

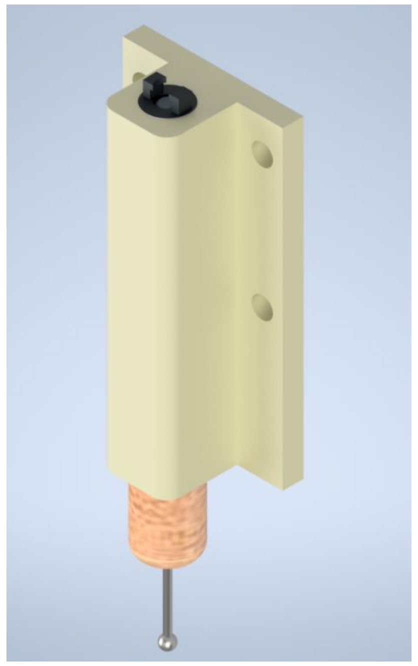




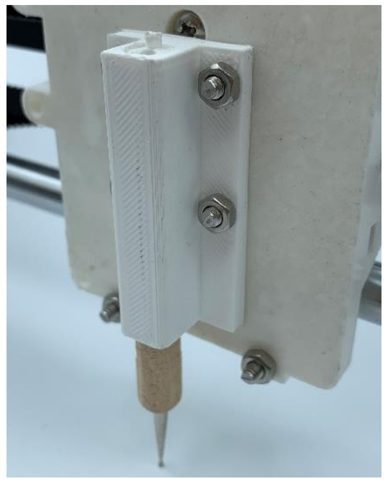


Unfortunately, the attempt to 3D Print this part was a failure and with lack of communication from TSD it was not printed to move forward with this and time was of essence so had to keep going with the manual fixture workin with simple Origami range.





3D Printed the fixture and mounted it to the carriage and worked as desired.



In order to determine the stiffness of the spring used, I made a simple experiment and deduced from it.

$K = F / X = (0.328*9.81\ N) / (10\ mm)$

$= 0.322\ N/mm = 321.7\ N/m$

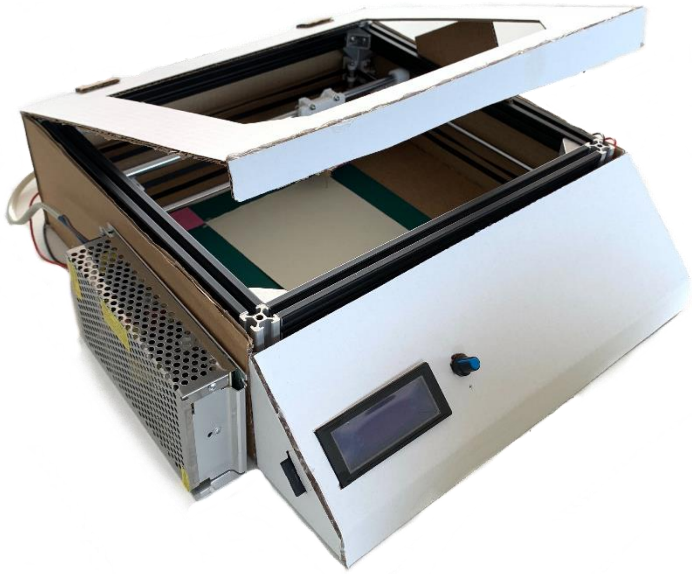
The displacement needed from the servo/nut;

$X = F / k = 5.91 / 0.322 \approx 18\ mm$

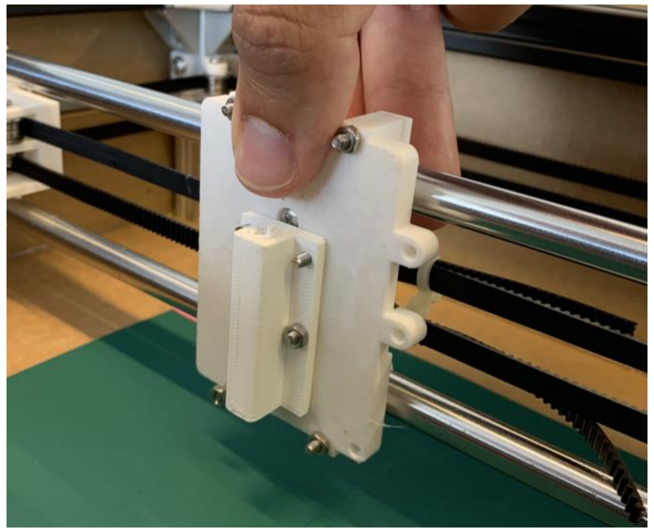
User Ergonomics & Human Factors:

When reached designing the external body of the system, which was important in accommodating all the components within and preventing the relative motion of the whole system around the intending stylus., there was a wide window for ergonomics and human factors to be tackled within such product.

The overall dimensions and weight of the product affecting handling it though it's made to set put on a desk top.



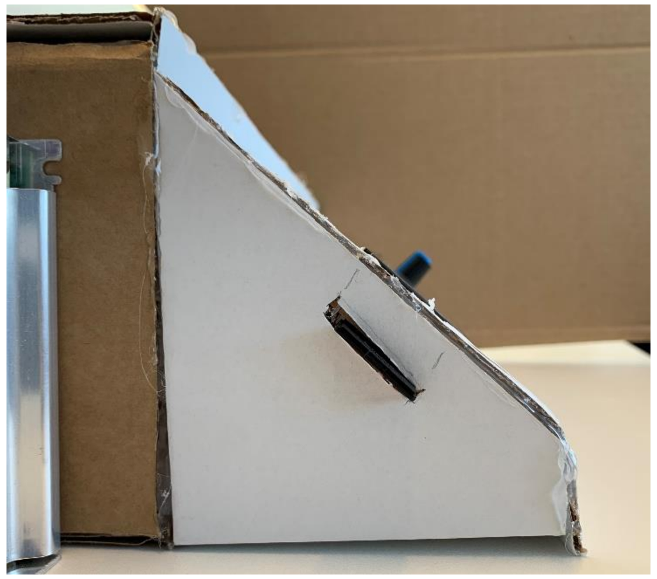
Moving the carriage to the start point manually needed the carriage to be of a suitable thickness to be grasped.



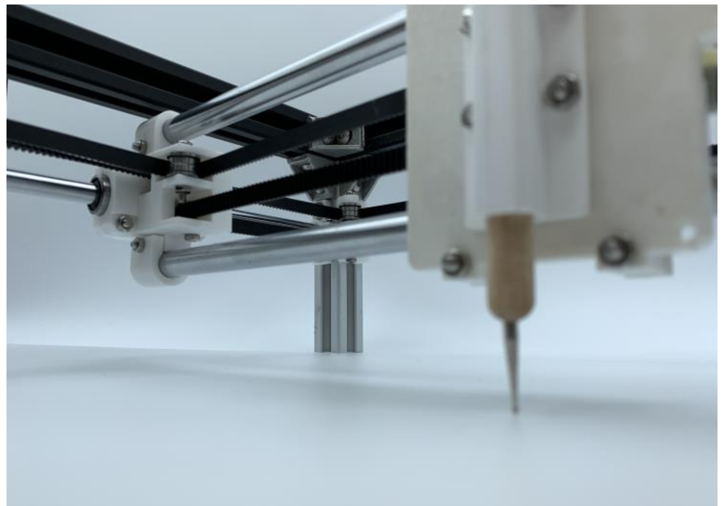
The turnover of the paper was set to be guided manual with 4 marks on the flooring material, it guides and pits the user in ease assuring the paper is in place

The interface and knobs and buttons used to operate the machine are huge touch points with human factors and might need UI/UX designer

The inclined angle of the interface is to have a comfier sight and hand posture for a better user experience

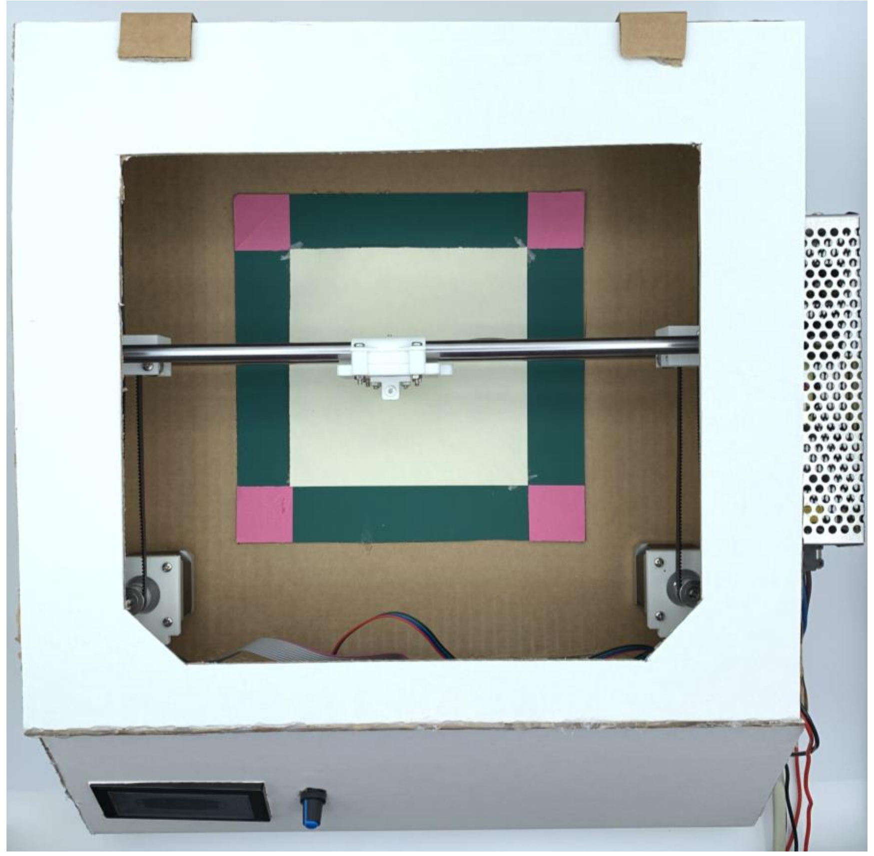


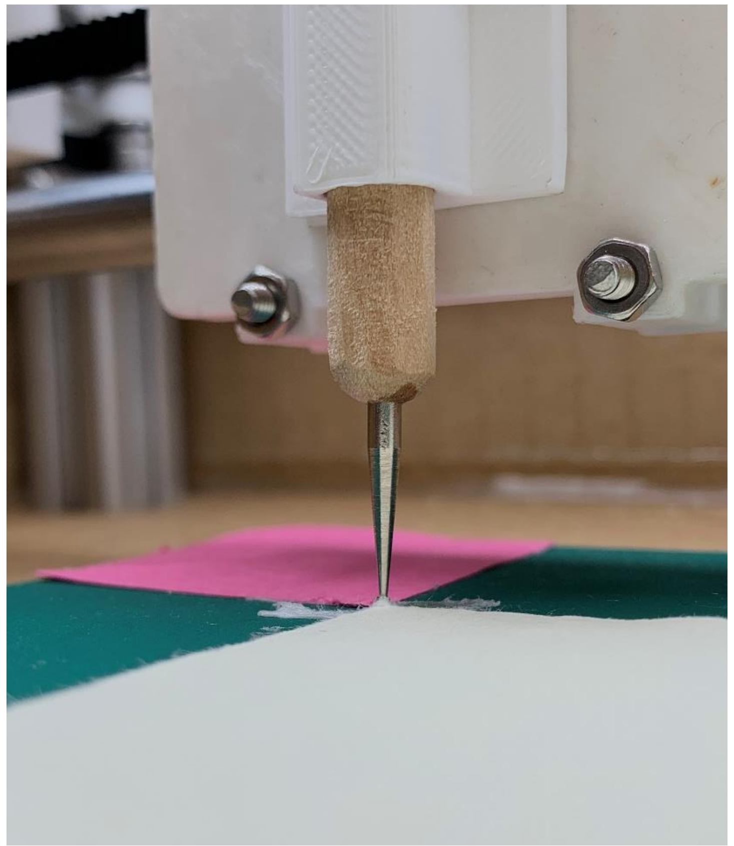
Regarding the maintenance of the machine, It should not need any maintenance.

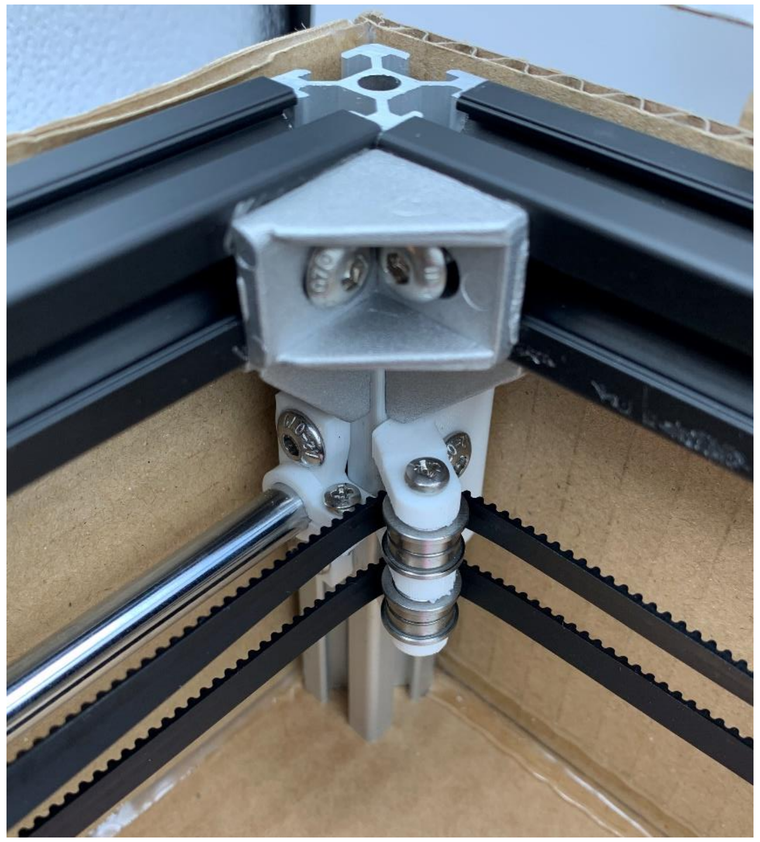


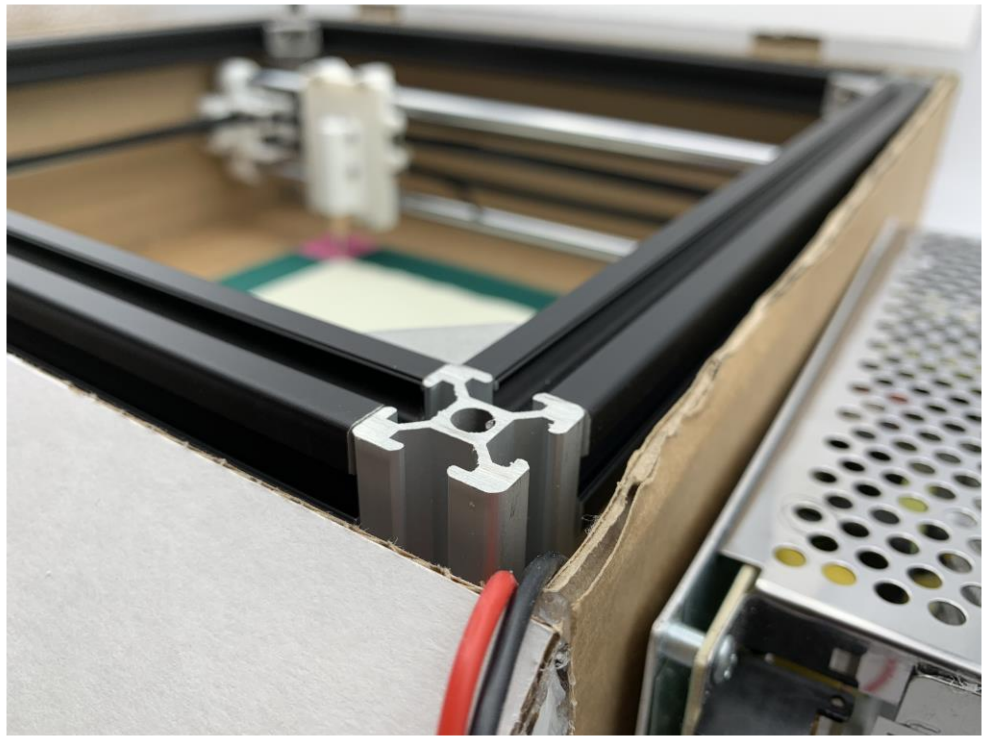
These factors can be tackled through looking into anthropometrics and percentiles and determining the best dimensions for each to have an optimum case within the design

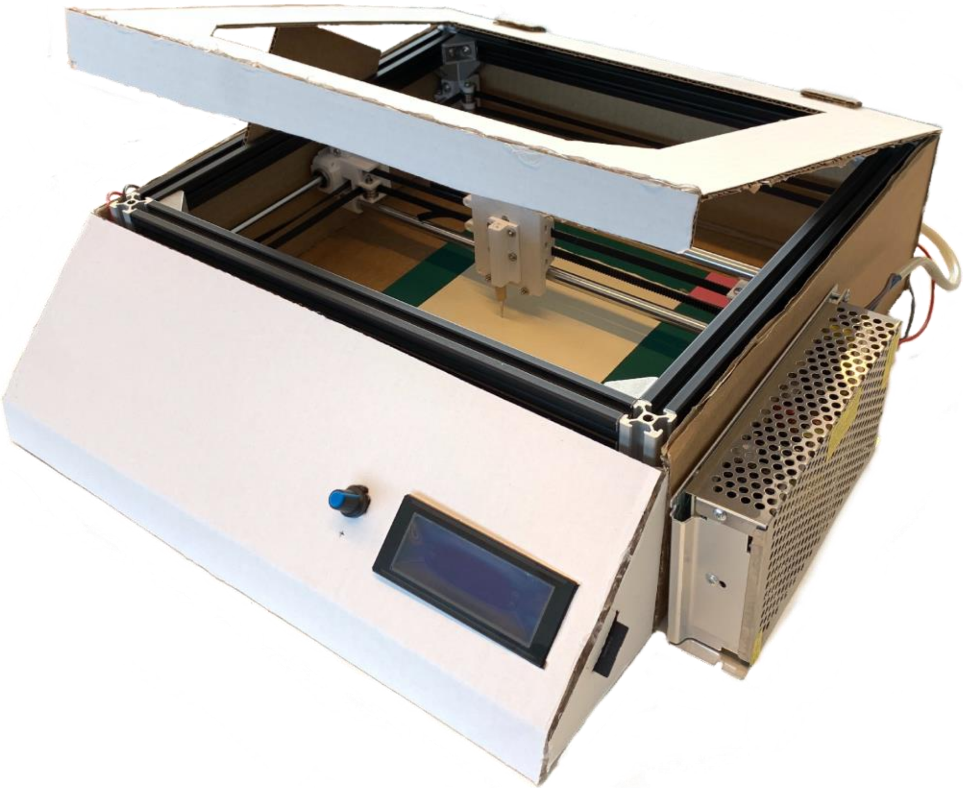
Final Product Representation:











Points of improvement:

- Thinking about the mass production implementation would require a whole redesign for the body and the brackets and would indeed affect the cost.
- The electronics would sure need some more work to shrink them as much as possible.
- An idea of using RFID with the product so that a chip is put and it starts with the specific crease pattern. Also, this idea can be built in a whole business model where people would need to buy more RFIDs for the latest designs and maybe reach out to designers to publish their new designs as RFIDs to the product.
- The mechanism to turn the paper over after finishing the first set of folds is something to think about which would be fascinating to the simple user and helpful too.
- The interface used needs to be altered and refined to suit a simple user, not an engineer; this would be through working on several levels of simplifying the language and making the controls more direct and automated maybe through implementing sensors and small actuators.
- Simplifying the design is sure needed as well and studying ways to engage the amateur and non-origami users to get to use the product too.