Improvisational Printing; travelling towards an alternative printing paradigm

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ABSTRACT

3D printing has widely been adapted as a great tool for makers and researchers to make parts. The way that printers are configured, with standardized slicing and software operations, can inhibit free engagement with additive manufacturing as a way of making. In an iterative process of making tools and making with the tools we device an additive manufacturing system inspired on modular synthesizers. Where the designer is the orchestrator of a live process of additive manufacturing. We contribute with the design system and methodology as well as reflections on making **with** a 3D printer.

Authors Keywords

Fabrication, Digital Craftmanship, Embodied, 3D printing, Additive Manufacturing, G-code

CSS Concepts

Human-centered computing --> Human computer interaction(HCI); Interactive systems and tools; User interface toolkits

INTRODUCTION

3D printing is widely accepted by the HCI community as a useful tool for fabricating parts and is mostly used through a standardized CAD/CAM process [10].

The HCI and maker community is increasingly striving to make 3D printing more accessible, faster, and more reliable [7,8,10,17,18,24,26,35,36], the configuration of the 3D printer with CAD/CAM reconfigures the way we as designers make compared to craft [6]. Often, we view the 3D printing as a fabrication machine, that should, without our attention produce parts like we designed in our digital software. This process can be described as a hylomorphic way of making [6,12]. The designers' intentions are forced upon the material through standardized software and machine inputs [10].

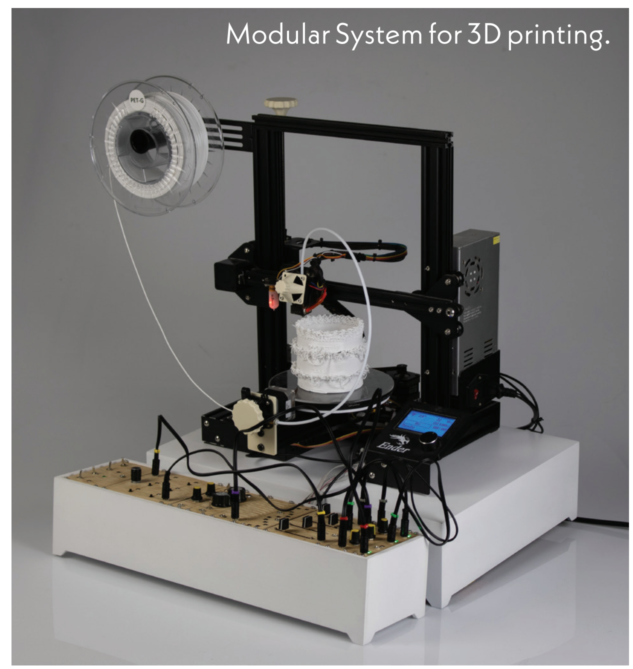
It is however, when we get the part, that we are prying out support, and negatively reflect on the "bad" surface finish [21], we dislike some of the inherent properties of the additive manufacturing process and see them as challenges to solve [19]. We attempt to control the materiality of extruding plastic through standardization, it is however when we embrace the individual experimentation, we can reconnect with materiality [10].

Leveraging the advantages of FDM printing is a heavily researched area, where individual layer level control is necessary to unlock the potential of the fabrication method like texturization and customization of geometry [3,7,16,22,25,30,24]. These works however still focus on pre-generating code to print with the machine through a process of CAD/CAM.

Other research explores alternative configurations of the fabrication process [6,27,32,34]. Synchronous designing and making with a 3D printer are explored by further work, On-The-Fly Print [20] makes a design system where digital choices are printed in real time. Capunaman takes turns in making with the machine [4]. In Playing the Print [25], the authors pre-determine mapping of variables, and can manipulate these on a midi-controller while printing. These interfaces, however, do require pre-defined mapping of variables to engage with, or are limited to either physical or digital control interfaces.

In this pictorial we take inspiration from modular synthesizers, which are often used for improvisational making of music, exploration of sounds and especially regarded as complex and divergent tools for making sound [29]. The control systems are designed per module, and complexity can emerge from the combinations of modules [2]. We apply this approach to making with the 3D printer, envisioning a 3D printer interface with rich controls that is able to stream G-code to the printer.

From this perspective we depart on our journey, we take a traveler's approach to design research [11] and start designing the system and printing with the system. In this



Modular System for 3D printing.

process we design the modules as tools which allow us to travel [11], and as such each module serves the purpose of generating new design opportunities and new paths to travel towards. The process of designing the system and making with the system is presented as a way of traveling.

We reflect throughout the process on the system from a first-person perspective [31], which resulted in five distinctions from “normal” 3D printing. We hypothesize the role of the manufacturing system changes from being about producing a part, to being about exploration and engagement.

We believe our system supports improvisational additive manufacturing. If the designer does not engage with the system, nothing will happen, if the designer is not constantly tweaking and interacting there will either be spaghetti or a knocked off print. The system is not set up towards pre-defined goals, the parameters are not mapped beforehand, the system necessitates live mapping, and exploration of data in 3D geometry.

We contribute with an improvisational approach to 3D printing mediated by a modular printer interface. We reflect on the changing role between the designer and machine and discuss differences between “normal” and improvisational 3D printing. We hope to inspire other makers to design their own tools to allow them to travel more freely.

SYSTEM SETUP

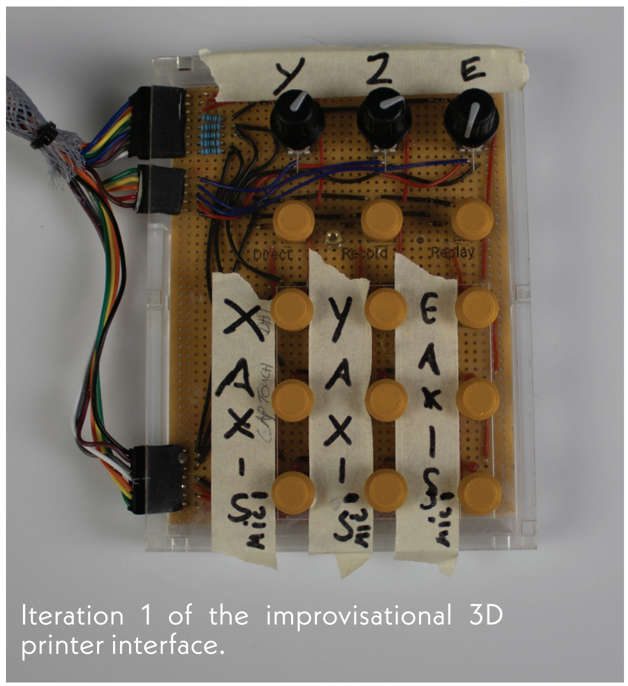
Before being able to start making, in order words, to enable us to travel, an initial 3D printing system was set up. The demands of this system will be explained below and are based on a pre-determined goal. On-the-fly printing through a physical interface. The system consists of three main functional entities, the 3D printer, a computer and the interface. We will explain these separately.

The 3D printer

The 3D printer is based on an Ender 3 by Creality [41], a polar Y axis was designed to facilitate easier interaction and data processing down the line. Klipper [42] was installed on an RPI3 [15] and connected to the printer, a local LAN network was set up to communicate between the designer’s computer and Klipper through the WebSocket. Extensive Klipper software modifications were made to decrease the size of the internal buffer, this to reduce the response time between designer input and printer output. The material used throughout the process is PETG by devil design [38].

Streaming Gcode

Sending commands to the 3D printer is done via a laptop, this unloads the RPI, and makes sure the Klipper software can run without interruption, furthermore, prototyping becomes easier as it is done directly and can be tested separately from the printer. A python script running in Jupiter notebook [43] is directly streaming G-code to the RPI through a local network. The script is working on a need by basis, the 3D printer upholds a buffer of G-code commands and as soon as one command is finished it returns an OK to the computer, which then calculates the new coordinate and streams it. The F-speed is calculated depending on the XYZ values sent to the computer. This is done to make sure that the execution of every G-code command takes 50ms. Setting this at a fixed value allows the modules to adhere to the same refresh rate and keeps all the modules roughly synchronized.



Iteration 1 of the improvisational 3D printer interface.

The interface

This part of the system is based on a teensy 3.2 [44], and communicates with the computer via serial, this microcontroller is the gateway to the computer.

first iteration

In the first stage of the process a design was made completely running on the teensy. Its goal was to open up the design space of live-3D-printing. It consisted of a three by four button matrix, and three pot meters. A variety of interactions were programmed on this prototype, like direct streaming of variables, manual intervention and sampling. However, when working on this system, it quickly became apparent that to add new functions previous functions had to be removed, otherwise, the system would lag. From reflecting on the system we found the interface became abstract and difficult to work with. Programming combinations of buttons for functions just did not feel very intuitive and clear. A modular approach was chosen to allow the system to grow in functionality, without sacrificing the interaction.

The modular system

Drawing inspiration from modular synthesizers a Eurorack [33] format was chosen. A case was made to house the modules with three power rails, ground, 3.3v and 5.0v. These power microcontrollers (5v), or analog modules (3.3v).

In the initial design a communication protocol was set up to ensure that all modules can communicate to each other, and that there is no risk of damage to components. Here again we borrow from analog synthesizers; 3.5mm jacks were chosen to transfer analog voltages from one module to another. The voltage range is between 0 and 3.3 volts, where 0 is low, and 3.3 high, 1.75 is the middle reference and is considered the default value. This range was chosen for compatibility with the Seeduino XIAO SAMD21 [40] microcontroller. This microcontroller is specifically useful in our case because it has a DAC (digital to analog) output pin, and as such can easily set reference voltages to be output. Every output has a 500ohm series resistor to prevent short circuits damaging the microcontrollers, and the inputs are all pulled low with a 20Kohm resistor, to prevent floating inputs.

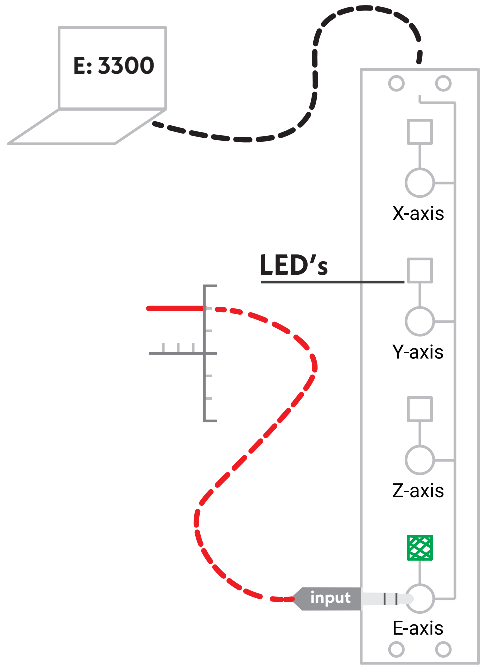
MAKING MODULES AND MAKING WITH MODULES

After these initial design limitations we started making modules, the first two modules were made concurrently, and started a basic system. We then started printing and devising new ideas for modules that might be interesting to make. This iterative process of making and using modules is a large part of the travelling process, and we continuously reflected on the role of each module as well as the whole system. There was only one requirement: the modules should aim to allow the designer to travel with them. And as such were made with a broad range of possibilities, not tailored for one specific predefined purpose.

Reference Voltage Module

The second module is the Reference Voltage Module. It consists of four sliders, with each a corresponding output jack. Every slider generates a reference voltage between 0v and 3.3v, this reference voltage is buffered with an opamp and connected to the output jack with a series resistor. The output thus is a static voltage reference that can be used by other modules, or directly input into the output module.

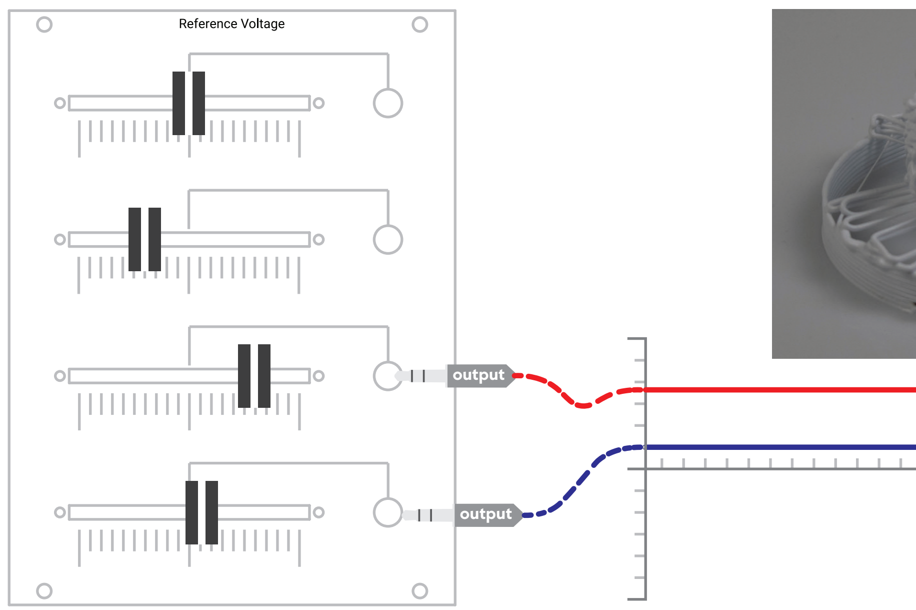
The use of the module is characterized mostly by setting a fixed variable for the machine, such as the Z-axis increments. However also richer inputs can be made with the sliders by the designer, like shortly increasing a parameter, or providing continuous input manually. The physical nature of the sliders makes very fine-tuned control possible, however no numerical accuracy is available, it is not possible to set a variable to exactly 1.75 volts, looking at the machine determines the tuning constantly.

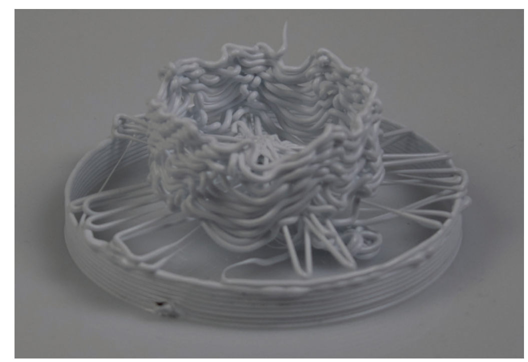


Output Module

The first module is the Output module, it is the link between the computer and the modular system. It consists of four input jacks: one for each of the printer's axis, and corresponding LEDs, when a jack is plugged in with a signal the LED will light up. The main module is run on the Teensy, the inputs are connected to four 12-bit analog inputs, which are pulled to ground and filtered with a 1nF capacitor. When the computer sends a request through serial, the values are measured and communicated. If there is no plug connected, the middle reference is communicated to the computer.

This module is the most important module for using the system, the jacks plugged into the sockets are the references that are used for printing. Naturally on its own the module doesn't do anything. However the interactions with it are quite significant, there is no pause/reverse option. Once a jack is plugged in that data is being sent. When using the system, you can constantly refer to this module to check what is going to the printer.



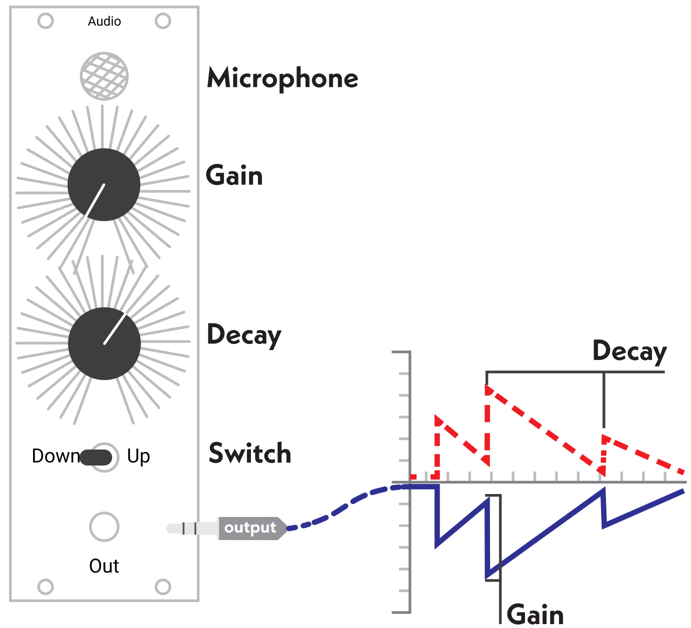


Printing using only the reference voltages, a lot of designer input can create quite expressive outcomes.

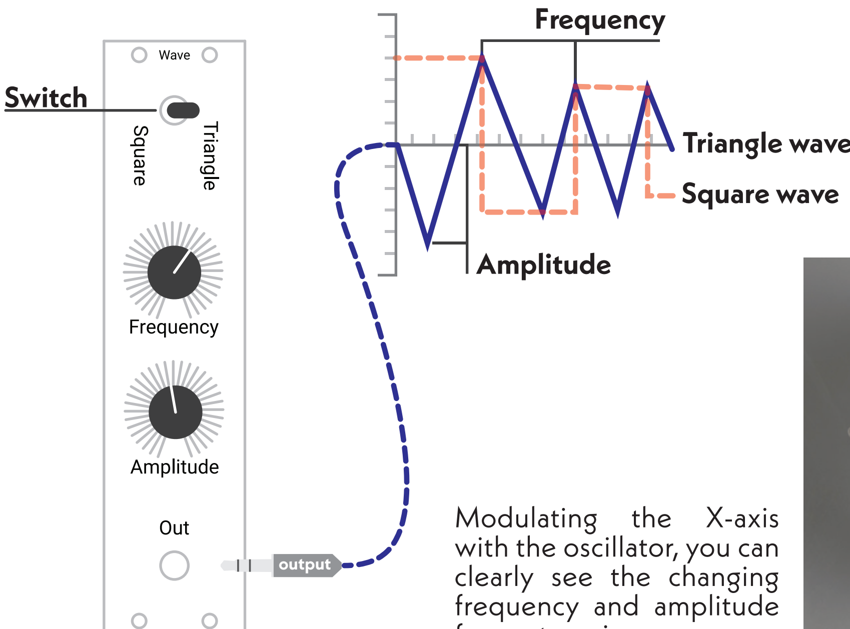
Microphone module

This module records the surrounding sound and translates it to a voltage reference. It is an analog circuit which consists of a MAX9814 module [45]. The output of this module is passed through a Diode and filtered with a capacitor and resistor (schematic in illustration). The two potentiometers set the gain and decay of the signal. The switch can change the output to peak downwards or upwards from the 1.75v reference. The resulting voltage is buffered with an opamp and sent to the output jack.

The inclusion of ambient data makes the module partly under control of the designer, their role is setting the range of voltages, not what the reference voltage is. This engagement with uncertainty brings a level of risk, but also an open door for unexpected behaviors. Moreover, it invites surroundings to join in on the improvisational printing.



Printing with the microphone modulating the X-axis while sitting in the lab, conversations are abstractly influencing the outcome.

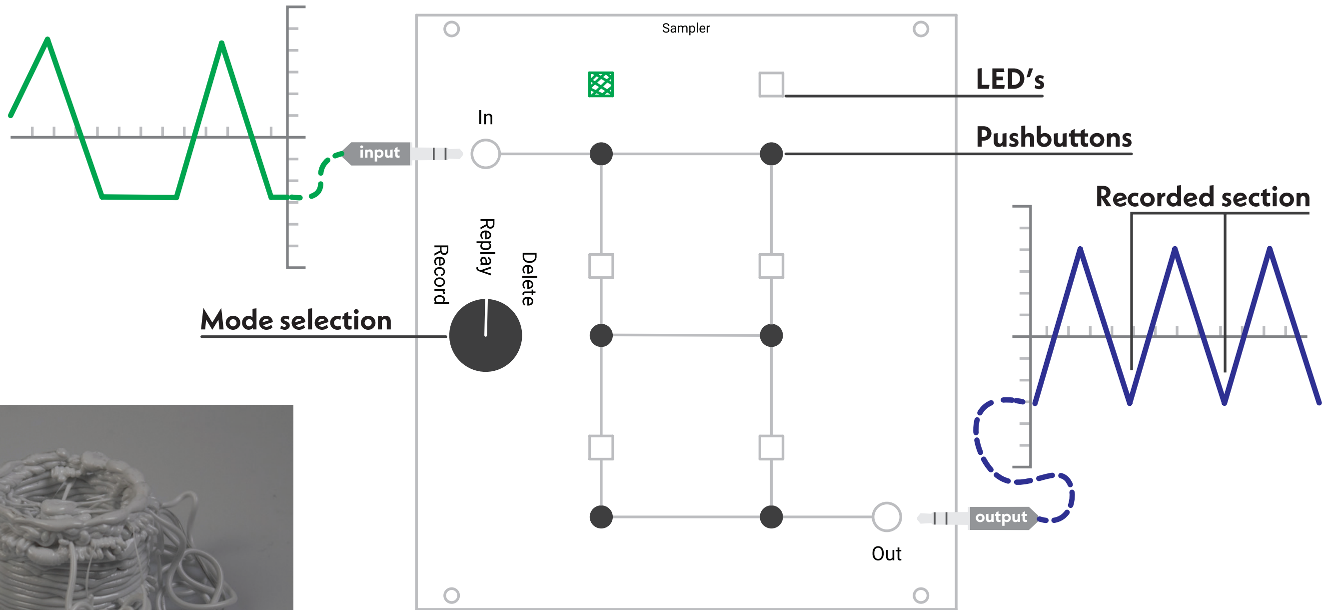


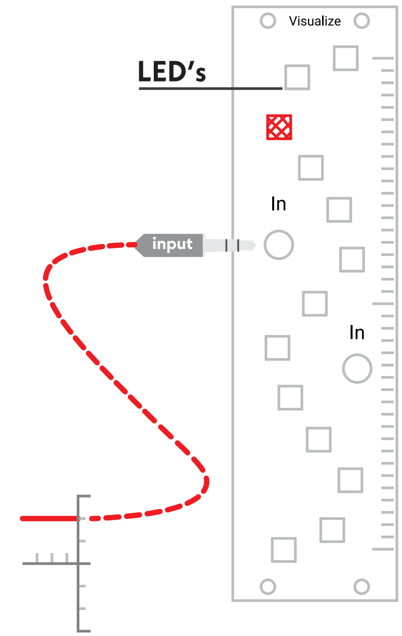
Modulating the X-axis with the oscillator, you can clearly see the changing frequency and amplitude from a top view.

Oscillator Module

The oscillator module borrows from modular synthesizers, and in essence is a Low Frequency Oscillator, adapted from the design by David Haillant [23]. It generates two main waveforms: a square and triangle wave. Which means that the voltage either toggles between the high and low value, or transitions linearly from high to low value. The frequency and amplitude can be altered with potentiometers. The output is buffered and sent to the jack. On purpose the range of frequencies goes from 0.01Hz to about 10Hz, to create a broad range of possibilities.

The use of an oscillator while printing can generate a multitude of interesting behaviors. The repetitive nature of the fluctuation can generate patterns that align and misalign, and dependent on what axis it is used on it can create a whole host of different expressions. When used on for instance the X-axis the visual behavior is immediately clear, however when used on a different axis the outcome is a bit more subtle dependent on the variables.





A sample was made, projecting the X-axis outward for a little while and returning to the center, one time looks like an error, repeated makes it look intentional.

Looping Module

The looping module consists of an input and an output. There is a three-position selection dial, which accesses the three modes; Record, replay and delete. Again, a Seeduino is used, which is connected to the input jack and output jack, as well as the LEDs and buttons. The three-position rotary switch is connected to an analog input.

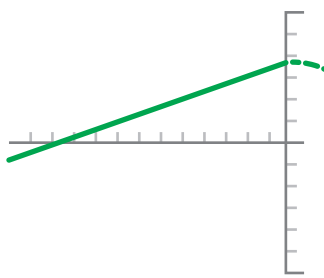
In record mode, the input value from the jack is measured and copied out to the output jack. When one of the buttons is pressed the LED above will blink red, and it will start storing the measured values in an array. When the button is pressed again the recording will stop, the corresponding LED will turn red signifying a sample is stored in that position. In replay mode, all the LEDs with a sample recorded will turn green, and when pressed will start outputting the previously recorded array to the output jack, it will loop this sample until the button is pressed again. In delete mode, all LEDs with a sample will blink blue, and if the button is pressed the corresponding array will be wiped.

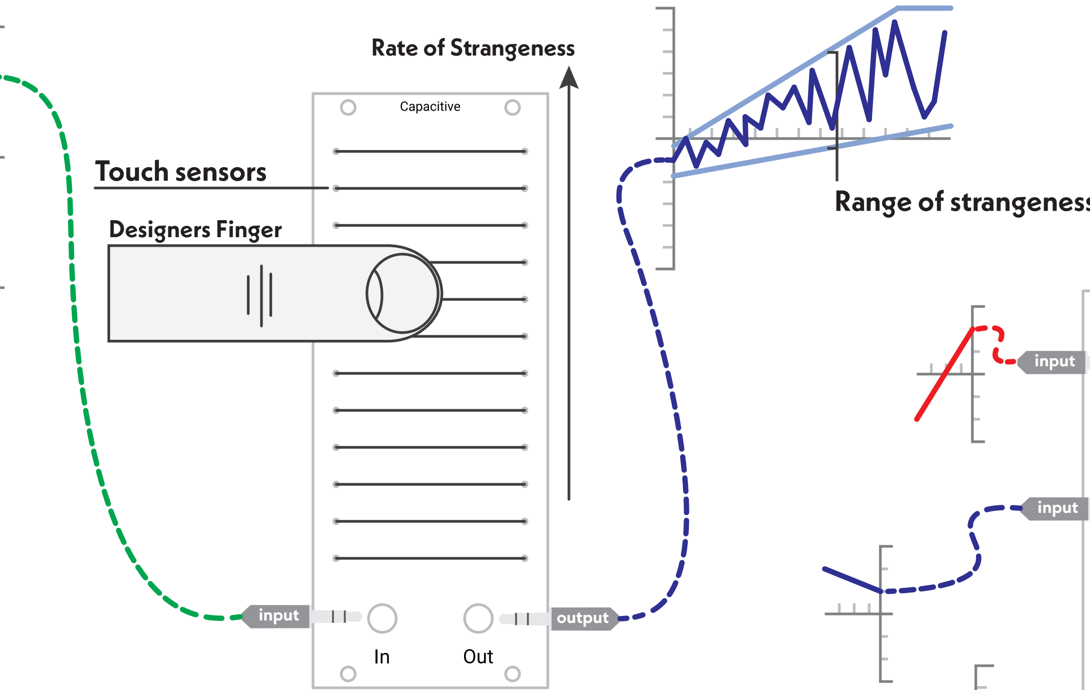
The module allows every output module to be sampled and looped continuously, freeing up the module for other uses, or combining complex movements for later repetition. Sampling a voltage can be inspired by some behavior visible in the print, or by generating a specific output thought the hands. When combined with the Manual Module physical movement can be used to program the voltage levels required to repeat that physical movement.

Visualization module

The visualization module is a passive module, and as such does not generate an output. It merely visualizes the voltage level coming in from the input. It consists of an array of 13 LEDs and two input jacks. The inputs are connected to the analog pins of the Seeduino and pulled to ground by default. When a jack is connected the voltage level will be visualized by an LED in the corresponding position. 0 volts means that the LED will be all the way at the bottom, and vice versa. The two inputs are separated by a different color on the panel.

The use of this module is mostly in understanding the behavior of the signal, and can be very useful, in tuning the voltage output before connecting it to the main module. It is a risk-free way of previewing a certain voltage level or frequency. However, there is a cognitive load on the designer, as to what the voltage level would look like when translated into movement by the machine.

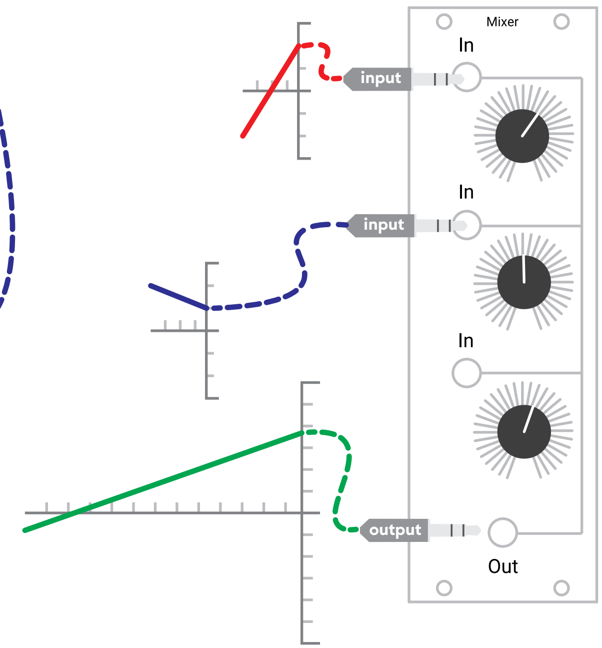




Capacitive Randomness
The capacitive module is a module with a lot of hidden complexity, every string corresponds to a sample which is partly random, but within a range. A higher input string corresponds to a sample with generally high values and large window of randomness, while the middle values are around the reference voltage, and have lower fluctuation. The window of vagueness is pre-programmed onto the microcontroller, while the actual output is generated randomly when accessed. When a string is touched the corresponding sample is played, when a string is released, the middle reference is output to the jack.

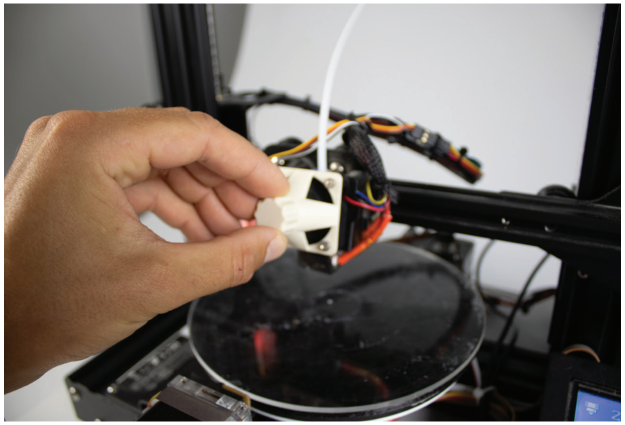
The circuit consist of a capacitive touch module MPR121 [46], connected to a Seeduino via I2C. The DAC output pin is connected to the jack with a series resistor. There is also an input jack, which when connected with a reference voltage is used as the base voltage, on top of which the sample voltage is added.

When using the module, the designer can use randomness as a way of exploring the printer's or material behavior. Inputting randomness intentionally can form new insight, while printing with the system. A similar feeling occurs with this module compared to the microphone module, as designer you set the window of variables, but do not determine the actual voltage level. Letting go of this control is quite difficult, and the missing intentionality makes it complicated to work with in this context.

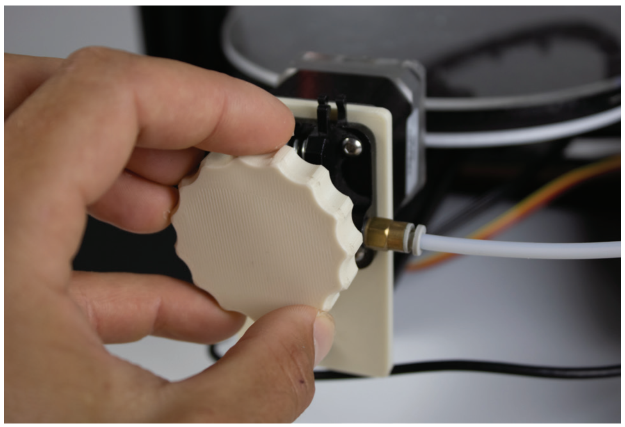


Mixer Module
The mixer module allows up to 3 input signals to be mixed into one. Three jacks coupled with three potentiometers form the input side, they are added through a series resistor to each other and buffered with an opamp, this signal is sent to the output jack.

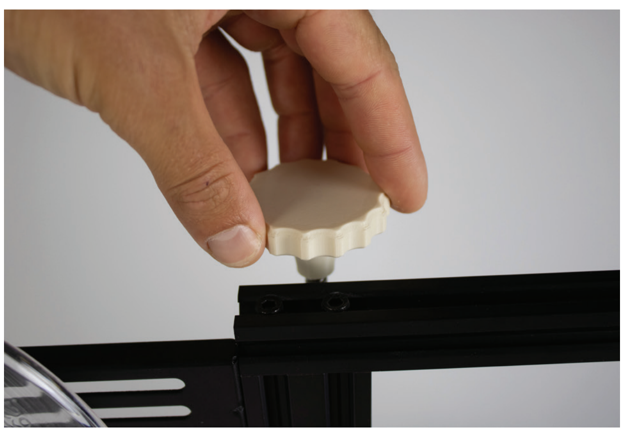
While using the other modules it became apparent that this module was necessary. One of the main purposes was to raise the overall level of one of the other modules, by mixing in a static voltage from the fixed parameter module. However, it also made it possible to combine different modules on top of each other for higher complexity on one axis. The added complexity makes it more difficult for the designer to predict and grasp the movement from the modules and makes it fun but also difficult to work with. When outputting only one specific module, you have a certain intention with that signal. However, combining two or three dynamic inputs makes the signal difficult to understand, which in turn makes the intention more difficult to form.



Control interface for the X-axis.



Control interface for the E-axis.



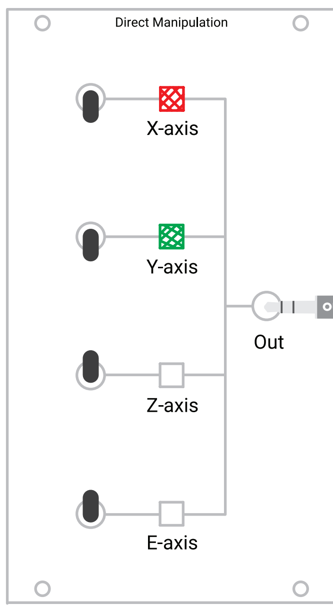
Control interface for the Z-axis.

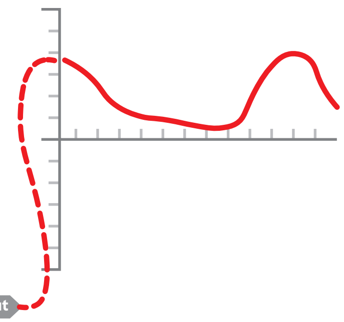
Direct Manipulation

To facilitate manual interaction with the machine, each axis was fitted with an interaction interface, for the Y-axis the print bed can be rotated manually, for the XZE-axis specially printed handles were made to ensure safe and comfortable use. Hard-wired connections to the motherboard of the 3D printer were made, to electronically access the enable pins of the stepper drivers. These are connected to the switches on the module. This combination allows the printers axis to be disabled with the switch, and manually moved by the designer.

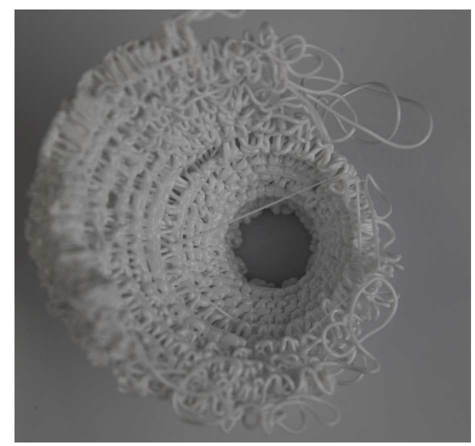
Secondly the XYE stepper motors were fitted with AS5600 hall sensors [39] to measure their rotation. When the switch is activated, the hall sensors are monitored and translated to a reference voltage by the Seeduino microcontroller. This reference voltage is written to the DAC output pin and connected to the output jack with a series resistor.

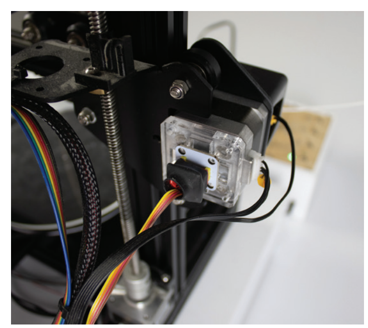
This module draws from previous work by Goudswaard et al. [9] and allows the designer to engage with the machine in an embodied way. When the designer cannot articulate or generate the necessary voltage patterns for an exploration they can try it directly with their hands. Which results in the voltage pattern of that movement, as such manual input is used to generate digital output. While printing this module was used very often, especially to quickly tune one of the axes offset, or to "fill" holes by manually moving the Y-axis. Moreover, the printer could quickly be paused by just de-activating all the stepper motors. Manual input allows the designer to intervene though uncomplicated and intentional means, there is no thought of machine code or commands.





Manually moving the X-axis outward every couple minutes.



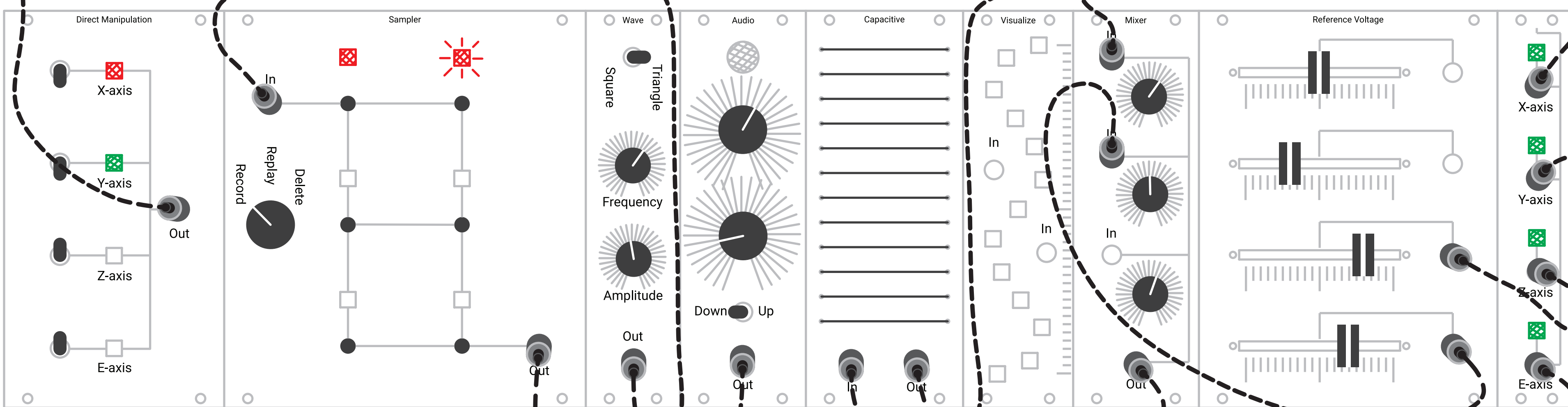


Sensor mounted to the back of the X-axis.

The manual manipulation module has disconnected the X-axis and the Y-axis; thus, they can be moved manually. The X-axis is currently outputting data into the sampler. A sample is currently being recorded on the second slot. The first slot already has a sample recorded on it. The designer can manually manipulate until the recording is finished and re-press the button to save it. When switched to replay mode, the button can be pressed again to loop the recorded sample.

The oscillator is connected to one of the inputs of the mixer together with a static reference voltage. This increases the overall average of the oscillation, from 1.75V to approximately 2.1V, the oscillation is of an average amplitude with a triangle shape. The frequency is quite high, so the voltage is changing at a frequency of approximately 2 Hz.

The input of the Capacitive module is connected to the output of the mixer, and as such the raised oscillator signal is fed out through the capacitive module, and copied into the output jack, which in turn is connected to the X-axis. When the designer does not touch the capacitive wires, the input is equal to the output. However, the designer can now and then place his finger to add randomness to the signal.



OVERVIEW/ EXAMPLE PATCH

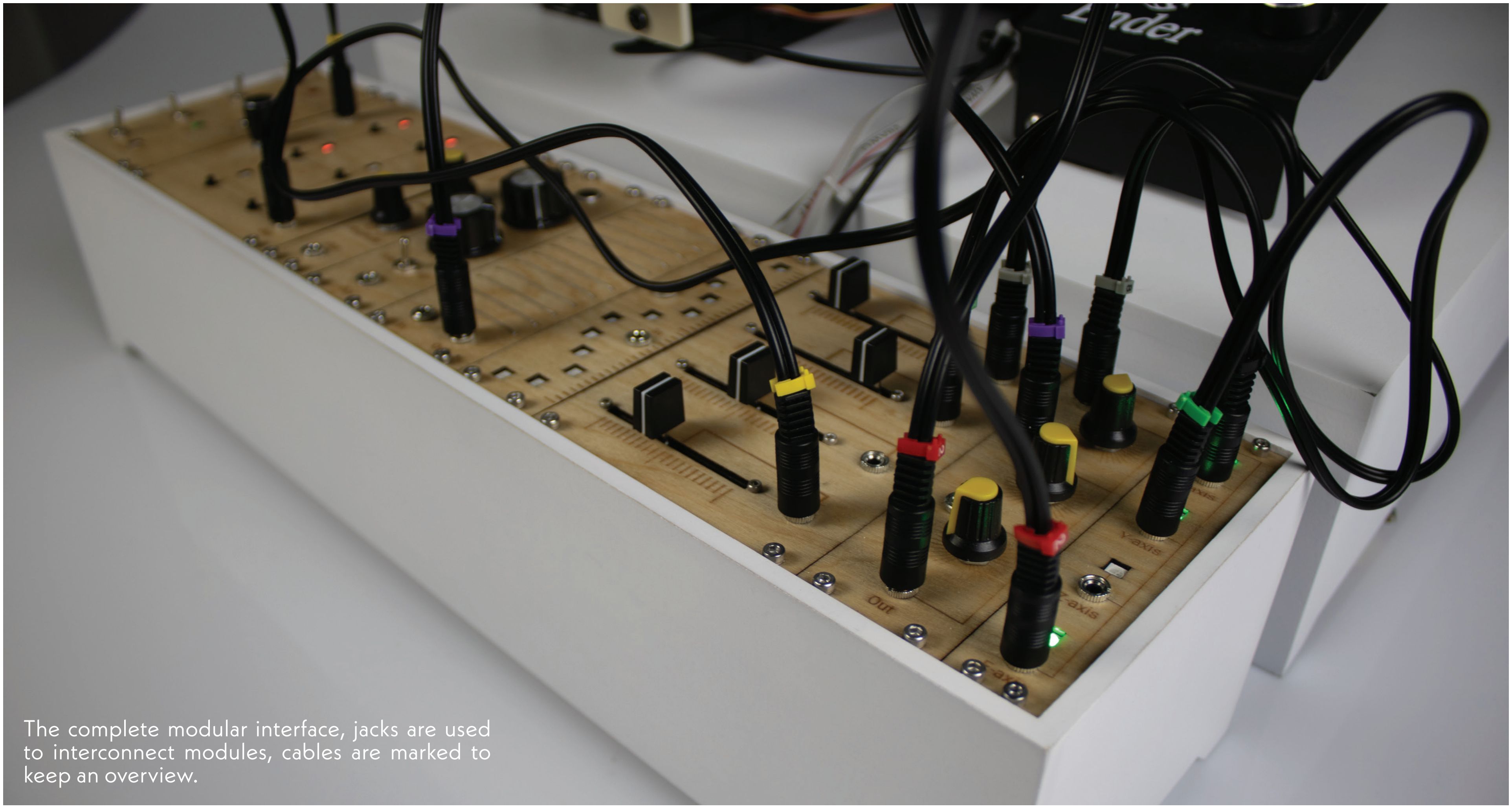
On this page we show an example patch, a configuration of the system for 3D printing, this is to showcase the complexity and interconnections that can exist between the modules. The data flows from the plugs and some are highlighted in text blocks. This illustration is just one way to configure the system, and naturally there are many more configurations to support exploration.

The output of the sampler is connected to the Y-axis, when the axis is active (by the manual manipulation module). And the sampler is recording, the Y-axis will copy the movement made manually by the X-axis (as the X-axis output is sent to the input of the samples). When the sampler is in playback mode, the previously recorded samples can be played on the Y-axis, looping continuously.

The microphone module is connected to the E-axis. The module is configured to increase the voltage level when there is a sound input, moreover the gain is quite high, and the decay is quite low. This will mean that high short voltage spikes will be generated when there is sound, resulting in larger blobs of filament being extruded.

SUMMARIZING FINDINGS
From the first-person perspective of making modules and making with modules, discrete properties of the system arose. We describe these themes shortly and reflect deeper in the discussion.

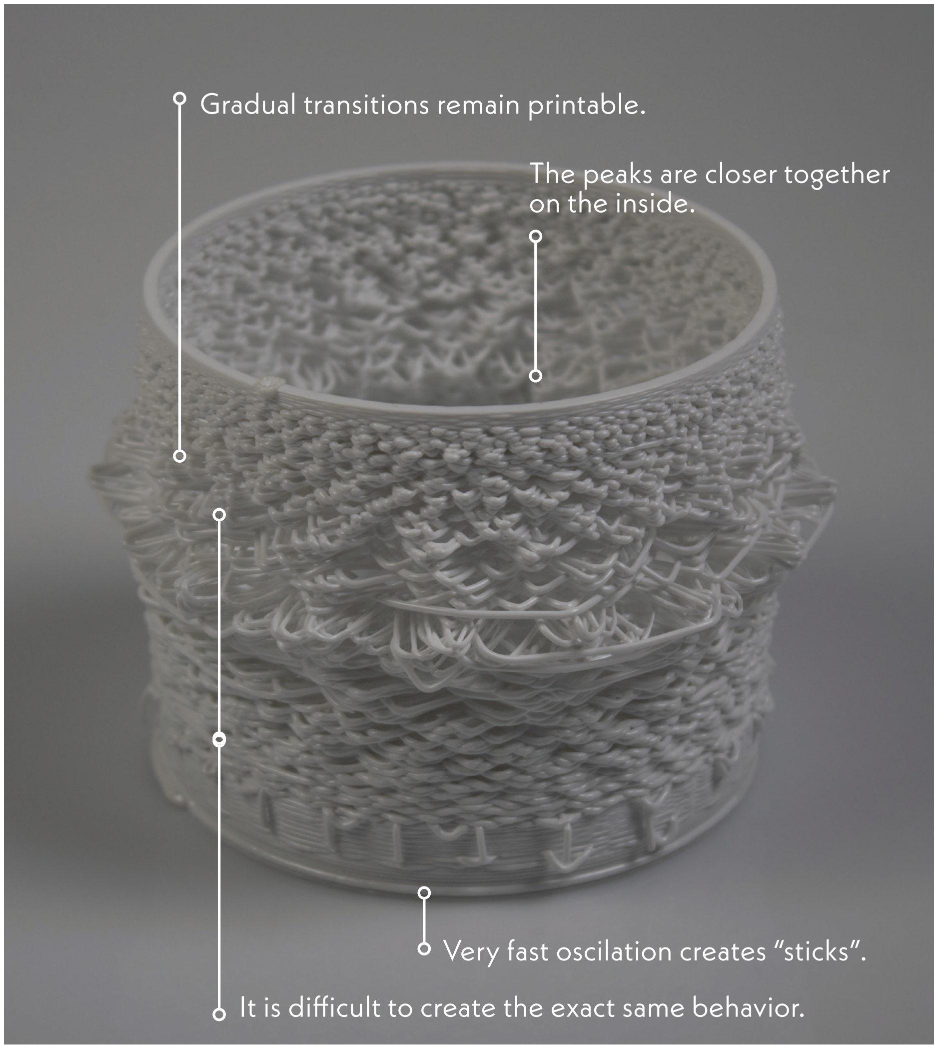
Data input
All of the output modules are made to incorporate a different type of data, the different data inputs are interesting to reflect on. We have some specific designer input, the reference voltage module for instance, where the designer very intentionally determines the output level. Other inputs like the microphone are a lot more passive, are not set by the designer, but a result of surroundings. Other modules like the oscillator generate a specific range of values set by the designer intentionally. In "normal" 3D printing there is only an intentional calculated input to the printer, engaging with different inputs highlighted interesting design opportunities.

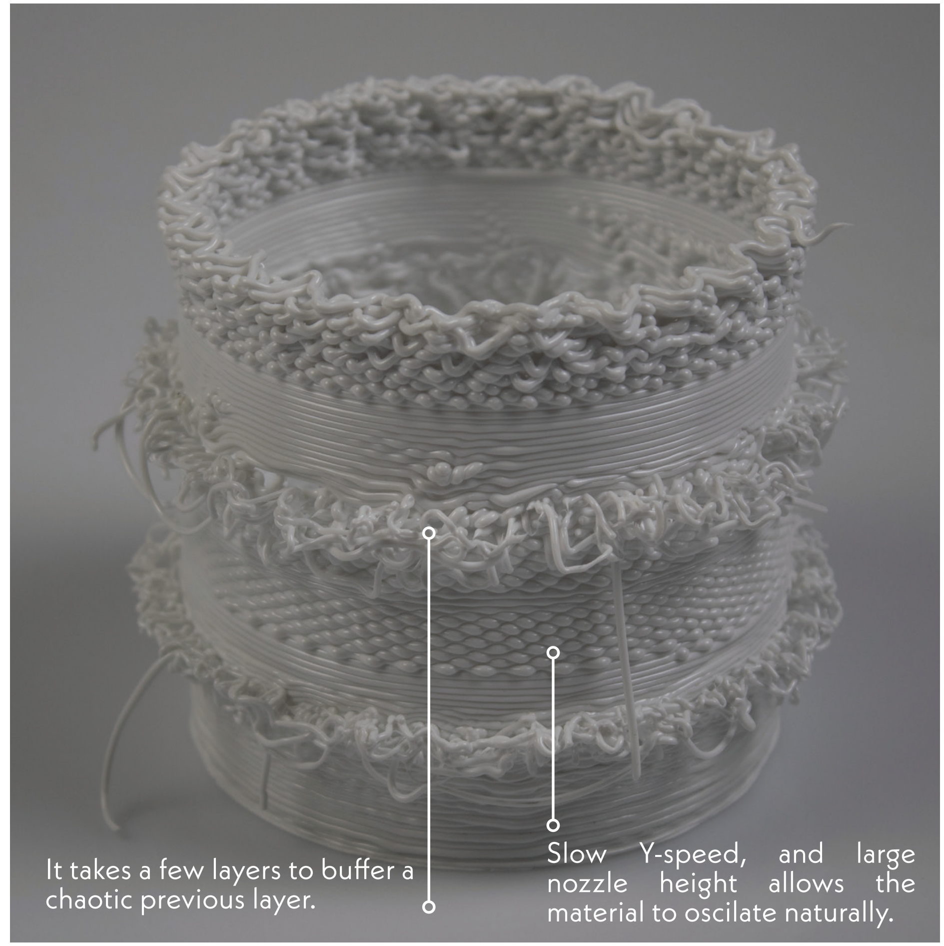


The complete modular interface, jacks are used to interconnect modules, cables are marked to keep an overview.

No two are the same, copies are boring

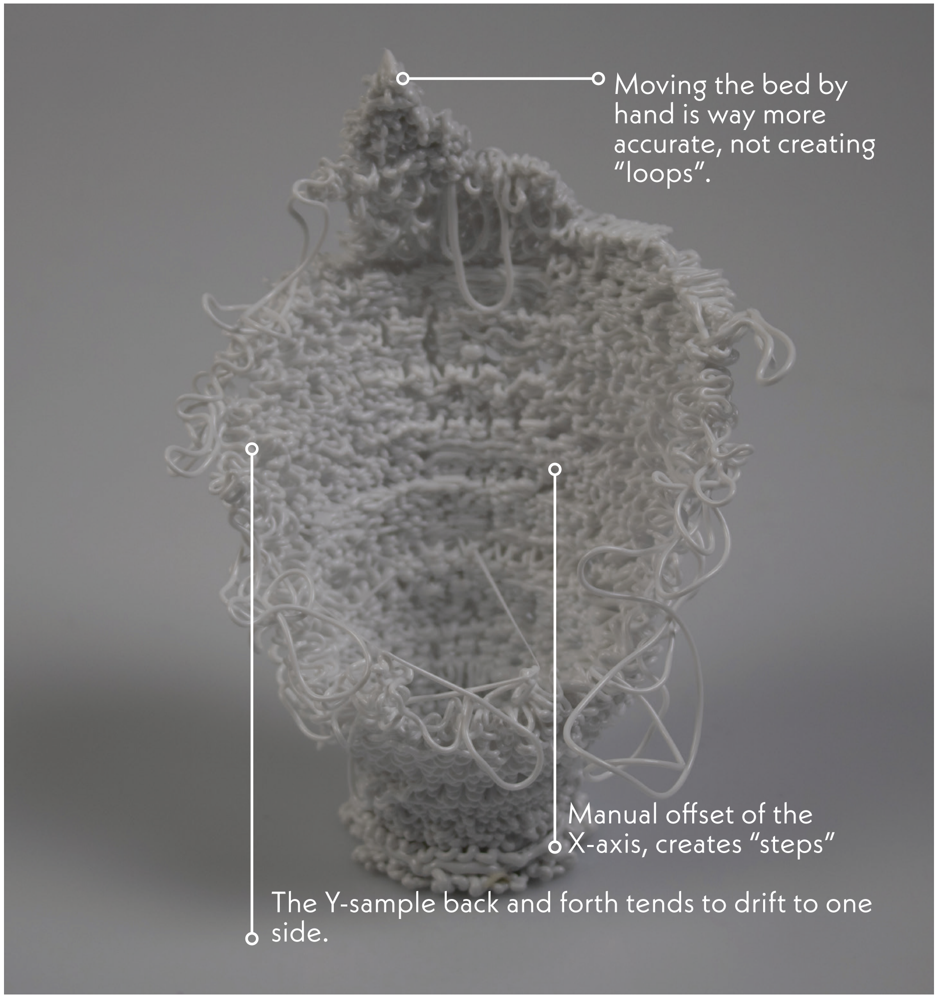
Because of the manual aspect of improvisational printing, it is virtually impossible to make two of the same things, however it is possible to recreate similar things. Settings are replicable however not reproducible; the plastic behavior and machine behavior embrace materiality and as such the samples are always different. This leverages on the quality of 3D printing, every sample can be different, unlike CAD/CAM processed g-code which aims to control materiality.





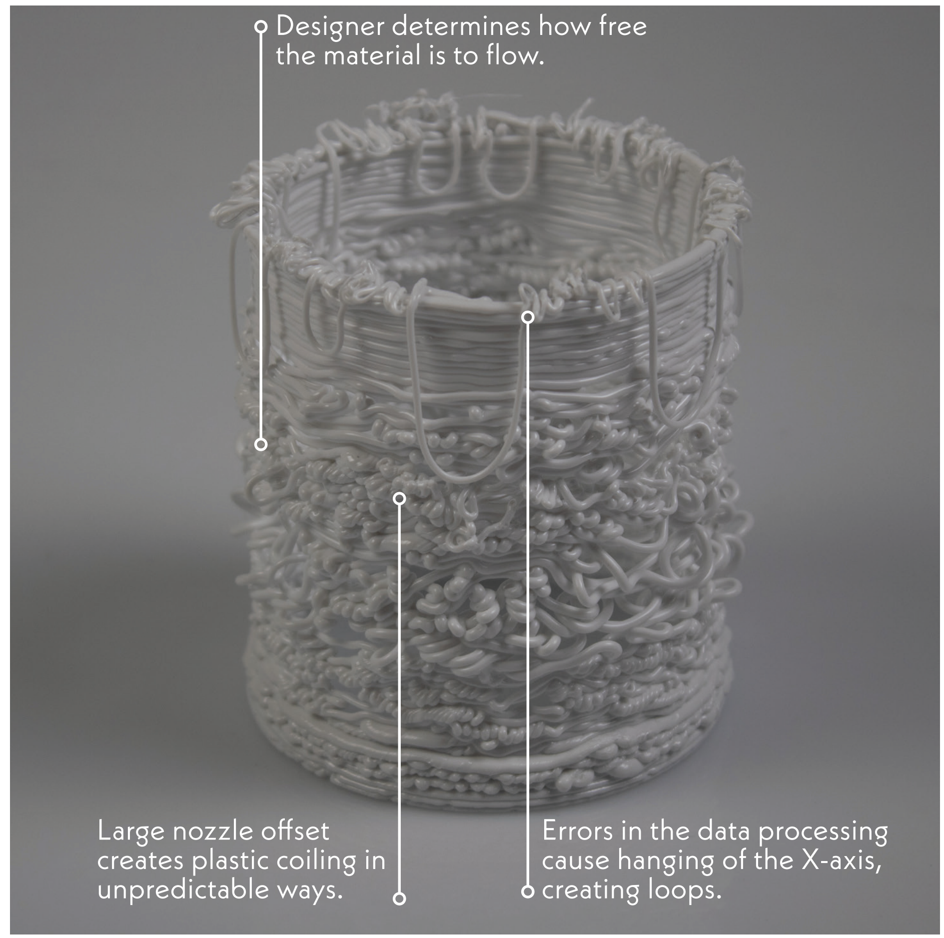
Designer as orchestrator, controlling the parameters not the expression

While printing with the system there was a distinct difference in the role of the designer. Normally in 3D printing the designer scans the G-code with a slicer, checking if everything is in order and will print successfully. The machine level code is explicitly checked for areas where the material might not collaborate as expected. While 3D printing with the modular system, the designer does not have this preview, they can only imagine what a specific change will do to the material. The designer can, however, quite clearly assess the material vagueness allowed by the movement. As such the designer is constantly negotiating between the “freedom” of materiality to express itself and limiting it.



Enticed to explore, just start making
Unlike printing normally, with the modular system it is not necessary to have a predefined design intention for an exploration. When coding specific G-code behavior you must have a certain idea about the movement you want to create, otherwise you cannot code it. Whit the improvisational printing system you turn it on and start printing. Naturally it takes time to build up some layers, however the low-key entrance to make and explore something makes it easy to just get started, there is no cognitive barrier or load for trying something.

Controlling the chaos, on the edge of spaghetti
During a demonstration of the system a very clear distinction between "regular" 3D printing and improvisational 3D printing arose, which was the constant attention required to the system. Every time the system would be tuned and set, as best as possible to continue on its own, it would fail. The consecutive nature of 3D printing, and the accumulation of small errors makes it impossible to let the system do it's thing. Constant negotiation is required with a system like this, unlike the "normal" 3D printer, where no negotiation is possible. This generates an exciting tension between what the designer is seeing and is doing. Thoughts frequently arose like: "Will my intention be represented in the material?", "Will the spaghetti adhere and re-structure itself with my inputs?".



DISCUSSION

Controlling the chaos

One of the main things you see concerning the explorations is a level of randomness and chaos, these are inherent of the process of physical making. Unlike digital environments there is no undo button, no preview of what the plastic will do, and especially no way of reversing the plastic extrusion. In regular 3D printing this is also the case, and more so often a reason for disregarding a "failed" print. The material expression and movement are in principle already quite complex, when printing with small layer heights the potential expression is rather limited, however when materiality is fully embraced in other words the "spaghetti" print, there is a lot of expression, but it is very unstructured.

When printing with a system that tailors for live influencing of the 3D printing while it is printing, allows you to explore this edge of chaos. Andersen and Knees [1] explore the concept of a "Strangeness Dial" in making music. Where computational uncertainty was introduced. Interacting with the additive manufacturing outside the boundaries, feels like a constant negotiation with strangeness. And as such this interface is not aiding those who seek ultimate control of their 3D printer. It is rather aiming to give handles to explore the strangeness of additive manufacturing.

Making as a way of performing

In "Playing the Print", Subbaraman and Peek [25] propose a "Live performance approach to machine control", which is something that we build upon. Where they are inspired by a midi mixer, however their performance is limited to the pre-defined parameters preemptively mapped. We'd like to compare the approach posed by their work as a way of remixing, changing some parameters of an already existing structure. We take a modular synthesis approach, by generating all the parameters, which lead to evidently different prints. Their work is however largely focused on re-printing later, while this work focuses on the same live performance aspects of a modular synthesizer. As soon as the patch cables are unplugged the piece ceases to exist, there is only a recording left. The process is what forms the result and cannot be repeated easily.

"recording"

A lot of research focuses on expressive reproducibility, researchers explore a specific material expression, and incorporate it in a design editor [3,7,22,24,28]. The notion of copying inherently incorporates hylomorphic aspects of designing, we impose our design intention back upon the material and machine, to make it respond and move in a pre-determined way. However, this again can be a cause of frustration, because one failure in the intention makes another "failed" print. In this case the expressive materiality we say to love is something we expect to be repeatable. In this research we do not make recordings, the complexity of stacking layer by layer makes reproducibility highly unlikely, every previous layer is responsible for the next, and thus one cannot expect the print to come out the same twice in a row. We can thus look at it from another perspective, we as designers set the boundaries of materiality. We design something where material is either relatively free to express, or not, which creates uncertainty off the outcome. Like modular synthesis, once the plugs are removed, we cannot remake the soundscape, we can come close but will never be able to remake the exact composition. In this configuration the designer sets the range of material expression and can dynamically alter and respond to this materiality on the fly.

Frictions in making the system

In the introduction we reflect on the normal 3D printer as being set up for certain pre-defined goals, during the setup and design of the system this got in the way. There are two main examples that arose:

To decrease the latency in the system the buffer that Klipper requires must be lowered. This required changing the firmware of Klipper, of which there was no documentation. In an extensive internet search, there was a mention of increasing the buffer to reduce stutter during high density G-code sequences. However, there was nothing about decreasing the buffer. The firmware is hardly documented, we assume, because there is hardly any use for lowering the latency of live control.

Secondly is the hard wiring to the enable pins of the stepper motors of the 3D printer. The Ender 3 motherboard is set up in a way that the XYZ enable pins are all controlled by one signal, as such it is impossible to disable one of the steppers while continuously using the other ones. To enable the designer to collaborate with the 3D printer, the traces to the enable pin had to be cut, and wires were soldered to control them externally.

These kinds of barriers are of course very logical, but also clear proof that the 3D printer is set up with pre-defined goals. Extensive know-how of the full system from software to hardware is necessary to create a system that can tailor to alternative configurations. These boundaries might not always be visible to the new maker, however, are there and to be aware of. They configure the use of the 3D printer.

Direct control of the systems.

The system proposed is tailored to a specific type of exploration, they are for instance, always in the form of a cylinder. This configuration of the system has an intention by design. The purpose our configuration is not to imply that this is the ideal configuration for designing a system of improvisational printing. But rather our design for improvisational printing. Other researchers might make a different configuration. We do not aim to present a complete system; we attempt to highlight the advantages of applying such a system, and propose potential inputs.

System configuration and agency

The configuration of a system always encompasses the designer' intention, Ingold [12] explains the role of hylomorphism through the example of splitting a wooden plank: the craftsman determines how and where to hit the wood, the natural weakness in the wood is where it will split. It is up to the craftsmen to engage with this characteristic, "surrendering to the wood, then following where it leads" [5:408]. However, the tool used to hit, also has an intentionality. When we compare "traditional" 3D printing, with the design proposed in this pictorial, we can reflect that the "traditional" printing paradigm diminishes materiality as much as possible, to increase the repeatability of a specific action. The infused uncertainty in the improvisational system gives way for materiality to express itself, sacrificing repeatability.

Embrace unpredictability
As described before, the modules had to open doors for exploration, and as such did not have a preconceived mapping. In other works, on improvisational making like Interactive Fabrication [34] and Playing the Print [25], the parameters of the interaction interfaces are predefined. In Playing the Print [25], the specific parameters must be made explicit in code before they can be used. This requires some preconceived idea as to what parameters to map. In this project no one module was designed to suit a specific axis. Naturally some preconceived ideas existed, however no specific design choices were made to pick one axis over the other. Rather the openness in design allowed the testing and exploring of said variable on every axis.

Travel to make, make to travel
We found that the modular approach to 3D printing controls allows the designer to travel very freely, the system being open to new inputs affords the designer to play around. And the simple communication protocol makes it quick and easy to envision new controls without having to pre-define the specific outputs. We believe that a modular approach to interface design might allow designers to make tools that are open to travel with. Moreover, the modular approach allows designers to start making without pre-determining the functions of the system as a whole.

Print got detached, why not continue?

CONCLUSION
TThis pictorial describes the process of travelling through designing and using a system of 3D printing. The system 3D prints with the use of an interface and requires no pre-made design to print. All the choices are made in the moment, by the designer. The engagement with materiality and inaccuracy in the physical controls opens the door for fun experimentation and allows the designer to start making without any pre-formulated design intent.

We describe the process as a journey through making controls and making with controls in the form of a modular system, that tailors to growing with the designer's knowhow. We take a first-person perspective and reflect on the differences between the proposed system and "traditional" 3D printing and summarize them in four themes.

These reflections change our relationship to additive manufacturing and represent a physical thought experiment as to what a different 3D paradigm could look like. We found that we were not printing with pre-defined goals, and let the materiality lead our explorations. And as such regard the process as improvisational and hylonoetic.

We aim to inspire and envision other makers what a more hylonoetic 3D printing paradigm could look like. And contribute with a concrete systems approach to complex design challenges, as well as our reflections on exploring an improvisational relationship with additive manufacturing.

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FMP PROPOSAL

Motivations and how we came to be here

The past year I've been finding a concrete corner of design that fits my area of interest and professional expertise. From my bachelor's I found that the area of digital manufacturing is really in line with my passion for design. The combination of Code, Machine, and material is something that resonates with my way of thinking and making. I am a digital craftsman; I aim to find the edges of possibilities and am motivated in exploring and broadening applications of machines.

My M1.2 and M2.1 have been illuminating an approach to research that really fits my development. In previous years I've been attempting to articulate my role in research as a designer, and especially as a highly technical designer. I've been having numerous conversations with Kristina as well as others around this about my role. And the following conundrum arises quite quickly; do I want to be the highly technical skilled person to fix difficult problems in software or hardware? Or do I want something more? I've always struggled with the application area of my design and research enquiries. And it always feels like I am doing a disservice to my own work by applying the design to a "lamp shade". However, I could not articulate the value of my work in another way. During this semester I've been working together with Kristina Andersen and Bruna Goveia da Rocha to publish a pictorial about my previous work.

The pictorial describes the process of me making a system allowing the designer to metaphorically enter the 3D printer, by manually manipulating one of the machines axes. This project was driven from my passion and frustration with the current state of the art research in 3D printing. A lot of work was done to make coding easier or investigate nitty gritty new techniques for 3D printing, which is interesting, but once it is done it is just a technical challenge to try it again. And on the other hand, highly philosophical explorations, where the concept of manufacturing and the agencies of the designer and machine are investigated. In between these two I found an area which does bring forth the arguments highlighted in the more philosophical papers, while retaining the complexity and advanced capabilities of the more technical community. Writing extensively and discussing with Bruna and Kristina highlighted the more philosophical contributions of my work. And is something I found difficult to grasp, but also made me eager to learn more. This physical making of a system, to grasp a philosophical concept has really empowered and provided a platform for my making.

This leads me to the current project; which is a further deepening of the "live 3D printer" control system. And I think it really surfaces new arguments to be made about how we as designers use and regard 3D printing, and I think it illustrates greatly how we can attempt to bring 3D printing into a new direction. There are however plenty of limitations of this system, as well as that it is still with one foot in the traditional printing paradigm.

When analyzing the past two projects, I can illustrate them from a control perspective; the first project (entering the 3D printer), is a human machine collaboration where we celebrate the layer lines, by precisely controlling the E-axis. When reflecting on this system there are a lot of hylomorphic aspects. There is a large design intent from the designer when making with the system and the expressive freedom is limited to texture. The physical movement of the axis by the designer is a deliberate and conscious process, where the machine is still acting like a "tool" for the designer.

In "Improvisational Printing" there is a larger potential for hylonoetic exploration, the designer directly has an influence on the code as well as manual controls for the machine. As such it goes one step beyond the previous project; the designer can intentionally alter the machine code as well as the machines' axis. The design of the system to generate the code, has an agency in how it was designed as well in how it generates the machine code. However, the machine still behaves in predictable ways. And as such the designer can quite intentionally image what the machine will do when a specific knob is turned. The designers' intentions are moderated through the machine. Because the movement system was deliberately designed to be simple, for instance, the rotary bed was made to decrease the complexity of code to movement mappings and make the designer able to "control" the machine.

The striking overlap in both projects is the approach to printing, just going to the machine and explore and make without printing a part. The role of printing changed over time when using the machine and it made the process interesting and exciting.

Proposal

As a third project in "letting go of control" of the 3D printer. I want to create my own machine. Instead of retrofitting an existing 3D printer I would like to create a machine that pushes the expressive freedom of additive manufacturing.

My proposal is to investigate the space where the machine has an agency in where it obstructs the designer from intentional making. I aim to do this by increasing the mechanical complexity of the machine, to make it too complex for the designer to understand the interface to machine mappings. When we regard for instance a cobot arm, the coordinate system is rather complex, the freedom of movement is rather large, but not very easy to map on an XYZ plane. When used for 3D printing, we use extensive software packages, to translate the toolpaths to the arm movement. The increasing complexity might make it difficult to arrange the system in a way that the designer can intentionally explore, but rather can steer the machine towards certain directions. It will be about exploring the complexities and fully embracing the uncertainty of printing with such a system. An interface will provide handles for the designer to steer the machine in a live process of 3D printing.

As described earlier, there is a change over time when the designer is using the system. My proposal is to attempt to capture this intricate relationship with the machine over time, by applying a traveler's approach [3], similar to the M2.1 project, travelling by making tools and making with tools. There is a large temporal quality in "Improvisational 3D printing", negotiations over time, feedback loops and learning are difficult to map. As such I aim to experiment with ways of documentation, to capture the changing agencies and intentionality in this assemblage of fabrication. These documentation templates will be analyzed and reflected upon through a first-person perspective [9], and a thematic analysis [2], with a focus on machine intentionality.

Background

As there is a large overlap between the background of the M2.1 pictorial, and the proposal I will not reiterate the full theory, however I will provide some additional relevant works which dive more in the area of machine intentionality.

Machine and designers intentionality has been previously researched by Somanath et al. [6], in their research on composite intentionality, they program a 3D printer to have an augmented intentionality. Altering the shapes of designs when printed, in their paper they reflect on composite intentionality of the designer and printer forming an assemblage of making. In this work they however program an exaggerated intentionality through material speculation [10] they investigate how a 3D printer can "direct" themselves at the world [6]. In "The Dial" [1] Kristina and Knees explore the thought of a programmed randomness, also as a source of inspiration.

A programmed exaggerated intentionality seems fun, however does the mechanical complexity inherently have an intentionality?

3D printing can be seen as a tool to physicalize the path taken by the printhead. Listencups [4], incorporates data in their clay 3D prints, they highlight that the point is not to read back the engraved data, but it can be used to interpret the data. Moreover in "Pathfinder" [8] the authors describe glitches in code and clay making the process exciting.

The role of the machine in 3D printing is mostly regarded as one of an executor of code. Like mentioned in the pictorial a lot of work is done to increase the accuracy, speed and reliability of these machines. Olivier van Herpt explores introducing mechanical intentionality through sound [11], and as such introduces a machine translation that is not directly graspable by the designer or controllable by the designer, it is however not random, or programmed and as such not easy to understand.

This leads me to my research question in relation to the complete work of literature and the additional literature:

"How does the intentionality of an exaggerated mechanical 3D printer influence the composite intentionality of a live 3D printing process."

The plan

To explore an exaggerated machine agency by increasing the complexity of the mechanics of the 3D printer. This will be explored in two iterations, first an adaptation of the M2.1 machine will be executed to explore how complicating a system will change my perspective on the subject. Secondly a larger mechanical implementation will be made, to capture an increased complexity.

Iteration 1

In iteration one I will make an adaptation of the existing 3D printer system, by connecting the rotary bed to the normal Y-axis. As such we have created a 4-axis 3D printer, after which I will extensively print with the system.

This iteration serves two main purposes; for one it is a trial, to experiment with documentation of the negotiations, and to be able to capture the changing perspective towards the machine over time. Secondly the purpose is to explore the complexity of more complex interface-machine mappings. The low-fi adaptation of the system will allow me to quickly get a feeling for the design space, and can help me define the requirements for a larger system.

The iteration will be reflected on, as well as the documentation format. The goal is to generate a clear idea for designing the second iteration, as well as ways of documenting the insights over time.

Iteration 2

After the first exploration, a design concept has to be made for the machine, the machine will be designed and developed from the concept described earlier, it is however difficult to describe what exactly it will be or look like. However, there is one main demand which is that the mechanical properties should be prohibitively complex, and as such, I as the designer should not be able to articulate clear machine mappings beforehand.

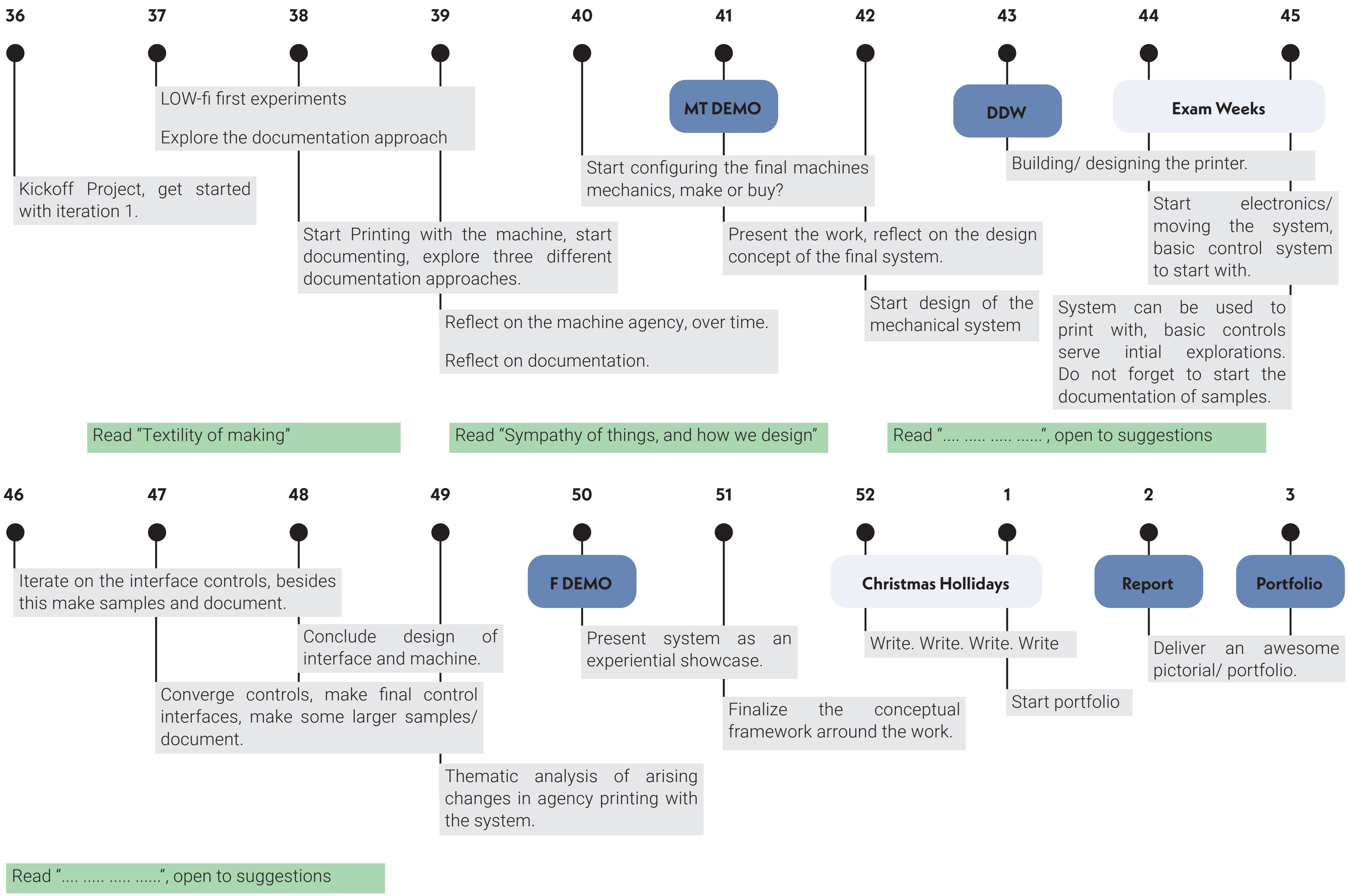
The second part of the system is designing the interface to tailor to the system, I aim to continue building on the modular synthesizer interface for the printing, as it allows me to develop tools as I learn more about the system, and reflect on the changing controls and agency throughout the process.

The previously explored documentation will be used from the start, to map the controls and use of modules, continuously I will reflect on the composite intentionality and agency of the assemblage of fabrication.

Outcomes of the project

To conclude, the outcome of the project is two-fold, it is a physical experiment of the "improvisational printing" paradigm, the designer live-controls the 3D printer through a variety of modules. The 3D printer consists of a printhead, and a complex geometry when compared to the "normal" XYZ 3D printer.

Secondary contributions will be in the reflections on the agency and intentionality of the 3D printer in this assemblage of fabrication. They will be developed trough documentation and reflections from a philosophical lens on craftmanship.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Kickoff Project, get started with iteration 1.
LOW-fi first experiments
Explore the documentation approach
Start Printing with the machine, start documenting, explore three different documentation approaches.
Reflect on the machine agency, over time.
Reflect on documentation.
Start configuring the final machines mechanics, make or buy?
MT DEMO
Present the work, reflect on the design concept of the final system.
Start design of the mechanical system
DDW
Building/ designing the printer.
Exam Weeks
Start electronics/ moving the system, basic control system to start with.
System can be used to print with, basic controls serve intial explorations. Do not forget to start the documentation of samples.
Read “Textility of making”
Read “Sympathy of things, and how we design”
Read “.... ....“, open to suggestions
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Iterate on the interface controls, besides this make samples and document.
Converge controls, make final control interfaces, make some larger samples/ document.
Conclude design of interface and machine.
Thematic analysis of arising changes in agency printing with the system.
F DEMO
Present system as an experiential showcase.
Finalize the conceptual framework arround the work.
Christmas Hollidays
Write. Write. Write. Write
Start portfolio
Report
Portfolio
Deliver an awesome pictorial/ portfolio.
Read “.... ....“, open to suggestions

Areas of expertise

I think it is clear to say that this project has a multifaceted contribution, however, it is centred around Technology and Realization and Math Data and Computing. What I'd like to make is a system which is accurate and precise, however engages with playfulness and materiality. As such there is no need to achieve a specific accuracy or speed. There should not be any hiccups or code delays that "artificially" generate an agency. This will be a challenge, and unlike the current project, I can potentially not rely on ready made systems for 3D printing.

Thus, I will develop my own control system, likely based on a raspberry pi, and stepper drivers. The advantage of my system is that there are not a lot of calculations necessary, the design interface will make all the difficult choices, and as such there is no need to write my own 3D printer firmware. The designing and the coding of the system, will require extensive electronic, mechanic and coding skills. The translation of data to movement will heavily rely on math data and computing skills.

The interface of the 3D printer system will heavily rely on similar skills, however also on the translation of user input into data. The role of data, it's meaning in movement and print outcome is very important for a deep reflection on the agency of the printer.

A third area is in design and research processes, I will aim to make a contribution to these processes, I aim to read works in design philosophy, like: "The textility of making" by Ingold [5], and "Sympathy of things, and how we design" [7]. Like mentioned this is a relatively new focus of mine (compared to digital craftmanship), and as such will require significant time.

Risks

Reflecting on the proposal I can see one main risk. Which is that the envisioned machine intentionality through complex mechanics does not exist or is difficult to map. This risk is rather difficult to assess beforehand, as it is based in theory but is not explored explicitly as far as I know.

The traveller's approach taken in the project does however allow for alternative results to arise from the making. The documentation of the samples most likely can result in potentials side-tracks to pursue.

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REFLECTION

At the start of the project I wrote my PDP, as usual there is a motivation and goal for this project. Which in this case was finding the societal relevance of my projects. I describe how I often lack articulation why I investigate a specific technique, or what specific purpose the research has. During this semester I have been working on a pictorial together with Bruna Goveia da Rocha and Kristina Andersen, and I think this together with my current project, has created the largest shift of direction in my design goals. Before my M1.2 project I was mainly focused on novelty, making something no one else had done, mostly by making. However, this was not fulfilling, and besides me having fun in the making, I missed a drive and often questioned “what am I making this for”.

Bruna and Kristina are more philosophy-oriented researchers, instead of focusing on novelty of a technique, prototypes and experiments serve a deeper goal of questioning ways we approach design. Starting to read and contextualize more philosophical works from Laura Devendorf, and Tim Ingold as well as more engineering-oriented works from Nadya Peek really resonated the role research plays in society, and the approaches you can take.

Throughout the process I found it very difficult to get up to speed with Bruna and Kristina on the sheer amount of research there is, which made it difficult but also motivating to learn more. The coupling from designing systems that question or explore ways of interacting with machines (3D printing), and concepts and insights that arise from these are significant.

Current conclusion of my goal as a design-researcher;

I aim to investigate the complex designer-machine relationship through making. In this I aim to take a middle ground, engineering proof of concept prototypes that challenge the status quo, and developing the design philosophy connected with these concepts.

Setting my goals

In my PDP I outline that I missed a higher purpose of my projects, and couple that to users, I wanted to include other designers in the process to ensure a clear viable outcome. However, when starting the project, I quickly found an increasing complexity of the variables at hand, making it difficult to understand even for myself. The insights related to the system only arose after a significant time making. I wanted to dive deeper rather than broader to deepen the philosophical implications of the design, which changed the goal of the project: not to make a tool for designers, but to make a physical thought experiment.

The second goal was to focus on the user interface, to facilitate complex interactions in an intuitive way. When starting with iteration 1 (the button matrix) I reflected on it quite critically, I made an interface/system that was quite capable, however It was only usable by me. Because of the intricate button combinations, menu structures and organizational mapping. Experimenting with different designs I found an inspiration in modular synthesizers, which are generally complex, but understandable because of the growing nature of the system. One can start with a small set of modules; learn them and slowly increase their complexity. The interfaces of each module can be specifically designed, and the complexity is able to grow and emerge from the combination of modules. Becoming inspired by the analog simplicity of the analog synthesizers I also wanted to make some analog modules.

My final goal was to create a prototype that looked like 3D printer add-on, not a gimmicky research tool, but something that would attract attention. I specifically remade all the face plates for the modules at the end to reflect this goal. I think this goal was achieved quite well as I got invited to join the drivers of change exhibition at DDW.

First iterations of the modules, not a lot of attention to aesthetics.

Making the modules

The making of the modules was a super fun and insightful process, first of all designing the communication interfaces, and ensuring that there would not be any short circuits or unexpected measurements really developed my understanding of electronics, more so how much can go wrong. Floating inputs, short circuits, load-based voltage dropping etc. Luckily, I could borrow a lot of safety and reliability principles from DIY synthesizer modules. Especially Moritz Klein [1] deserves a mention, because the principles discussed in his video were applied in almost every module.

[1] Moritz Klein - YouTube. Retrieved from https://www.youtube.com/@MoritzKlein0

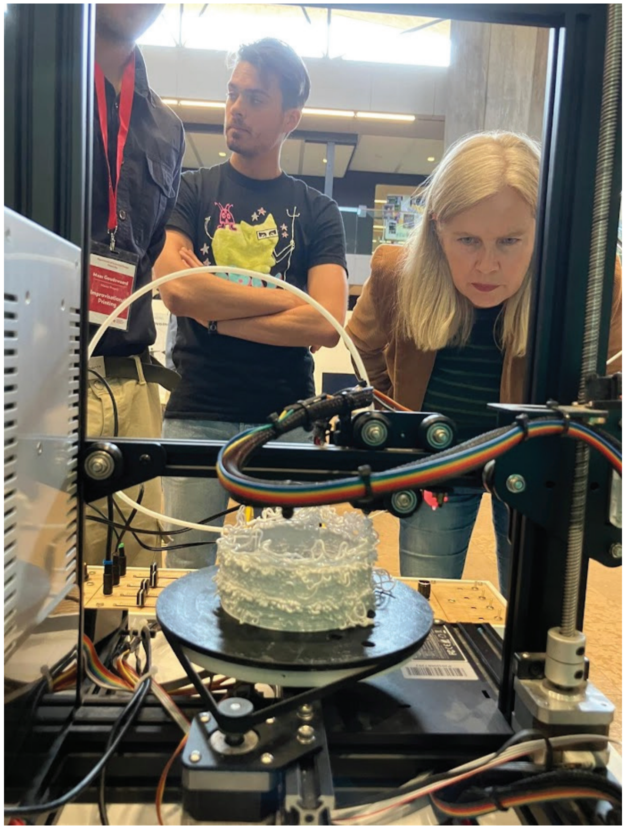
Playfulness

During the demo-day I've had numerous interesting conversations, however the ones that stood out were with children. Naturally they are curious about a machine bleeping and booping, however the possibility of manually playing with the printer had some extremely enthusiastic. Two kids were playing with the printer for over 20 minutes, slowly learning the system, and individually controlling some of the modules. For me this really was an eye opener, as you are often finding the complexities and looking for limits, the basic principles are actually not as complex. A child can control it, the role of playfulness and simplicity in this kind of design I think really hits home the point of open and fun exploration.

Project outcomes

Firstly, I'd like to state that I am very happy with the outcome of this project. The numerous interesting talks about the system and the deeper insights from reading and making the system have resonated deeply with my passion for design. However, there are some opportunities for improvement, for one is the documentation throughout the process, while making thoughts constantly arose about the system. These I captured through taking notes, however it was very difficult to capture the complex negotiations between the designer and the system. I could've brought more structure in my explorations by using a format, or at least experimenting with different template formats. Secondly, I've written the report in pictorial format, and I aim to again submit it to a conference after reflecting on the contributions again. I do feel that the points I wanted to make are there, but I can't articulate it very strongly, I still find myself grasping for the knowledge, and cannot take it in as fast as I'd like. This also is related to the late-ish start on actually writing and reflecting on my writing. I am very much an iterative writer, and there just weren't enough iterations and insightful discussions to really nail the contributions down.

To conclude, I think this semester was a very fun and insightful semester, the pictorial, the project and especially reframing my work in relation to philosophy of design has made things clear. However, there is still a lot to learn, and I find it very motivating to continue deepening my knowledge.



It was awesome sharing my work, with my family (in the picture), but also with strangers more familiar with 3D printing.

REVISED PROFESSIONAL IDENTITY AND VISION

Vision

A designer designs, however in this new age of digitalization we are continuously engaged with systems we do not understand. We work with computers, code, machines and artificial intelligence, while we seek to grasp the underlying principles we are held back by the complexity. This mitigates our opportunity to develop our design intent, we are limited to what we can design with the system.

I believe we need more concrete handles and more in-depth understanding of the relationship between designer and technology. My aim is to increase the understanding of the designer-machine relationship in the context of 3D printing. 3D printing is becoming an integral part of designing and consists of a highly complex interplay between physical and digital translations of design intent, moreover, the physicalization of the G-code in plastic is a rich way of capturing intricate negotiations and as such can provide a very convincing case to study.

I believe that physical thought experiments can open up the understanding about manufacturing and increase the knowledge base around designing with machines. I aim to develop the philosophical understanding of hylonoetic collaborations with machines through making.

Professional Identity

The interactions and translations of code to physical part mediated by a machine is not trivial. There are many negotiations in many layers of the formation of design intent. I've experienced first hand the barriers to making a 3D print, from industry, education and research. Forming design intent through digitalized standardized processes is in my opinion not the way to leverage the qualities of 3D printing.

Making has been important throughout my life. Through crafting I've gained knowledge about the world around me: hands-on learning is the way to gain knowledge quickly and efficiently.

"I express myself in making better than any other way"

My physical approach to design interacts very well with the digital manufacturing environment. I'm able to experiment, observe and interact with machines and code. Constantly switching between the physical, digital and back. The process of hands-on tackling of these challenges allows me to learn about it, as well as communicating the intricacies visually.

I aim to be a translator, designing means for other designers to navigate the complex world of code, machine and craft. Through critically reflecting on design practises and experimenting with alternative approached in a hands-on way.

ORIGINAL PDP

Vision
Designerly intentions are increasingly mediated by machines, the shift from craftmanship to mass production necessitates it, the practice of mass manufacturing overseas is very wasteful and non-personal.

I believe that digital manufacturing like 3D printing can tailor to these challenges, however we must not just place the 3D printer like an injection molding machine, process and application innovation is necessary, and designerly intentions can mediate the process.

3D printing can be tailored from part-to-part, and can generate extremely complex structures and patterns, however the current processing of machine code does not facilitate this in straightforward ways.

I aim to investigate and highlight what we can do with 3D printing, and empower other designers to do the same.

Professional Identity
The interactions and translations of code to physical part mediated by a machine is not trivial. There are many negotiations and I have extensively experienced that in previous projects.

Making has been important throughout my life. Through crafting I've gained knowledge about the world around me: hands-on learning is the way to gain knowledge quickly and efficiently. Moreover, the hands-on approach directly informs me with opportunities and limitations of techniques.

My physical approach to design interacts very well with the digital manufacturing environment; I am able to experiment, observe and interact with machines and code. Constantly switching between the physical, digital and back. This process of hands-on making and finding the limits often results in new opportunities for design.

I aim to be a translator, designing means for other designers to navigate the complex world of code, machine and craft. While respecting their respective craft.

Goals
For this project I've set some specific goals to challenge myself and tackle frequent fallbacks I've encountered in my studies. On which I will reflect first. One of the main fallbacks in my designs is the alligment with users and with society, often I ask the question, but why do I do this, why do I create this thing, why do I research the technique? And often I come up with the answer, because this gives new opportunities for design, because it broadens what we can do with manufacturing machines, however what this is remains to be developed after the project.

Secondly is the ease of use, I often create research/ design tools that develop a specific function or use, and they contain multiple software and hardware layers to get through, If I were to pass it to someone extensive explanations and hours of work would have to be done before someone could actually use my system.

Lasty I've been developing these tools and making proof of concept implementations and hardware setups. Open unedited scripts, interfaces on breadboards, etc. The product design aspects of the tools that I make have been neglected significantly. I have a large passion for making, especially woodworking, so I aim to use that in my project.

So that brings me to three main goals I have for this project;

I want to create a design that people use and want to use. I aim to include a whole host of designers and ask them to engage and work with my prototypes and final product to an extent that I can honestly say, this thing matters.

To facilitate this I want to make a intuitive and complex but clear interaction, which does not undermine the rich possibilities of interaction but does undermine unnecessarily confusing interfaces, code and hardware.

And lastly I want to wrap it all in an aesthetically pleasing shell, which conveys the product and idea not only as a tool for research, but as a sophisticated 3D printed add-on.