Designing a 3D printer; how reflective making engagements enriched my practice

A thesis by Maas Goudswaard
Coached by Kristina Andersen

ABSTRACT

Digital fabrication allows the making of parts with the accuracy of a factory process, without the need for extensive skills and investment. These advantages have increasingly integrated machines like the 3D printer into the design practice. However, the basic architecture of 3D printers still relies on the industrial workflow of CAD/CAM, where the designing is done through a digital interface and the making is done by the machine autonomously. This workflow can be regarded as hylomorphic, linear, deterministic and inhibiting engagement with the materiality of making. By using these machines, the designer risks being dissociated from making practices and its respective insights. This project explores the case of designing an alternative 3D printer. A live, improvisational, serendipitous machine, which is live programmed through a modular interface inspired by music synthesizers. In this process I engage with the process of designing this 3D printer and printing with it, while continuously reflecting from a first-person perspective on the practice of making. This process resulted in a 3D printer which speculates on what a 3D printer is, and what the process of 3D printing can entail. In the end I present a two-fold contribution, the speculative 3D printer and its corresponding reflections on making practices, and secondly highlighting how the active engagement with the practice of making has fostered these reflections.

PRE-FACE

Before reading this work, I'd like to position myself as the writer of this document. This project has been developed by me, Maas Goudswaard, and is grounded in my personal experiences with designing, 3D printing, and making. This thesis is developed from a first-person perspective and as such the outcomes are situated in my practice and cannot be separated. I aim to be transparent about my assumptions, and as such provide first-person contextualized results.

Design Context

This project has been developed as a final master's thesis Industrial Design at the Eindhoven University of Technology, in the squad of crafting wearable senses. As such I have been in continuous conversations with Kristina Andersen (also coaching me this project), Bruna Goveia da Rocha, Rong-Hao Liang and Troy Nachtigall. The focus of this squad lies heavily on making first and explores (digital) craftmanship.

Experiences in Digital Craftmanship

I've been working with 3D printers and laser-cutters since 2014. In high school I followed a project-based learning program (technasium) where I have made numerous 3D printed/laser cut designs.

In 2018 I entered the Industrial Design program at Eindhoven University of Technology, where I continued to explore working with 3D printing. For instance, 3D printing molds for silicone casting and programming G-code replicating structures similar to A-Line [52]. In 2020 I worked on a large project, Fabriclick [19], where we integrated digital embroidery and 3D printing into a functional on-body button matrix. This project was pivotal in my studies as it confirmed my interest in the physical and digital nature of digital craftmanship, the tensions that arose when translating from digital to physical in particular. In 2021 I worked on a project exploring laser cut lattice hinges, this was also my graduation project for the bachelors Industrial Design.

From 2020-2022 I worked at Signify 3D printing [59] at the R&D department situated in their 3D printing factory in Maarheeze. Where in three semester projects worked on A) multi material 3D printing, B) Multicolor Pellet printing, C) AI image integration into a pellet 3D printer, and D) Visual product inspection.

I started my industrial design masters' at Eindhoven University of Technology in 2022. In 2023 I worked on a project: "Entering the 3D printer" where I manually augmented a 3D printer to facilitate on-the-fly improvisation, this work got published at dis 2024 [20], and I got the honor to present it in Copenhagen at the conference. From 2023 I started working at the faculty 3D printing service, assisting students in 3D printing of prototypes and maintaining the machines. In 2024, I developed a 3D printer which was live coded by a modular synthesizer interface, which I got to present at Dutch Design Week 2024. This project was the preparatory project for this thesis, and as such forms the base of the 3D printer interface [60].

Why my background matters

My previous experiences in making with machines has given me reflections on what it means to 3D print, how we engage with 3D printing, and how we can alter the configuration of 3D printers. Some of these experiences are more influential than others and I would like to highlight two:

Working at Signify 3D printing was an opportunity to see how a large company is aiming to integrate personalized on-demand 3D printing for consumers and professionals [59]. To me this seemed like one of the main advantages of 3D printing, however the yield of "successful" 3D prints was quite low. When a consumer buys a product, the demands are different than for a prototype. I worked on integration of an automated scanning system by Keyence [61]. The visible part of the 3D print was the first layer, and any imperfection was scrutinized and rejected from being sold. The solution to this low yield was to reprint until it was successful, instead of reconsidering the process. I can say that this company embraced a very hylomorphic approach to 3D printing: where their intentions; a perfect first layer, was inhibited by the materiality of the process.

I've spent my masters and bachelor's on the academics of fabrication, this was kickstarted by the FabriClick project [19]. Reflecting on my work outside of the university, how to provide value for others and thinking about the contributions outside of my own scope was meaningful. This first encounter with academics sparked my passion to not only make things but provide pointers to other design practitioners about my insights. In my masters I've published another project: Entering the 3D printer [20]. The project was tailored for an academic audience from the start, developing a philosophical contribution on the agency of machines next to the technical contributions.

Me using the machine developed in "Entering the 3D printer" [20]

VISION OF THE PROJECT

These experiences have prompted me to start this project, have given me the tools and knowhow to execute this project and to talk about its significance. As such I'd like to finish this preface with my vision and motivation for this project:

As designers we are increasingly delegating our making tasks to machines, consequently making design more and more dependent on software. These digital interfaces for design lack engagement with materiality and are tailored for linear making practices. Moreover, ignoring the materiality of the process can inhibit effective use of technology.

I'd like to explore a speculative 3D printer, which embraces an alternative paradigm of digital manufacturing. Where the designer and machine enter in a continuous conversation with the material, mediated through a physical interface.

This is with the goal to foster critical reflection on what it means to 3D print, on machines' and materials' agency in printing, and how we as designers can engage with making in this digitalizing practice.

INTRODUCTION

In the current age of digitalization, we are increasingly delegating tasks to digital devices, and fabrication has not been exempted from this. Digital fabrication methods, like 3D printers, allow the fabrication of parts with high accuracy, speed and largely independent from the designer's making skills [3]. These tools and techniques are increasingly integrated into the design practice and can hardly be separated from it anymore [16]. These fabrication machines work with standardized machine protocols which are increasingly complex and sophisticated.

3D printers are mostly mediated by a process of CAD/CAM [20], as such it works by first making a design on a computer (CAD), after which it is processed with a slicer by the designer and 3D printed autonomously by the machine (CAM). This process is optimized to provide a linear solution from digital design to physicalizing that design, and as such it is outcome oriented: effectively optimized to accurately fabricate the CAD made design [11]. The outcomes of these printing processes are predictable: the staple 3D printed part, neatly stacked lines of plastic deposited on top of each other. Increasingly design researchers have explored ways to creatively appropriate this CAD/CAM process, and this has shown how expressive and creative the use of a 3D printer can be [16,19,20,26,39,45,48,52]. However, the designer is often left out of physical making.

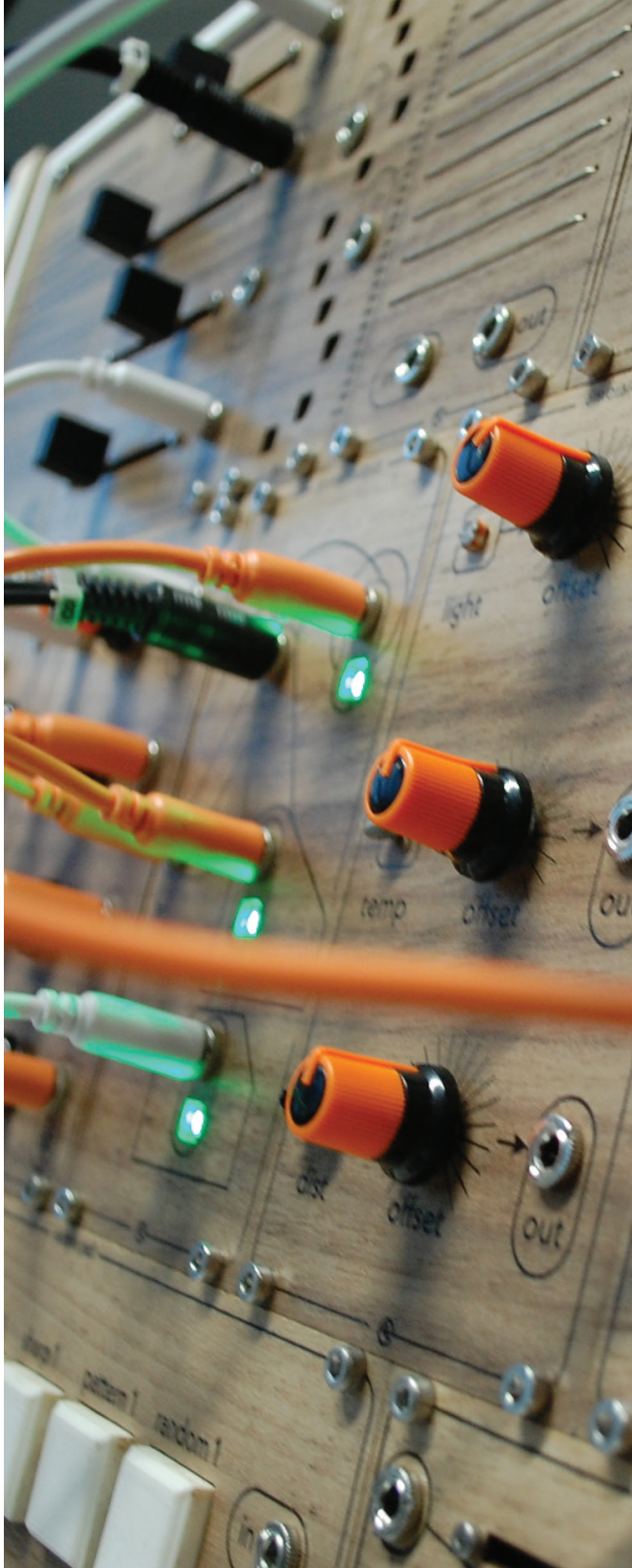
This risks the designer from being dissociated from the making process, which is so often rich in insights [20]. Engagement with the materiality of making is often the source of new design opportunities [20,48,51]. And engagement with this materiality is inhibited in the 3D printing paradigm [11,13,42]. Researchers have explored re-uniting designers with the making process creating machines that allow the designer to collaborate with the machine iteratively and hands-on [5,6,13,39,47,53]. It however remains a challenge to bring these insights into design practice. They are either complex and specific purpose solutions, or generalist philosophical explorations.

This project started from the vision: re-imagining 3D printing as a performance art [12]. And applies a traveler's approach [23]: just start making the machine, and explore its properties along the way. To capture and communicate the contributions this project takes a first person perspective [10,30], and therefore leverages auto-ethnographic field notes to document the insights along the process [15,34]. I draw inspiration from modular music synthesizers to inform the machine controls [4], and also engage with expert makers and theory to frame my practices. A process of designing the machine, while 3D printing with it ensued. Resulting in a 3D printer, and a lot of auto-ethnographic field notes.

These auto-ethnographic notes were analyzed and processed in an annotated deck of slides. Which presents a case study of designing an alternative 3D printer tailored for live, improvisational, performative, and serendipitous modes of making. In effect reconfiguring the designer from an observer of the fabrication process, to an integral part of it [13]. The process is intuitive and improvisational, like the 3D printer it aimed to design. And actively engaging in the design of this machine has triggered critical reflection on my design practices.

The reflective process of designing the 3D printer in this project has given rise to two contributions. Firstly, is the 3D printer and its corresponding reflections on 3D printing as a making process. The 3D printer engages with an improvisational mode of 3D printing and it generated reflection on how this approach to 3D printing altered the way I make. In effect it has casted the "traditional" 3D printer in a different light and as such points to a different paradigm of 3D printing. Secondly, the act of actively engaging with experts and theory diving deeper into the role of agency, intentions and frictions in my process has led me to review my own making practices. And as such this case serves as an example of how making first engagement with reflection, has led to a new perspective on my practice.

This project aims to provide an exemplar of how we can engage in the making of making centric machines and highlights how actively exploring and reflecting on ones making practice can lead to new thinking.



Close-up of the final interface implementation

THEORETICAL FRAMING

On making

We interact with the world around us, and when making we are engaging with materials, shaping them following our "designerly" intentions. A way of interpreting this is to look at making as collecting materials, imposing forms "internal to the mind upon a material world" [28:21]. This is referred to as a hylomorphic approach to making, and is generally seen as limited in its reality with making practice [13,28]. Ingold outlines a more conversational approach to making; where the work is created by a continuous engagement with materials [28]. This is referred to as a morphogenic approach to making, where the human actor (designer) and non-human actors (tools and materials) "correspond" to make [11,28]. Ingold poses the question: "If everything about a form is preconfigured in the design, then why bother to make it at all?" [28:22], inferring that there lies a richness in the making practice that cannot be intended/predicted by the maker. Consequently we should celebrate the makers engagement with materials [28].

When we zoom in to making with a 3D printer, we can reflect on this practice as hylomorphic [11,13,20]. The designers intentions are pre-formulated through a computer aided design software (CAD) and forced upon the material through the machine outputs [20]. Critically looking at this notion, we still deal with the materiality of the physical world, the designers' intentions are captured beforehand, and these intentions are physically enacted by the machine. However where Ingold describes a conversation with materials [28], we might reflect on the making with the 3D printer as setting the initial parameters after which the making happens outside of the designers reach [11,20]. The physical making process is locked off from the maker [11], there is little chance for a maker to engage with the making process.

Making with a 3D printer

A 3D printer works in a standardized way: A design is drawn on a computer in a CAD program, this digital design is translated into machine code (G-code) by a slicer, this code in turn is uploaded to the machine which fabricates the part. This standardized approach works well for fabricating parts, and as such is increasingly integrated into design practice. A large body of research is thus focused on increasing the versatility, speed and reliability of this process [16,29,36,50,55,56]. Research often focusses on one of these aspects in the process and aims to increase its potential for design. For instance, designing software that mitigates the translation of a CAD drawing into machine code, immediately designing the G-code [5,41,44]. Other works aim to reduce unintended results in the production by reducing unpredictability and mistakes in the 3D printer [17,26,39,40]. More work attempts to reduce the linearity of the process and explore more iterative and faster ways of working with a 3D printer [38,39,46].

Besides improving the standardized process there is a large body of research which aims to increase the designer's involvement in the fabrication process. Researchers have included designers in the 3D printing process, making it more expressive, creative and improvisational [5,20,33,49]. Other works aim to unpack every step in the process and explore how the role of designer and machine can be reconfigured [13,45,47,53]. Or explore the agency of machine and material in the process [20,42]. Other research has explored how they can break this linear process of CAD/CAM. By live generating the code to be streamed to a 3D printer, here the linearity of the process of generating the code and executing the code is changed to a continuous process of making [38,45].

Technology shaping practices

Technology is shaping the way we make [1], the tools available to us allow certain outcomes. "We shape our tools, and thereafter our tools shape us" [8:70], outlines the two-way relationship we have with making and making of tools [27]. There is however a tendency to look at tools and technology as "objective" neutral outcomes of a research and development process. A "Darwinian Ideology of technological progress" [35:146], however we can attest that the development of technology is laden with cultural, societal and political consideration [35,54]. And as such technology/tools have to be critically assessed and reflected upon, to open doors to a broader range of possibilities [35].

Some researchers have tried to unpack and reflect on the role that 3D printers have in fabrication [13,20,42], and in our design decisions [42]. 3D printers are outcome oriented, they are optimized to produce a part [12]. A 3D printers design is inherently optimized to express particular values like "accurate replication" and not others like "close interactions with materials" [11:2]. The shaping agency of the 3D printer as such is important to reflect upon. Devendorf et al. use their work on "redeform" to reflect on the practice of 3D printing [11]. Speculating what other roles manufacturing might have in our future can provide potential directions to research, however it can also prompt us to reflect on our current practices [12].

METHODS AND PROCESSES

The process of this project applies theory from well-defined methodologies, it is however situated in my own design practice. As such this chapter will highlight the theories that informed the process, as well as how they were applied and adapted throughout. Below is a visualization of the complete project process which the rest of this chapter will further elaborate.

Design process

This project adapts a research through design approach [18,57]. Where the activity of designing as well as the artefacts designed, generate and communicate knowledge [43]. During the project there will be four main design activities, which form the subject matter of the project. These are A) making the machine, B) making with the machine, C) engagement with designers, and D) engagement with theory.

A) Making the machine

The processes of making machine parts fall into this category and entail the process of designing interface elements, fabricating machine parts and writing code for the machine and interface. In short everything that makes the machine work. The role of this process is to develop the machine, as well as generate insight and reflection into the practice of making.

B) Making with the machine

This process entails using the machine for any intention, like using the machine to test functionality, to explore or to communicate. Basically everything that the machine does when turned on. The role in the project is to develop insight and reflection into the 3D printing as a practice, what it means to make with this printer, as well as provide input into the other design activities.

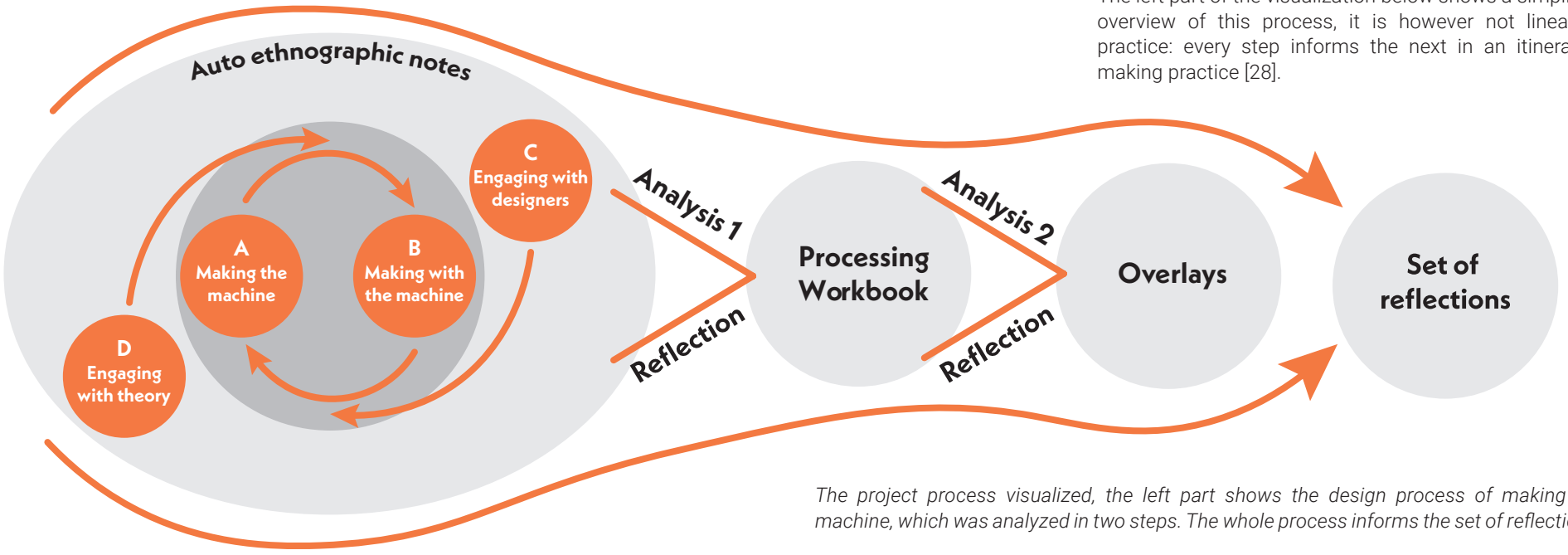
C) Engaging with designers

This process entails the production of a podcast, exhibiting work and interviewing with maker. The role in the process is to reflect on making practices together with other makers, to evaluate the narrative and to generate new design input.

D) Engaging with theory

This process entails reading and listening to theory, actively linking it to the other processes. By writing about it, and by looking for parallels from theory to practice. The role of the theory is to provide framing, context and inspiration for the other processes.

The execution of these activities was not pre-planned, rather left to unfold and let every step inform the next, adopting a travelers approach [23]. There was however a general intention beforehand. Process A) Making the machine and B) Making with the machine iteratively alternate after each other. In practice: envisioning, designing and making a new machine part (A), after which this would be tested by 3D printing with it (B), in turn informing the next machine modification (A). The other two activities would intermittently come through and inform specific activities or the process as a whole. The left part of the visualization below shows a simplified overview of this process, it is however not linear in practice: every step informs the next in an itinerative making practice [28].



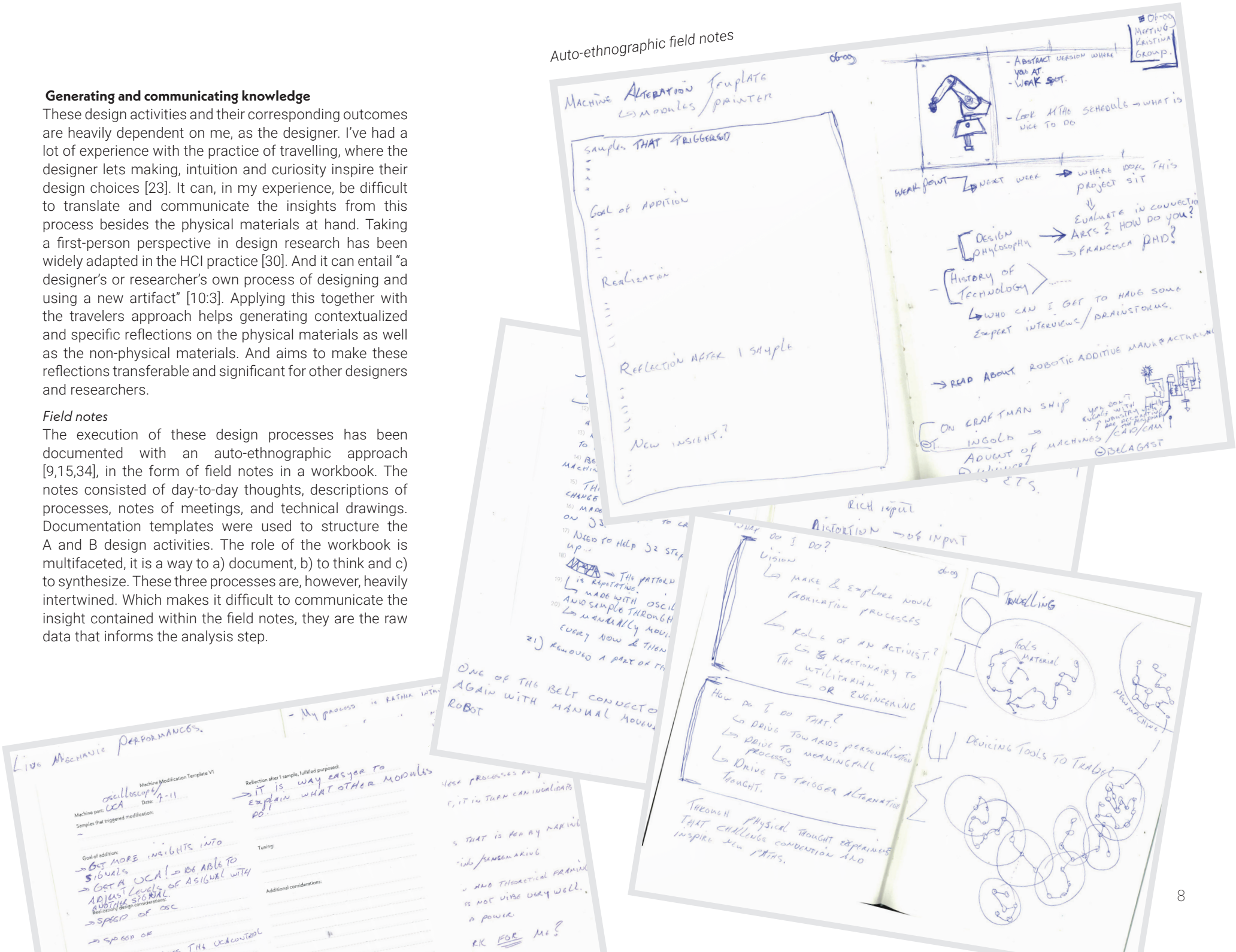
The project process visualized, the left part shows the design process of making the machine, which was analyzed in two steps. The whole process informs the set of reflections.

Generating and communicating knowledge

These design activities and their corresponding outcomes are heavily dependent on me, as the designer. I've had a lot of experience with the practice of travelling, where the designer lets making, intuition and curiosity inspire their design choices [23]. It can, in my experience, be difficult to translate and communicate the insights from this process besides the physical materials at hand. Taking a first-person perspective in design research has been widely adapted in the HCI practice [30]. And it can entail "a designer's or researcher's own process of designing and using a new artifact" [10:3]. Applying this together with the travelers approach helps generating contextualized and specific reflections on the physical materials as well as the non-physical materials. And aims to make these reflections transferable and significant for other designers and researchers.

Field notes

The execution of these design processes has been documented with an auto-ethnographic approach [9,15,34], in the form of field notes in a workbook. The notes consisted of day-to-day thoughts, descriptions of processes, notes of meetings, and technical drawings. Documentation templates were used to structure the A and B design activities. The role of the workbook is multifaceted, it is a way to a) document, b) to think and c) to synthesize. These three processes are, however, heavily intertwined. Which makes it difficult to communicate the insight contained within the field notes, they are the raw data that informs the analysis step.



Analysis (first round)

The four design activities and their corresponding outcomes, collected with the auto-ethnographic field notes informed the next step. Pictures of all the activities executed were collected onto slides, this formed a relatively chronological design process.

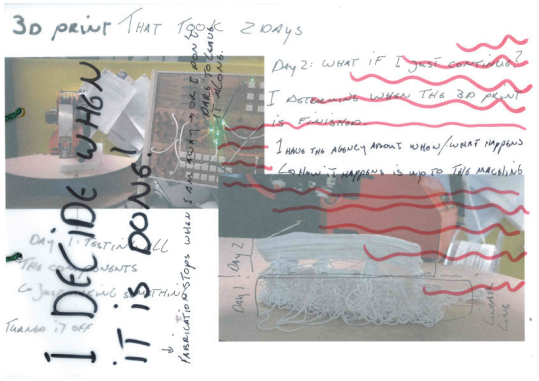
These slides were printed and annotated with relation to the field notes, here there was a focus to summarize the auto-ethnographic notes capturing thoughts that were present during the execution of the activity. This so called "processing" workbook is included in large part of the project section.

Analysis (second round)

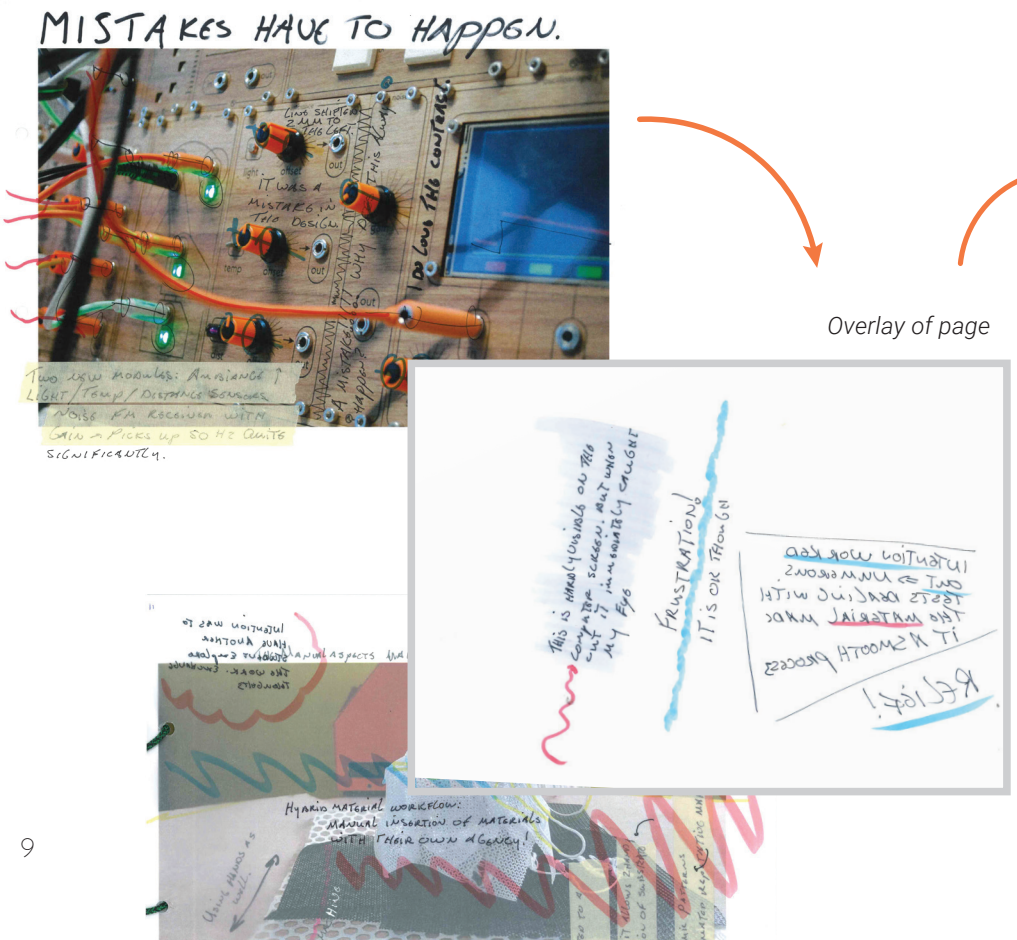
In the second round of analysis, a translucent paper was used to look at every annotated slide from the processing workbook again. The intention was to reflect on the auto-ethnographic notes from a theoretical perspective. Every slide was annotated reflecting on the role of: Agency, Intention and friction. These three themes arose from the design process, and surfaced throughout the project in the field notes as well as the first analysis step.

Generation of reflection.

Actively making the processing workbook, and going through it again, has informed the reflections which form the results section of this report. These results have a focus on qualitative first person perspectives [10,30]. And aim to provide insight into my journey and my reflections on making this machine.

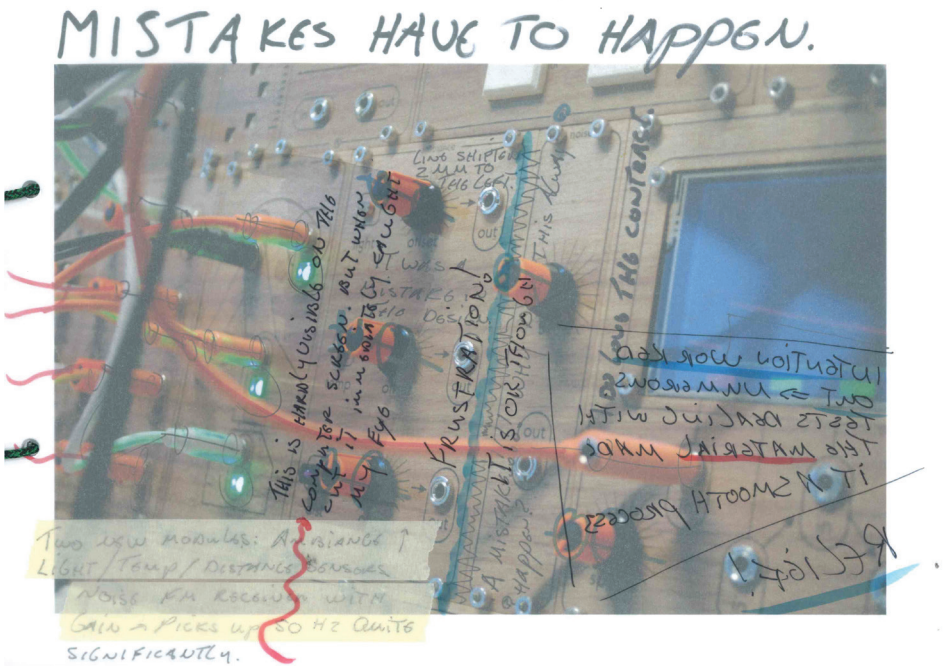


Page from the processing workbook



Overlay of page

Overlayed page in processing workbook



TECHNICAL DESCRIPTION AND EXPLANATION.

The following chapter describes the technical facets of the system, The base principles of the modular system have been explored and developed in a preparatory project, and as such this chapter partly summarizes descriptions from that project [60]. The 3D printing system consists of mainly two parts. First is the robot arm with extruder mounted to it, this is the mechanical part of the 3D printer. Next to that is the modular interface, which live-programs it.

Robot arm

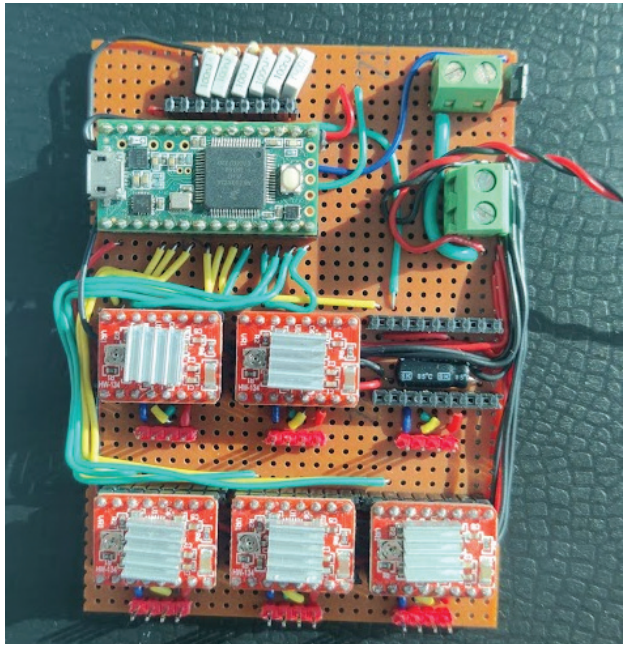
A robot arm: the Sekuria Cobra RS3 [58], made somewhere around the 1980's, was used as the base of the movement system. To make it suitable for 3D printing two of the four stepper motors were replaced for stronger nema17 stepper motors [62]. A new driver circuit was built with a teensy 3.2 as microcontroller and A4988 stepper drivers [63,64]. A Creality Sprite extruder was mounted to the end of the robot arm [65], and a heating circuit was made to power the Hot End. Homing switches were mounted to the arm to facilitate an automated starting procedure. The steppers run at 24V as well as the Hot End, the teensy is supplied with 5V.

The Teensy was programmed to read 5 analog inputs, one for each of the stepper motors (J1, J2, J3, J4 and Extrusion), and translate that reading to a position. This means that when input J0 reads 0V it will move all the way over to the LEFT, if this voltage changes to 1.75, it will move to the middle. As such there is no G-code, the Teensy just reads voltages and moves the steppers accordingly. The output module is the interface between the robot arm and the rest of the modular system.

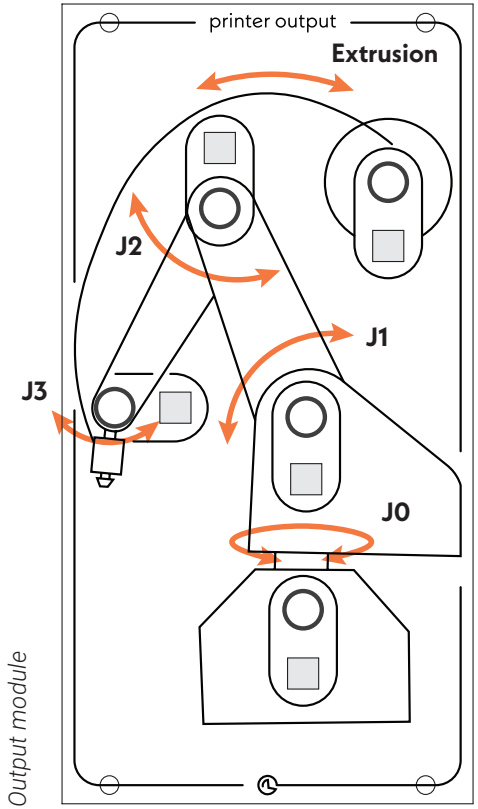
Base of the modular system

The modular system works with analog voltages, it is heavily inspired by modular synthesizers in the way they work. Modular synthesizers work by stripping the synthesis of sound into different modules, every module does one or more specific things. And the modules are daisy chained together with patch cables, through which the signal travels [4]. The way that the artist daisy chains the modules together and the settings of the individual modules produce the outcome. A Euro Rack format was chosen, of which the voltage signals are normally in the -12V to 12V range. For this prototype a signal range of 0V 3.3V was selected. This mainly because of the compatibility with the SAMD21 based Seeduino Xiao microcontroller [66]. These microcontrollers have a couple of digital pins, ADC (analog to digital converter) pins and most importantly one DAC (digital to analog converter) pin. Which means that the microcontroller can read as well as write signals in the 0 to 3.3V range. To protect the output part and ensure clean signal transfer, every output voltage is buffered with an opamp and protected with a 470 Ohm series resistor.

Some modules were digital and thus contained a microcontroller, which were supplied with a 5V supply. A large number of modules were completely analog, and as such were supplied with 3.5V.



Motherboard for 3D printer



Sekuria Cobra RS3, with extruder

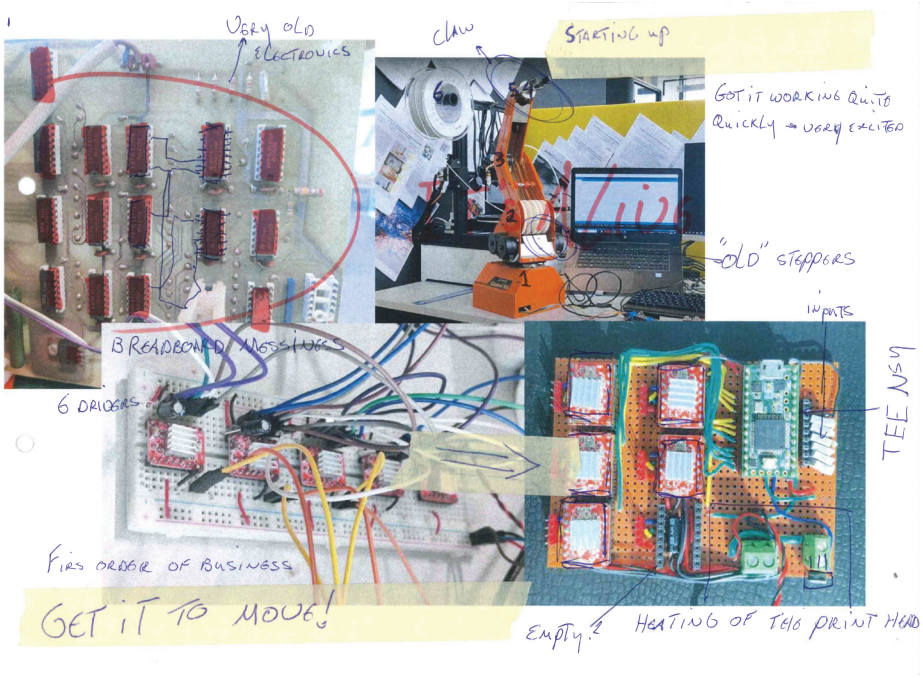
THE PROJECT

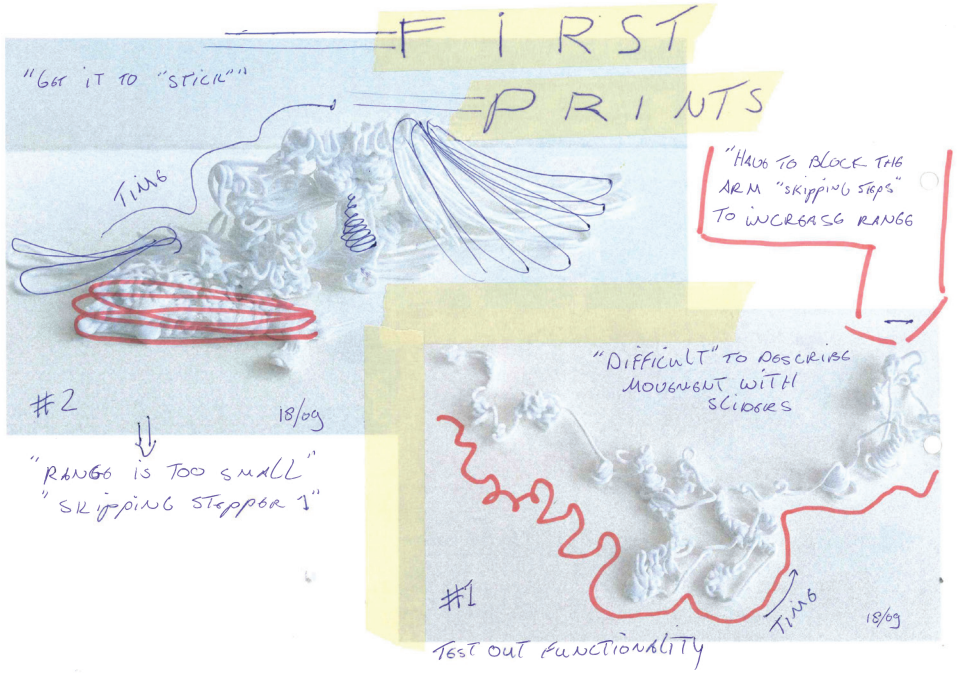
This chapter describes the auto-ethnographical journey of me the designer making the system, engaging with the process of making the machine and making with machine. The pictures are snapshots of the processing workbook (as outlined in the method), and a short summary of the activities is given.

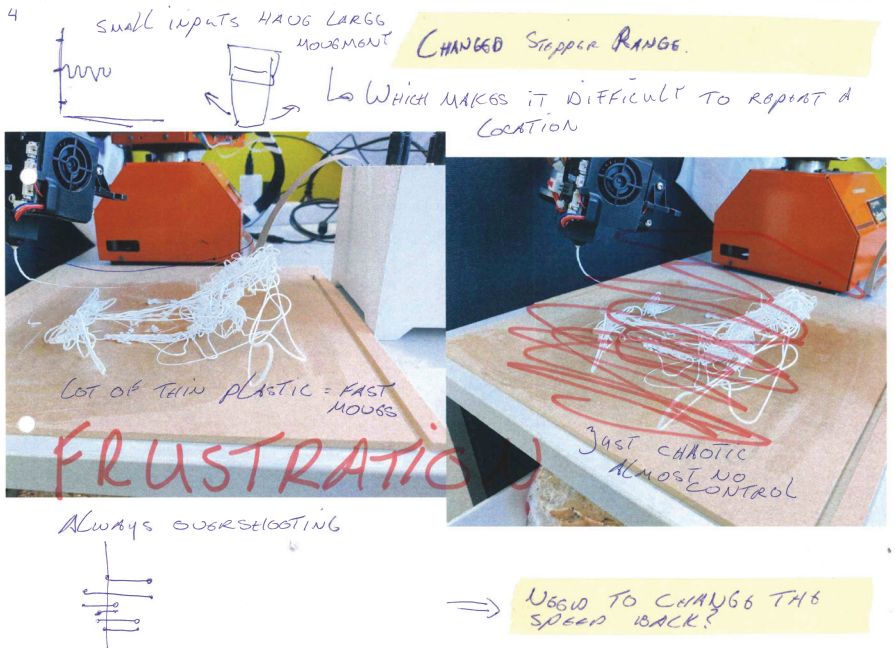
Starting up

The start of the project revolved around getting the machine working as fast as possible, a lot of concrete little steps had to be taken. Revitalizing the mechanics, designing and making a motherboard and programming controls. After the first startup it was immediately apparent that the original steppers on the robot arm of two axis would not be strong enough, so they were replaced. After these initial modifications it was possible to start 3D printing with the interface crafted during the preparatory project [60]. 3D printing with the machine was exhilarating, to start this process so quickly in the semester was very motivating and exciting.

Immediately thoughts and inspiration started to arise from working with the machine, the mechanical play in the machine, the material not sticking to the build plate and the complex interaction to name a few. Moreover, the vision of the project already started to shape in more concrete ways, I could see examples of live-3D printing materialized before my eyes.



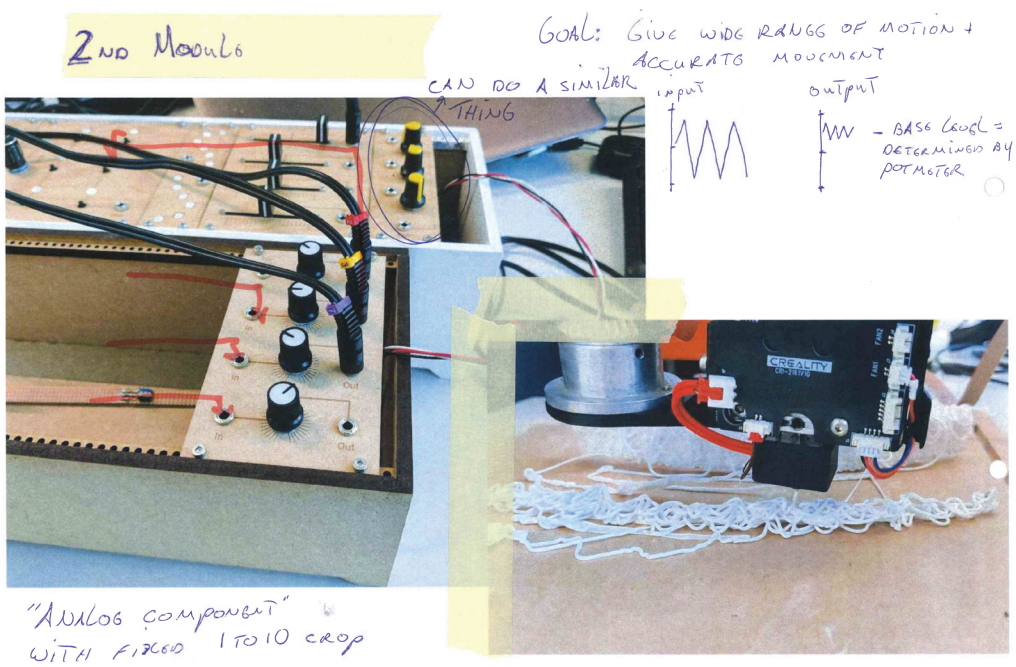


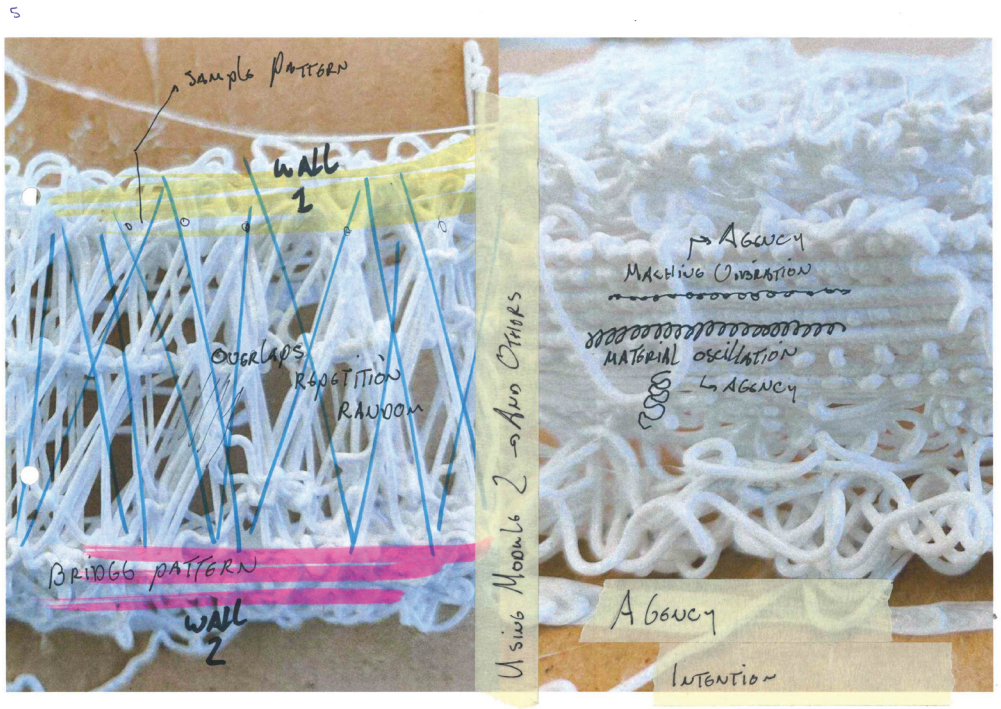


First module

After the initial prints one main concern was the range of motion, the analog voltages used were read by the teensy and converted to steps. However, how large the range of motion is was important. In the initial setup the full swing 0-3.3V was about 5CM of movement, which made the control fine-tuned but impossible to make large objects. The system was reprogrammed to facilitate larger objects, the full range from 0-3.3V was around 40cm; this however, made it impossible to have fine-tuned control. Which sparked the necessity for the first module; a module which allows fine-tuned control.

After implementing this module, and printing with it, immediately a large difference was experienced. As the knob allowed coarse control, another module could inform the expression of the plastic. As such the geometry was intentionally set by me, and the small movements on top of that large movement were controlled by another module.



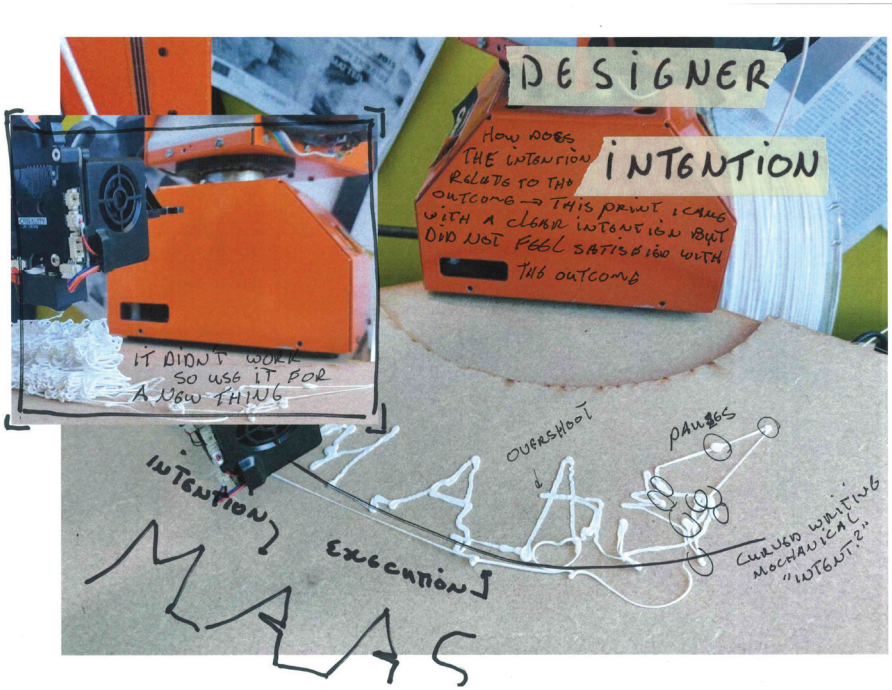


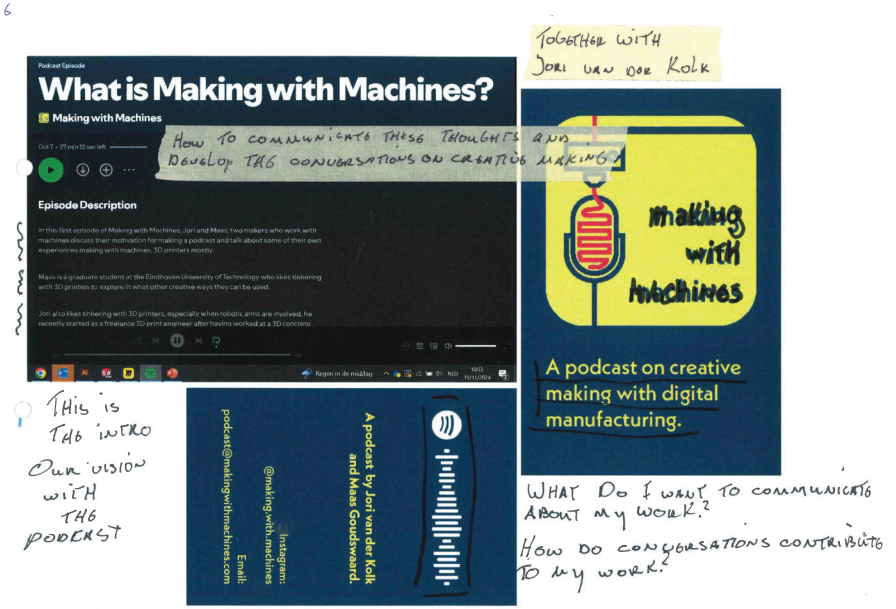
Dimensional accuracy

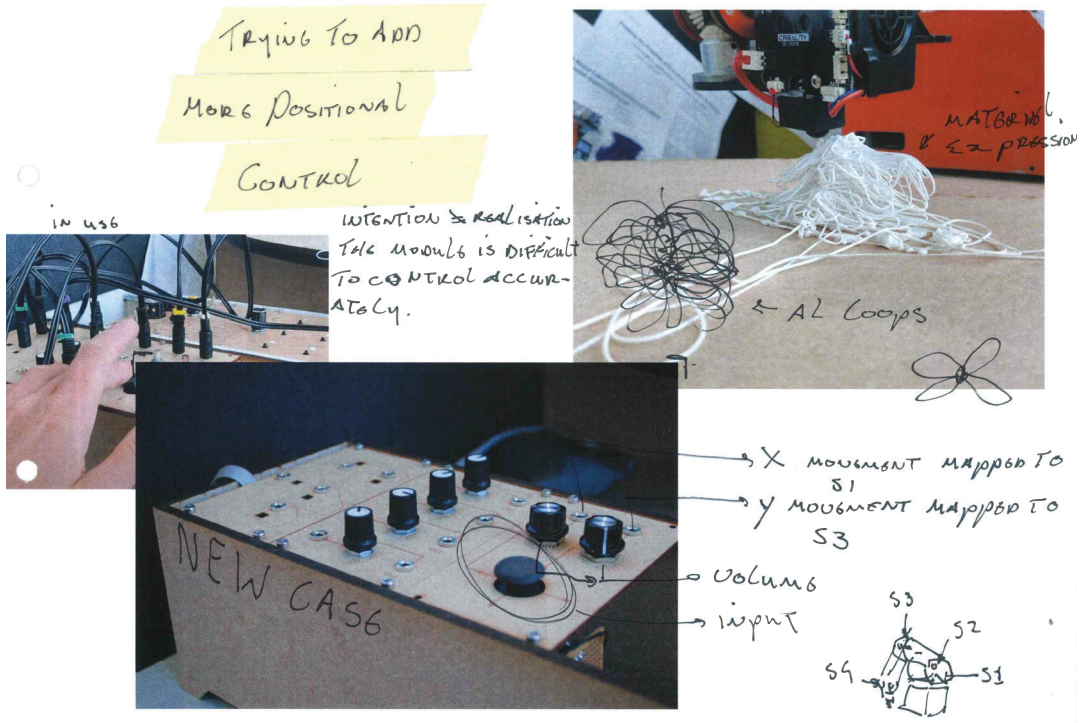
In 3D printing there is a large focus on accuracy, the designer's intention captured in the CAD-model should be flawlessly materialized. In the next 3D print, I started with a clear intention as well: writing my name with the 3D printer. Controlling the J1 and J3 junctions with separate manual controls I was roughly able to write my name. Controlling the path accurately was difficult. Ideating how I could solve this I stumbled upon a joystick module in a free electronic parts bin. I could generate two outputs with one manual input with the joystick.

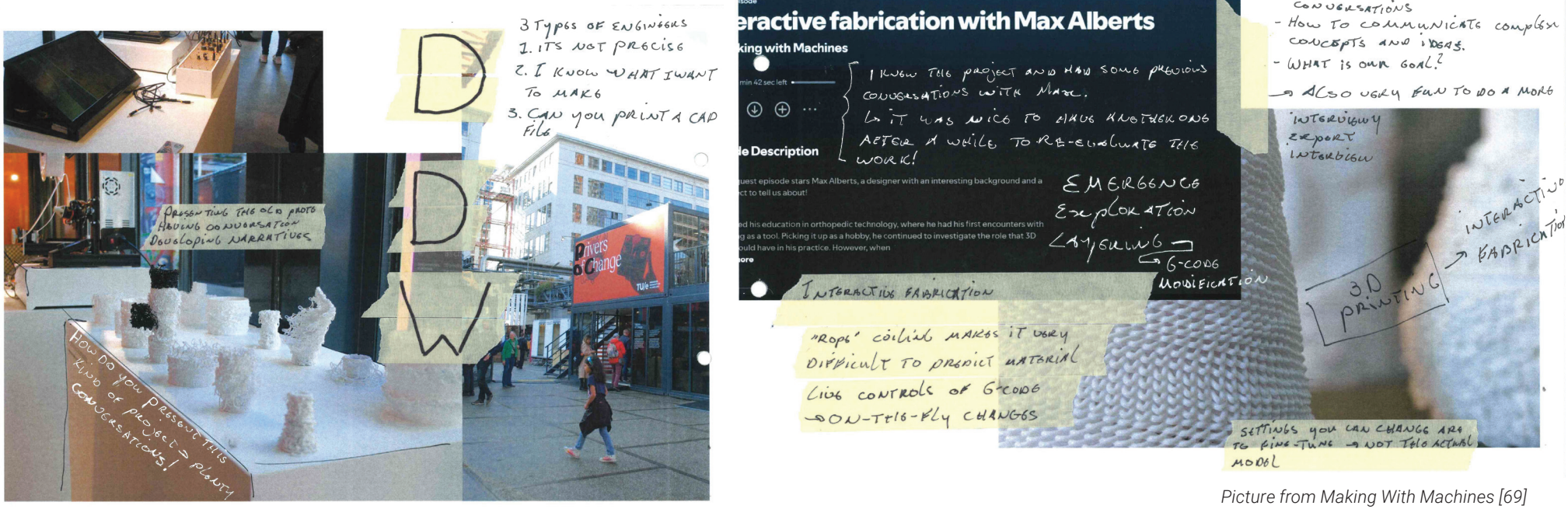
Making the joystick module and printing with it was not as intuitive as I expected, it made it super difficult. Fine finger movements translated to huge movement by the machine. The combination of accurate large scale control was difficult to do quickly. However, an interesting observation arose while printing, the joystick very reliably returns to the center when let go. As such it can be used to explore loops which return to the exact same point.

During these activities I also started conversing with Jori van der Kolk [67]. We wanted to create a platform to talk about making centric engagements with design where we would go into conversations with expert makers about their practices. We decided to make an introductory episode [21], introducing our vision for the podcast and introducing ourselves as makers and designers. Attempting to generalize my vision on making for a wider audience and conversing with Jori about his vision, was a good exercise in articulating my intentions of the project.

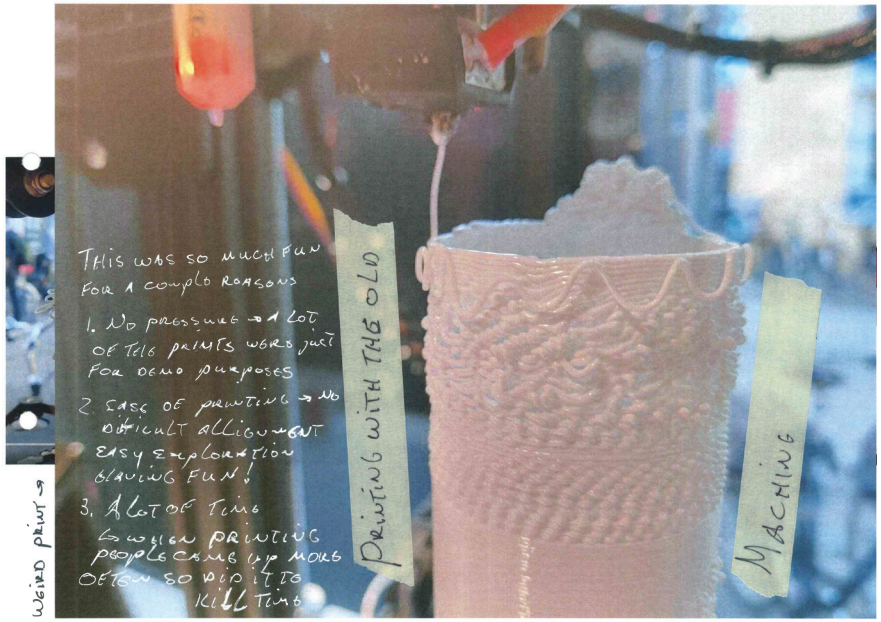








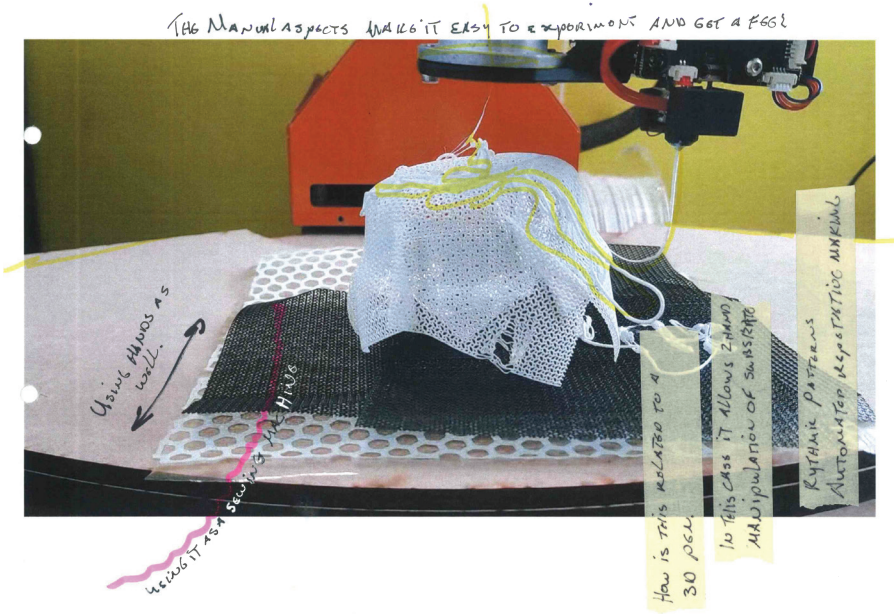
Picture from Making With Machines [69]

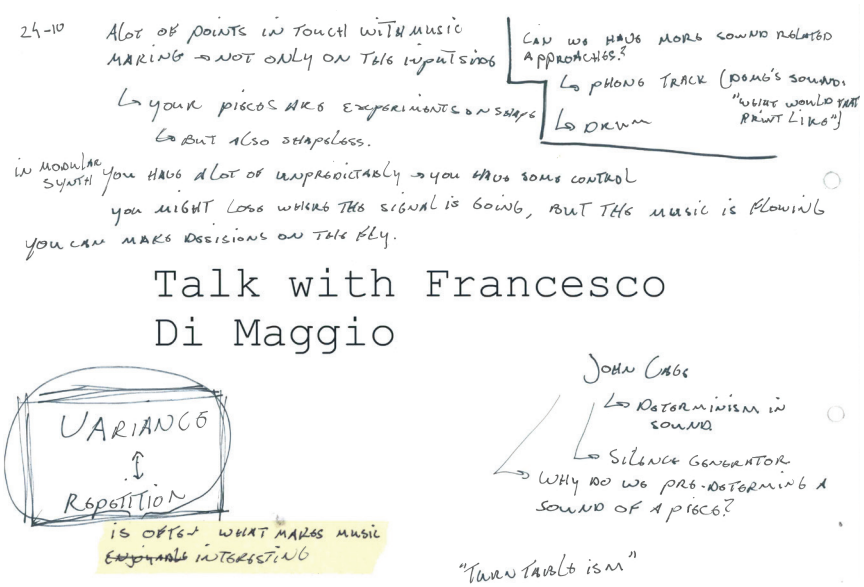


Dutch design week

This page describes presenting my work on Dutch Design week [68], the 3D printer from my preparatory project [60] was presented and showcased together with 3D prints. It was insightful to talk about this project outside the context of the Industrial Design department. Having lots of conversations with engineers and designers experienced with 3D printing. Conversations often led towards the imprecision of my 3D printer, it's inability to repeat things and the manual labor involved. Often, they concluded that they could not see the use for my machine. At the end of this conversation, I made the point: "This 3D printer is not about changing your way of 3D printing; however, it is to aid in having this conversation: questioning how and why we 3D print". The reflection on this seemed to spark a passion in my conversation partners, and ideas would be brought up about functions they would like to add to the "standard" 3D printer.

We also recorded the first guest episode of the podcast Making with Machines [22]. It was insightful to talk to Max Alberts about interactive fabrication, his perspectives on live-controlled 3D printing, and interface choices. His perspective on making with a 3D printer was different to mine, and as such broadened my perspective.





Coincidental encounters

The joystick module did not facilitate the precise control I had envisioned it having, to explore this further an XY slider was made to provide precise output of two variables with one input (one handed).

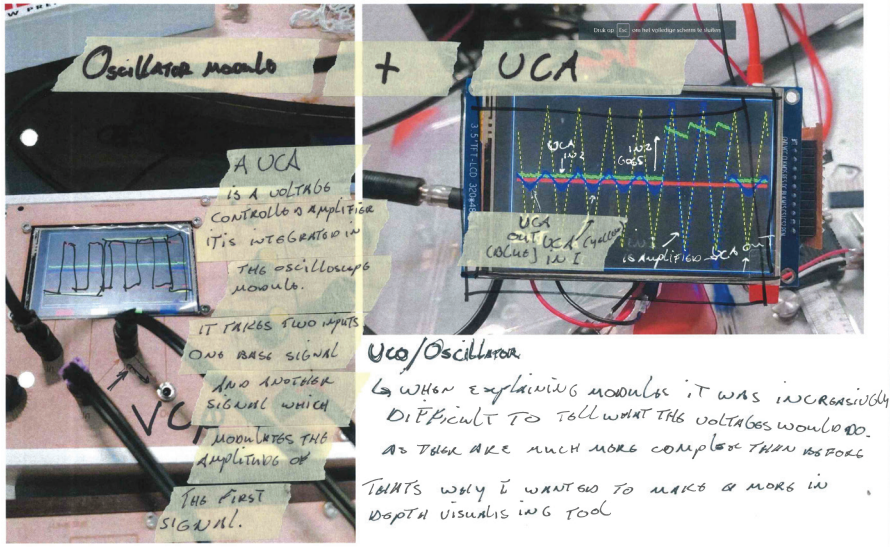
At the same time another student approached me about exploring their own materials with my machine. We worked together combining prefabricated materials and freshly extruded materials, in different configurations and patterns. The XY-slider proved to be quite intuitive for the student. Exploring outside my personal scope and being able to immediately facilitate other explorations really highlighted to me how improvisational 3D printing could be.

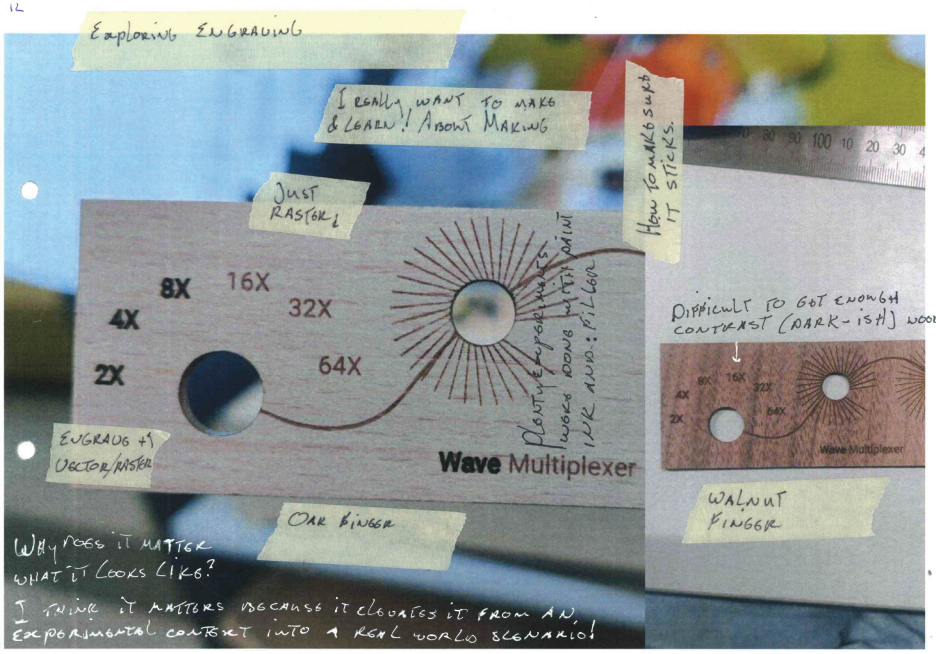
While working on my machine I was approached by a PHD student: Francesko Di Maggio. He is experienced with improvisational music making and designing of embodied instruments [14]. We organized a conversation, which revolved around making music and improvisation. As well as discussing parallels with my making, how music making could be included more in my system. After this conversation I was filled with new ideas, inspiration and motivation to make more cool modules and investigate musical analogies for my work.

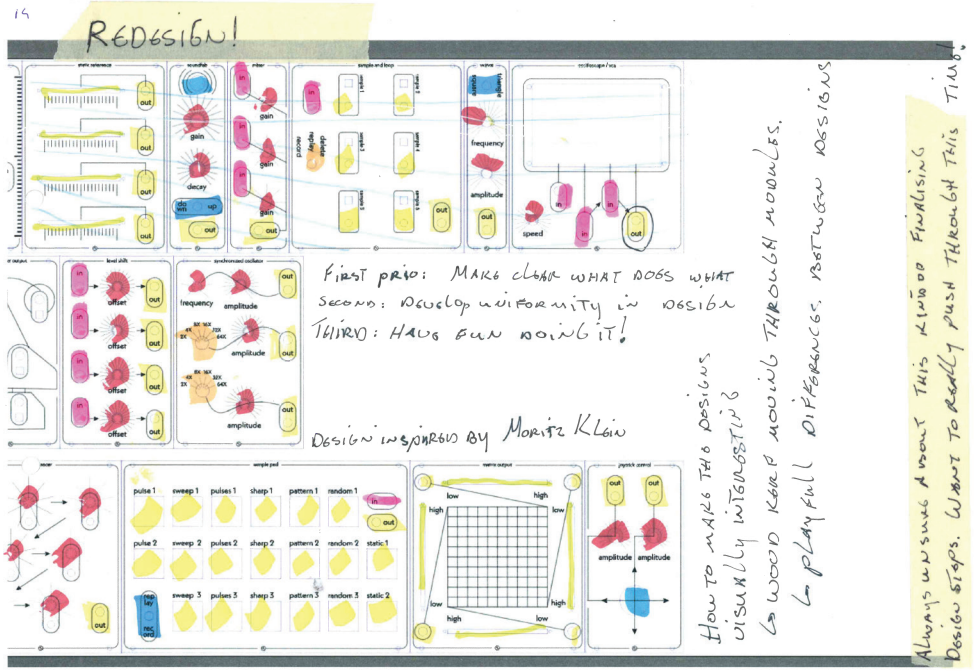
VCA and exploring aesthetics

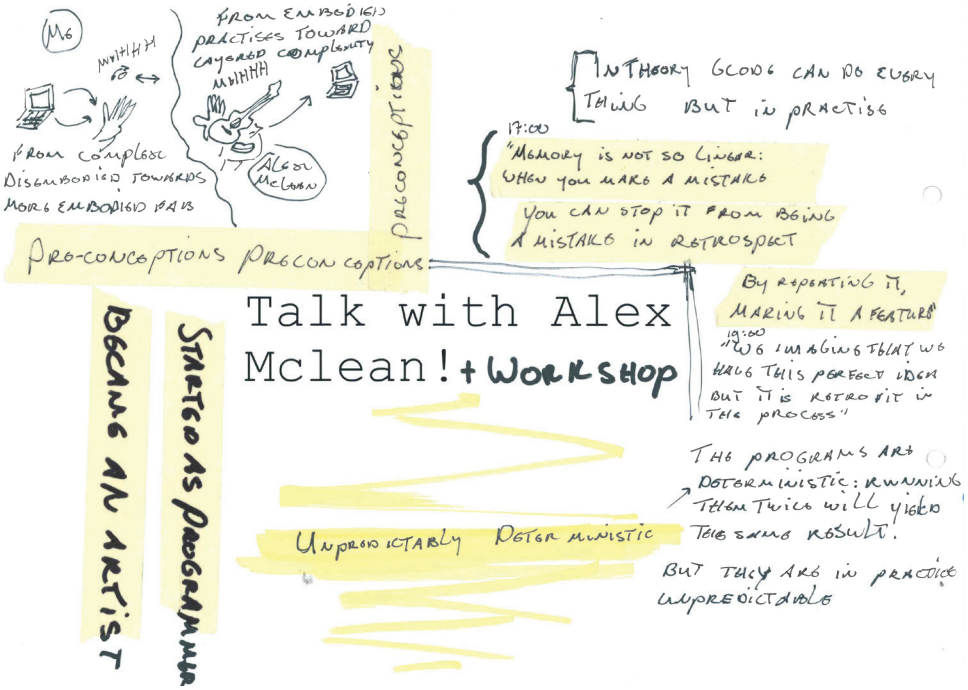
Francesko Di Maggio inspired me to increase the complexity of signals by layering. Visualizing signals in a more comprehensive way was also an intention of mine for a bit. Communicating how the system works to others was quite difficult which might be solved with transparency of these signals. That's why I wanted to make a module with an oscilloscope, and a voltage controlled amplifier (VCA) [32]. The combination made sense, as it would be able to visualize the VCA's inputs and outputs directly, as the layering of the inputs is quite complex.

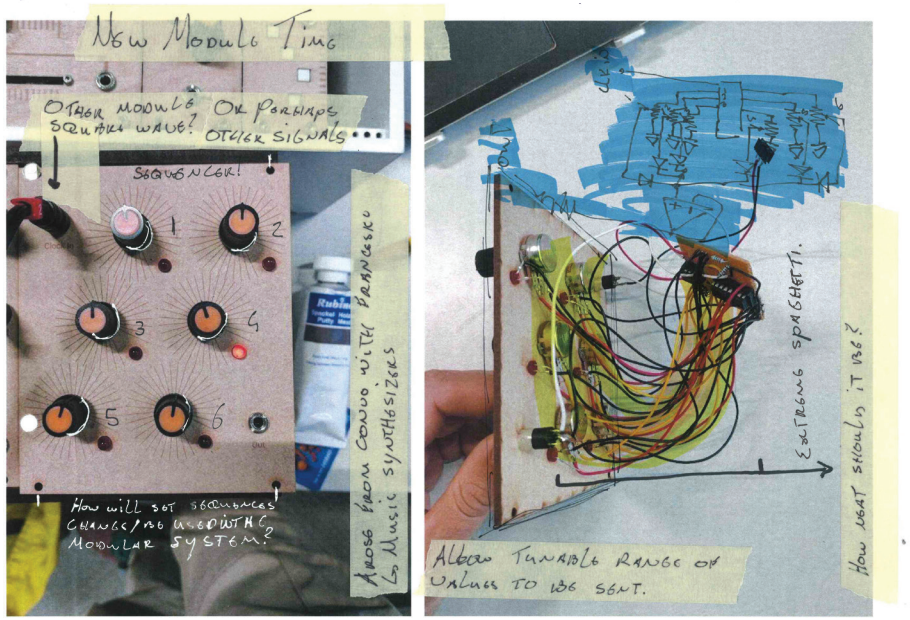
I also started experimenting with the design of the modules itself, mostly because I wanted to have fun. I really like making, but for some reason the 3D printing did not scratch that itch (anymore). Designing something and aiming for it to come out perfect, every detail paid attention to, is something I enjoy a lot. I explored engraving on different wood-veneers and started redesigning the modules to be more informative and uniform.









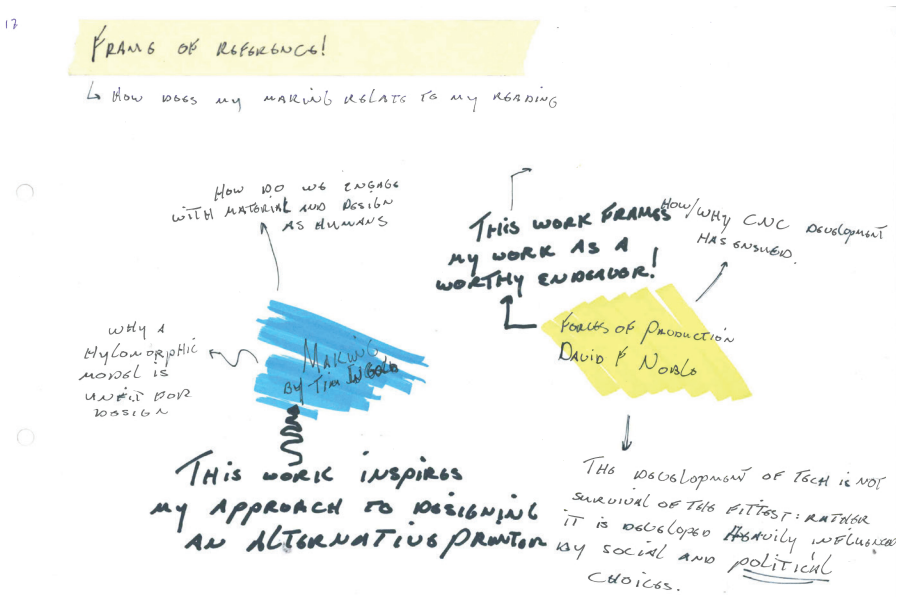


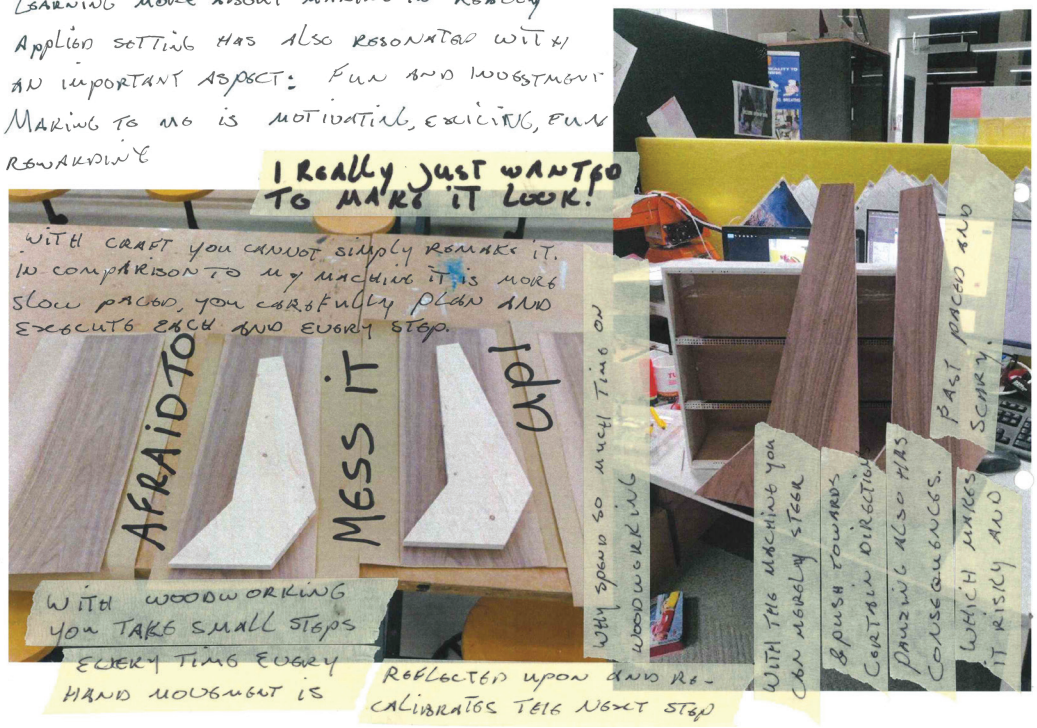
Theoretical framing

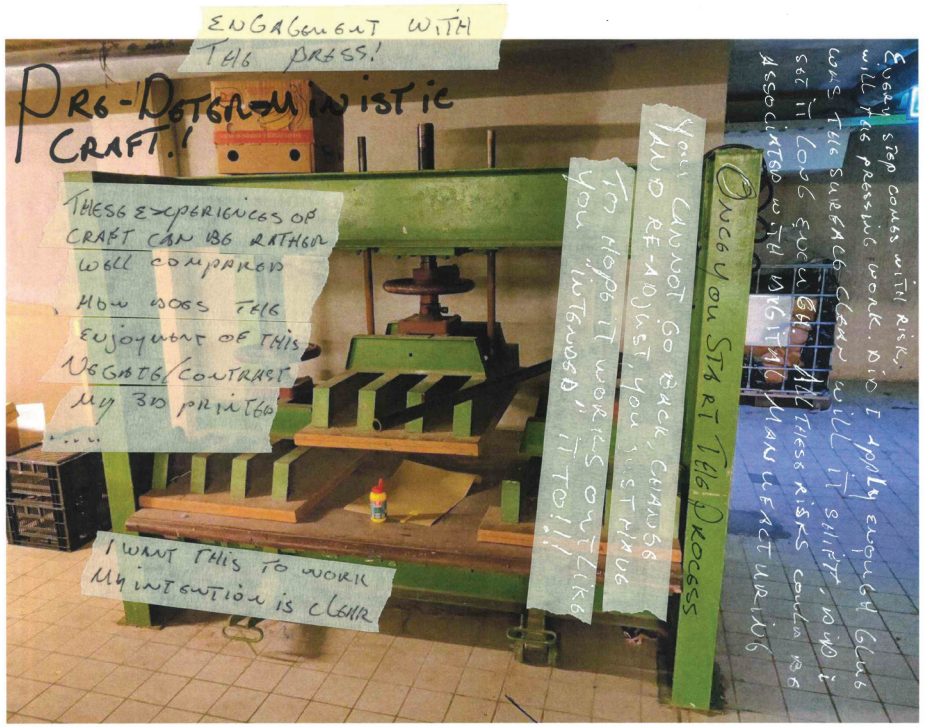
During this process I've read two books: Making: anthropology, archaeology, art and architecture, by Tim Ingold [28] as well as Forces of Production: A Social History of Industrial Automation by David F. Noble [35]. At this point I could start to comprehend their position and relation to my work. I vividly remember reading a paragraph in Forces of Production, and finding a fellow explorer of alternatives, it helped me to frame my work. The following paragraph articulated a notion that I had been aiming to articulate for a while but could not, this felt like a puzzle piece dropping into place.

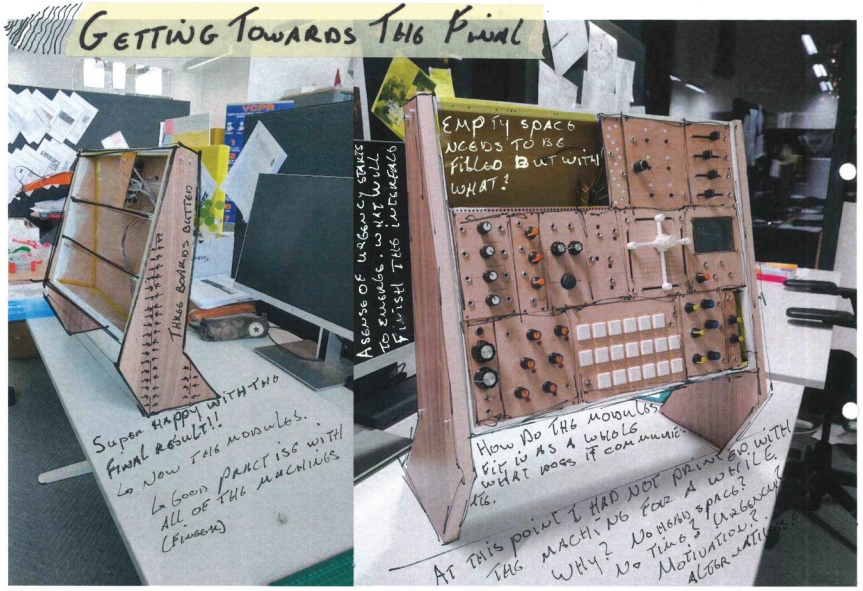
David F. Noble explores the automation of the factory and highlights how it is not a process of evolution, but rather laden with social and political considerations. He highlights how traveling "down roads not taken", can "re-awaken us to a broader and largely available realm of possibilities" and "casts technologies in a new and critical light and thus stimulates reflection" [35:146].

I also had a conversation with Alex Mclean, a live coder, artist, and established academic [31]. What I found striking was that Alex was changing a largely embodied practice (making music) into a very cognitive disembodied practice (live coding of music). As I on the other hand was attempting to investigate changing a disembodied cognitive practice (3D printing) towards more embodied improvisational practices. While both asking similar questions on making, improvisation and agency. One of the more interesting thoughts about improvisation Alex Mclean shared with me was that "Memory is not so linear, when you make a mistake, you can stop it from being a mistake in retrospect". Reconfiguring design intent on the fly, is something which is engraved in music making, but is unthinkable when 3D printing, at least not in one print. I believe this is the core of what formulates improvisation; live enactment on things that happen, whether they are mistakes or not, trusting the process, and enjoying the result as much as the process of making it.







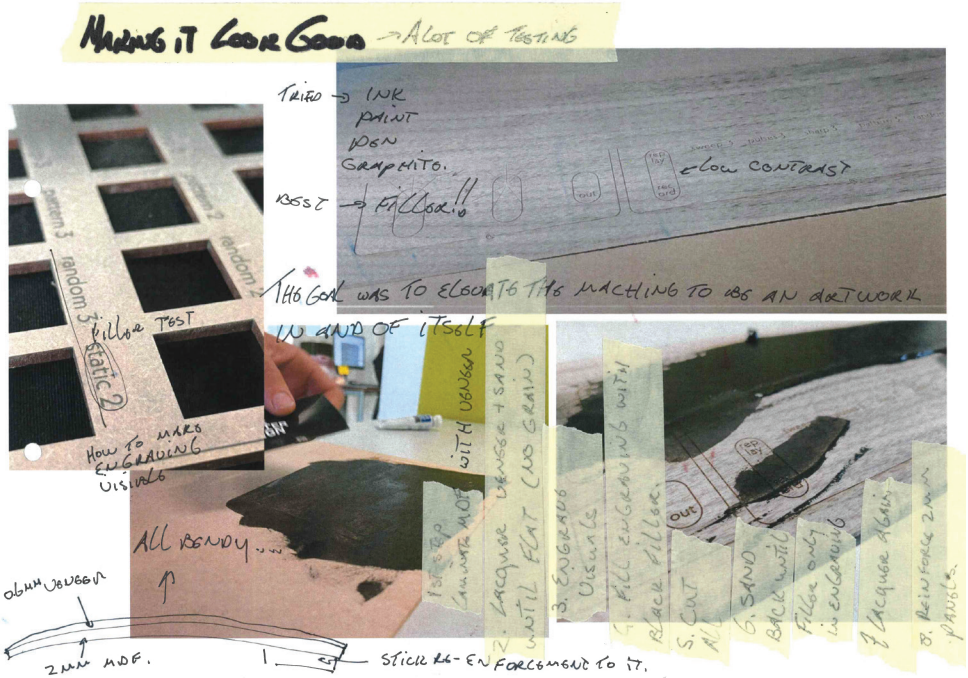


Making

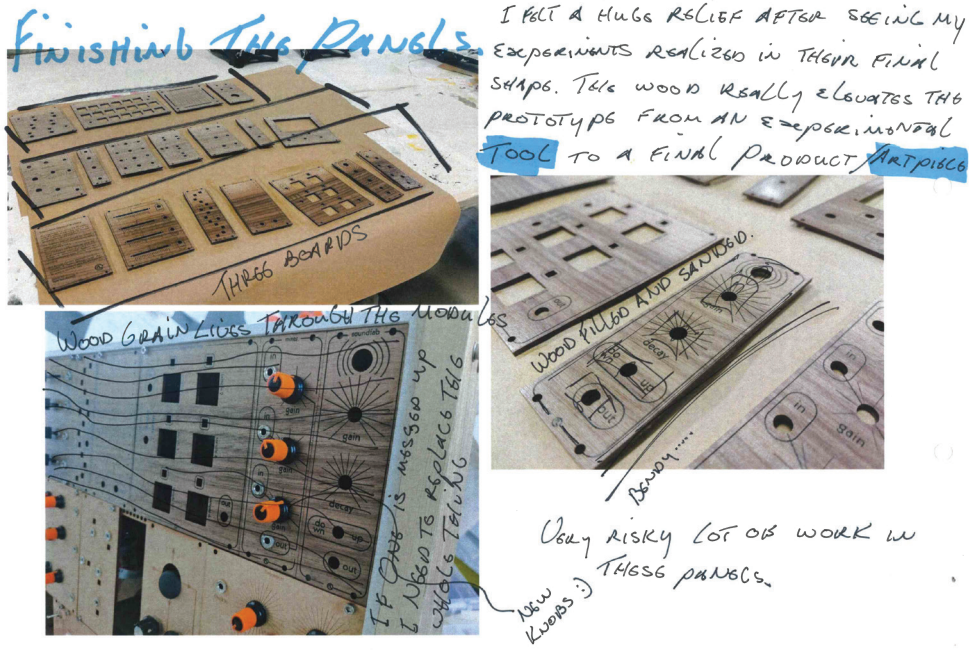
At this point I had not 3D printed for quite a bit, I didn't have the inspiration, it felt purposeless, I wasn't sure what to explore. So, I started making to revive the lost inspiration. The Euro Rack case was full so I had to make a new one. I started exploring materials, shapes and tools to use. I wanted to learn how to work with veneer, and as such I experimented with glue, clamping and lacquer. I made the side-panels for the case, from three planks, planed and squared, glued, shaped, sanded and laminated with veneer. I had a lot of fun! I was learning again, making with my hands, itching to be making more. It was only after I glued the panels and was noting my process down that I found all these parallels with my 3D printing practice, but especially with the theory I read about making [28]. Dealing with unintentional outcomes (like the wood splitting), is what makes woodworking engaging. Experiencing the friction between what you want to happen, and what happens. Reflecting on these making experiences as well as my 3D printing experiences enriched my perspective on making, and it gave me more examples to talk about in my results..

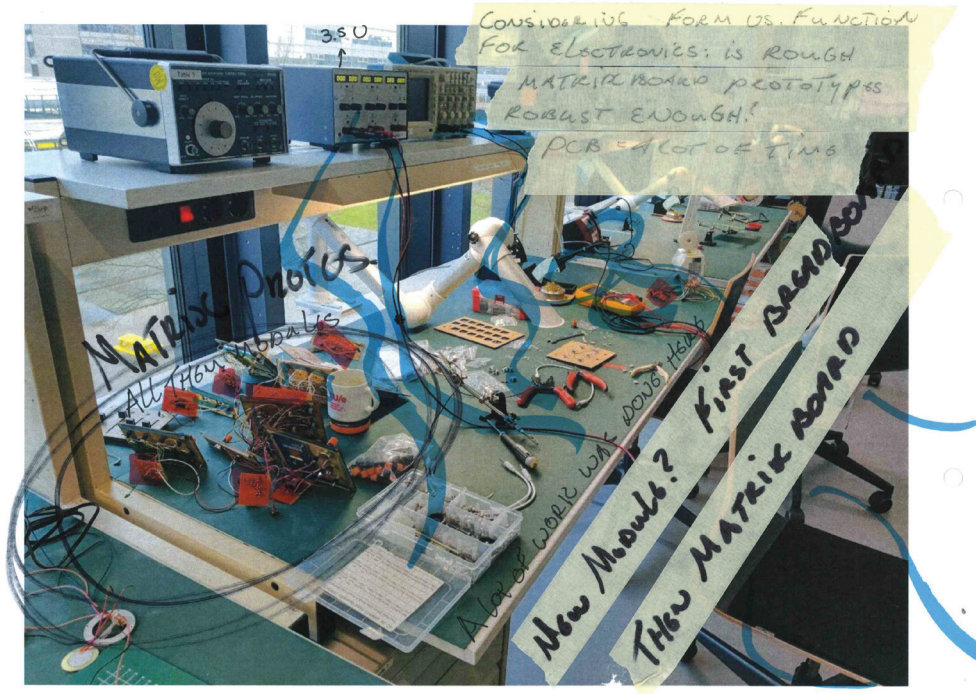
Making and Laser-cutting

Not yet satisfied with the previous laser-cut veneer I continued exploring. Eventually I came up with an elaborate process: First the MDF was laminated with veneer, after which it was sanded and lacquered to fill all the grain structure. Then the laser cutter was used to engrave the graphics. After which a black wood filler was squeezed into the grooves, and the panel was placed in the laser cutter again to cut out the shapes. After this the panels could be sanded and lacquered. This long step-by-step manual and computational process felt risky, as any mistake would result in a discrepancy in the result, which would only emerge at the final sanding.



The fidelity of the electronics was also topic of thought at this point. Everything had to work smoothly and reliably, however how "nice" should it be? I decided to go for a medium-fidelity integration, matrix board electronics would have to suffice. Knowing that all the processes would come together, that the modules would work and would look as I intended was a very large relief. It seemed that my close engagement with the processes would generate my intended results.



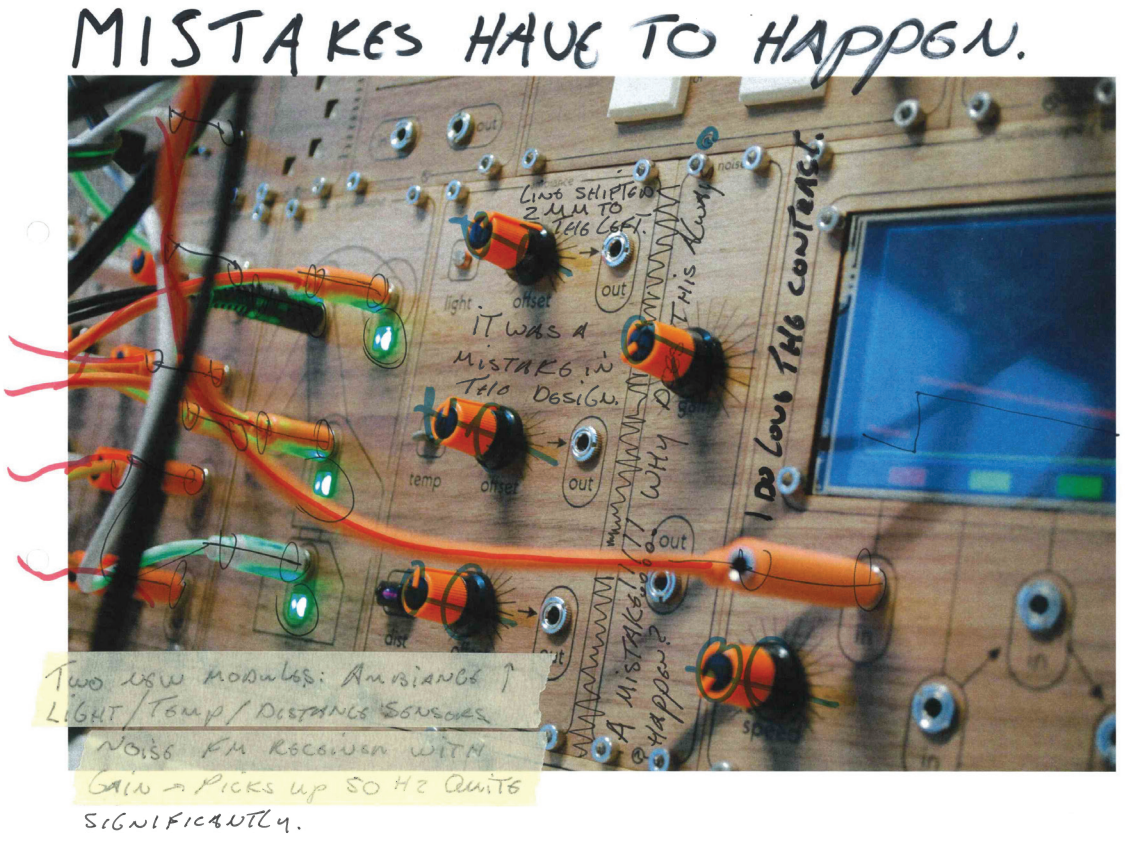


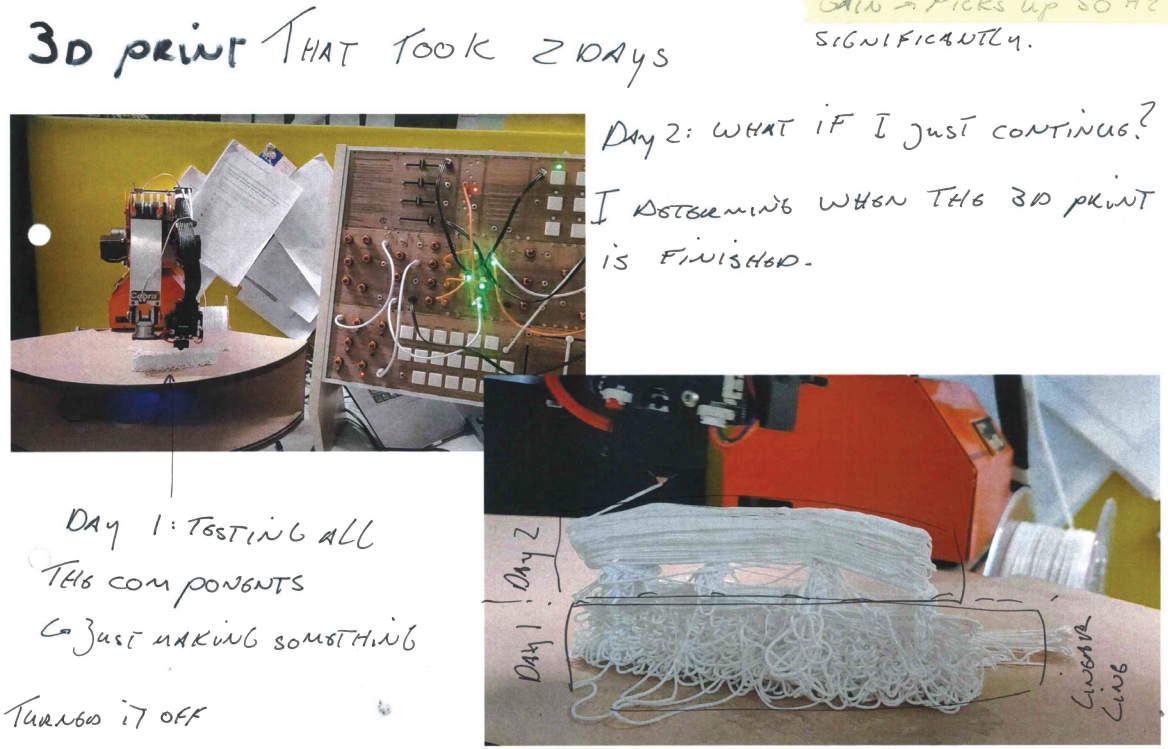
Finalizing modules

Off course there had to be one mistake. When engraving the graphics one line had shifted in the cutting file. This meant either of two things, remake the whole middle row, or leave it. I felt a bit torn: on the one hand I am advocating for uncertainty and mistakes when 3D printing, while I want my interface and woodworking to be perfect. To confront myself with the tensions in these materializations of intention I left it in the final machine.

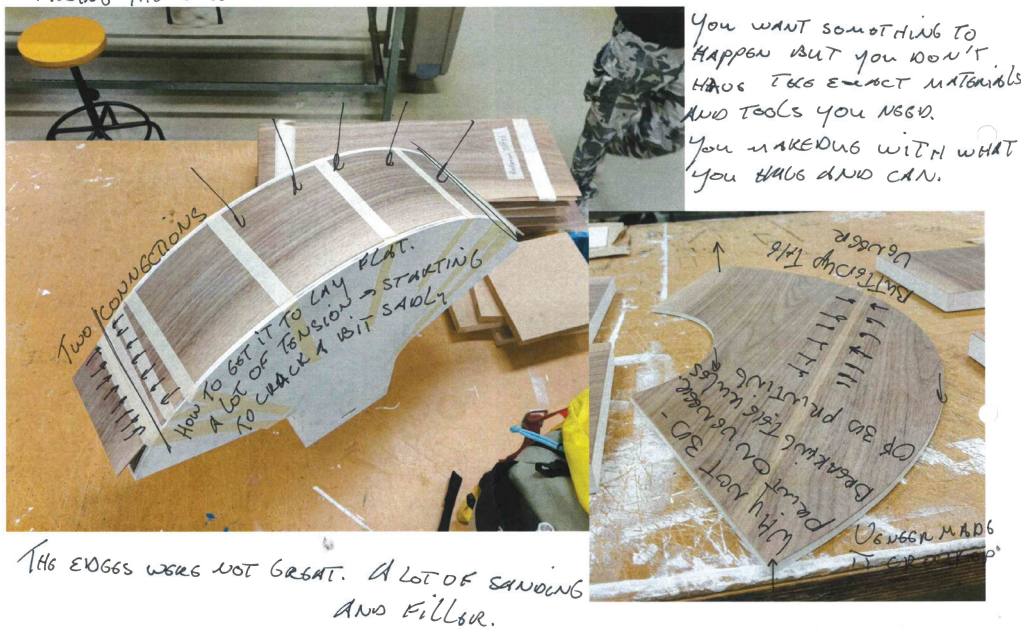
Finishing all the modules led to me continuing 3D printing with it, at this point it was over a month since my last 3D print. It was quite a revelation to be working with my machine again, instead of just building it. I could feel the tension from the previous week's release and found myself wanting to explore again!

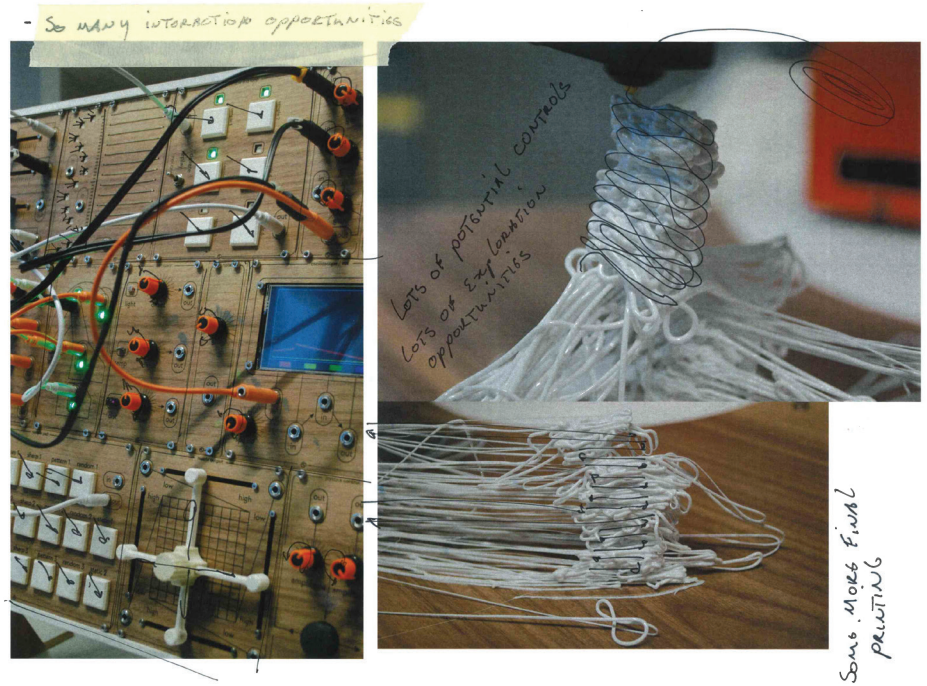
On the second print I started and lost track of time, necessitating me to leave for home quite abruptly. Turning off the printer I left the print on the build plate and went home. The following morning the same 3D print was still there, with the cables all still ready to go. I turned it on again and continued printing, half-laughing I said to myself: "I wasn't planning to print this morning, yet here I am". The simple notion of just returning to the printer and continuing resonated with me that day, I get to decide when it's done. And if I am out of inspiration, I'll just turn it off and continue later!





We also recorded another podcast episode this week, together with Bruna Goveia da Rocha, who is known for her sample making practices [23,24]. In this conversation we talked about the digital embroidery machine, serendipity in making practices. And especially how she negotiated the design of the digital embroidery machine (optimized to produce embellishments) in exploratory research. We reflected on how the design of the digital embroidery machine is reflected in an age long practice of manual embroidery, and how 3D printing does not have that tradition. The 3D printer has been developed from a technical practice and was pushed towards applications. The configuration of the 3D printer is less grounded, which provides opportunities.





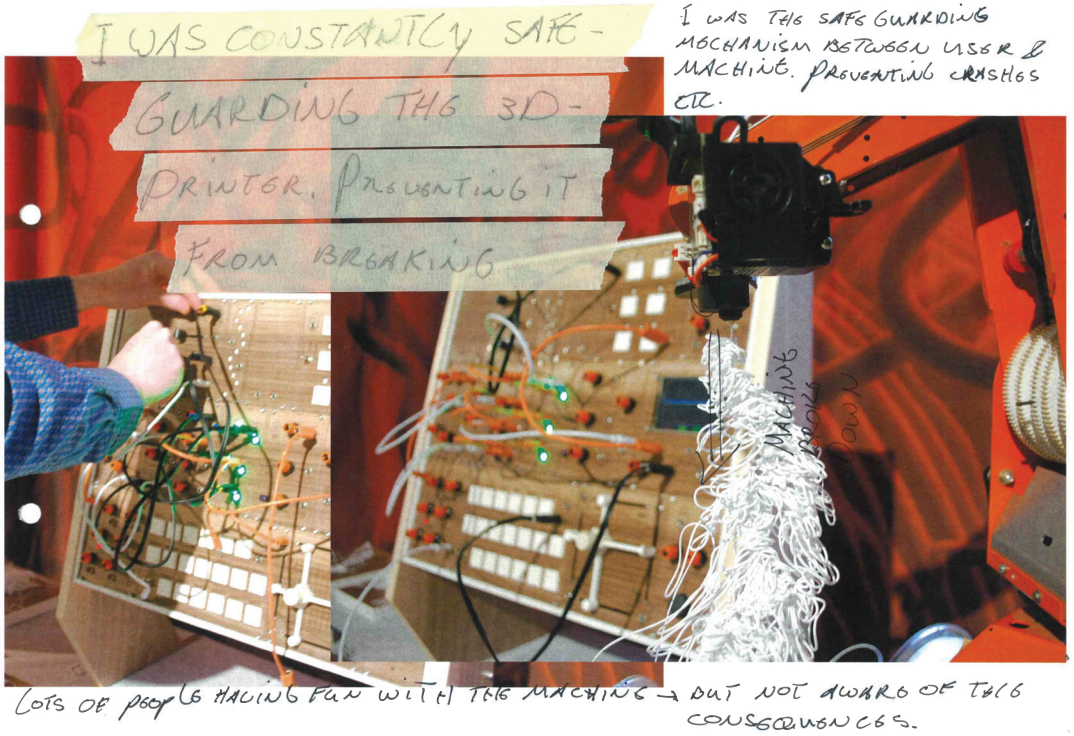
More making

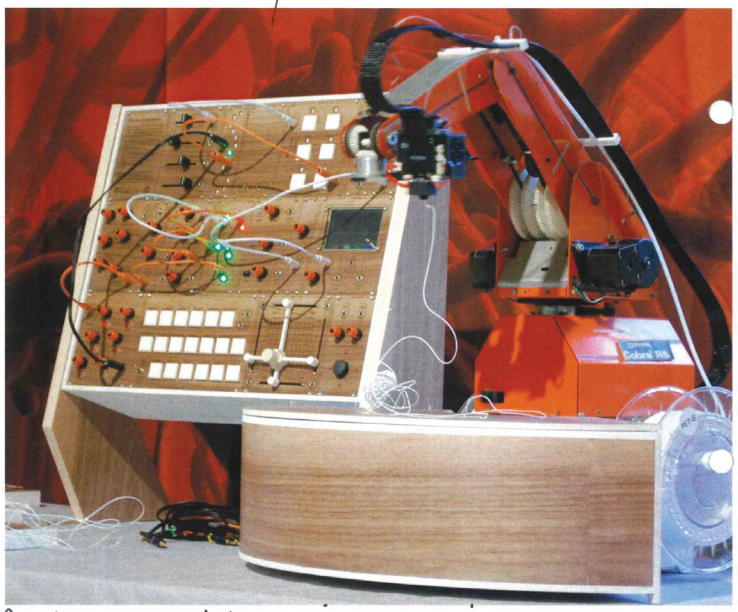
To bring all the parts together in the "final" 3D printer the base was due for some work. The round part of the base was to receive veneer as well. A new (to me) technique, where the wood had to be bent around the shape of the base. I prepared by testing and practicing clamping the veneered wood around the curve. When starting to glue, of course, it didn't really go as smoothly as I'd hoped. And after removing the clamps, assessing the outcome, I found it rather unsatisfactory, the edges had popped out 2mm on each side. Due to time constraints, I could not re-make it, and patched it with wood filler.

While making the build-plate I completely forgot about the materiality of the process. When laminating the MDF plate, I forgot that this would warp the MDF plate. As such when it came out of the veneer press it was quite bent. It was quite funny to be reading, writing and talking about materiality, to totally forget to consider the materiality of my making process. The rushed maker in me just wanted the material to cooperate according to my intentions.

Final DemoDay

The DemoDay is a presentation moment for the full industrial design faculty, every student presents their project of the semester to a diverse audience of students, staff and visitors. This was a great opportunity to let visitors use my 3D printer. During the Dutch Design Week my machine was presented as a tool to re-unite the designer with making. I decided to present this work more as an experienceable art-piece instead of a research tool. I noticed that the questions were different compared to Dutch Design Week, and more visionary than practical. It was fun to actively question the "rules" of a 3D printer, by slamming the print head into the baseplate, or making a huge spaghetti mess intentionally.





When visitors were using the printer my role as designer changed. Instead of orchestrating the printer, I was mediating the user-printer relationship. Because there was very little scaffolding to protect the machine (I broke it myself earlier in the day as the machine doesn't have protection for its limits) I was constantly safeguarding the printer from the visitor's input. My relationship with the machine was quite close, I had made it, I knew what it could and could not take. A visitor's relationship with it was more superficial: a demonstration where they could turn a couple of knobs and explore. It felt difficult to let go of my control over the machine, to trust another with the controls.

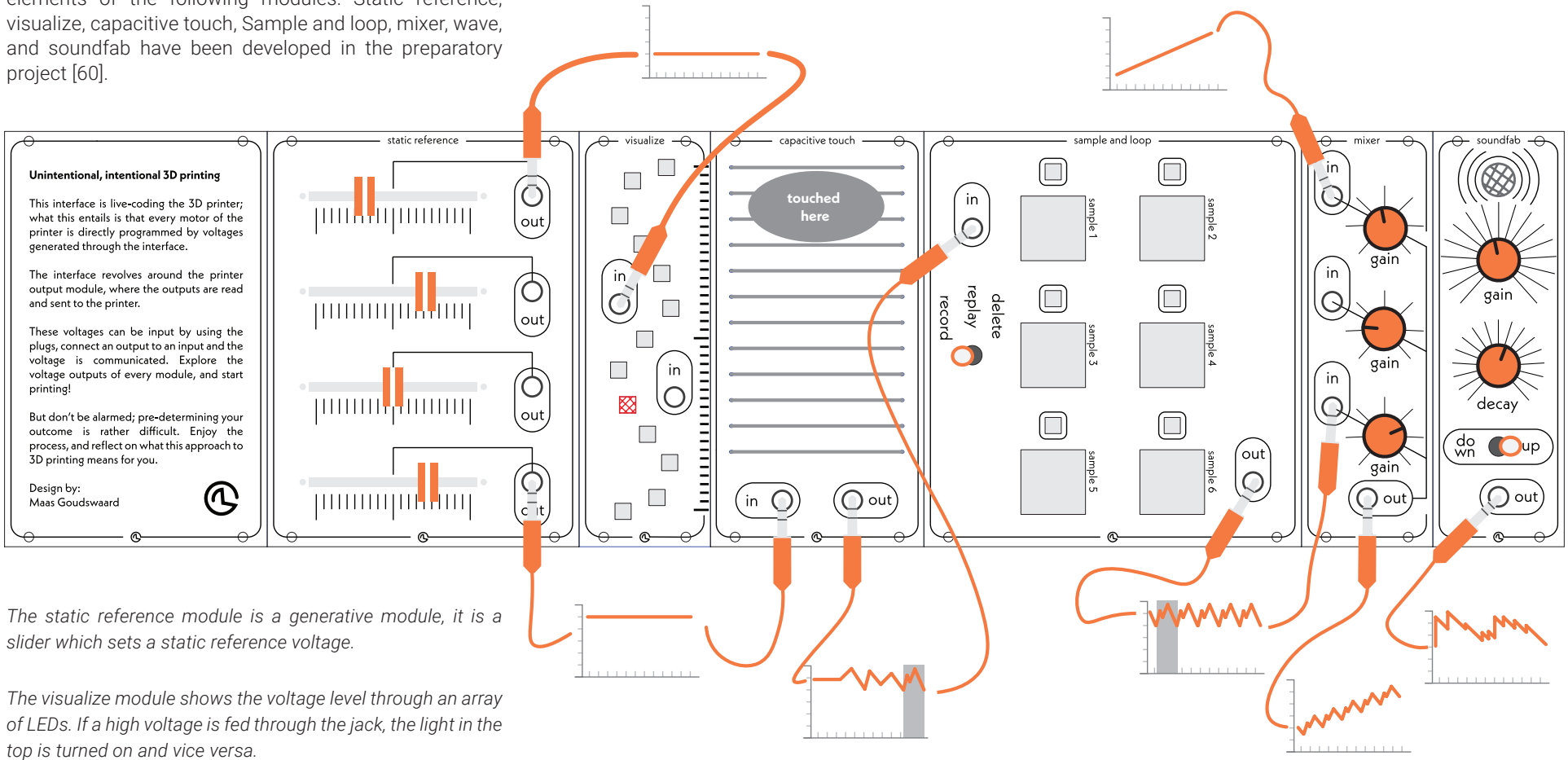
OUTCOMES

System overview

This chapter shows the final 3D printer and describes its properties. To explain the functionalities of the system we can look at the modules as doing either of three things: generate, modify, or visualize signal(s). The electronic elements of the following modules: Static reference, visualize, capacitive touch, Sample and loop, mixer, wave, and soundfab have been developed in the preparatory project [60].

The capacitive touch module modifies or generates a signal. It reads the input signal and adds a voltage on top (If no input voltage is set, a default 1.75V is used). The voltage added is dependent on the location and the number of wires touched on the tangible interface.

The mixer module is modifying the signal and can have up to three inputs. For each of these individual inputs the gain can be set. These three are all additively mixed and sent to the output jack.



The static reference module is a generative module, it is a slider which sets a static reference voltage.

The visualize module shows the voltage level through an array of LEDs. If a high voltage is fed through the jack, the light in the top is turned on and vice versa.

The sample and loop module can record a voltage pattern over time and stores it in one of six slots. These samples are then played back by looping them continuously to the output. The samples can be layered on top of each other.

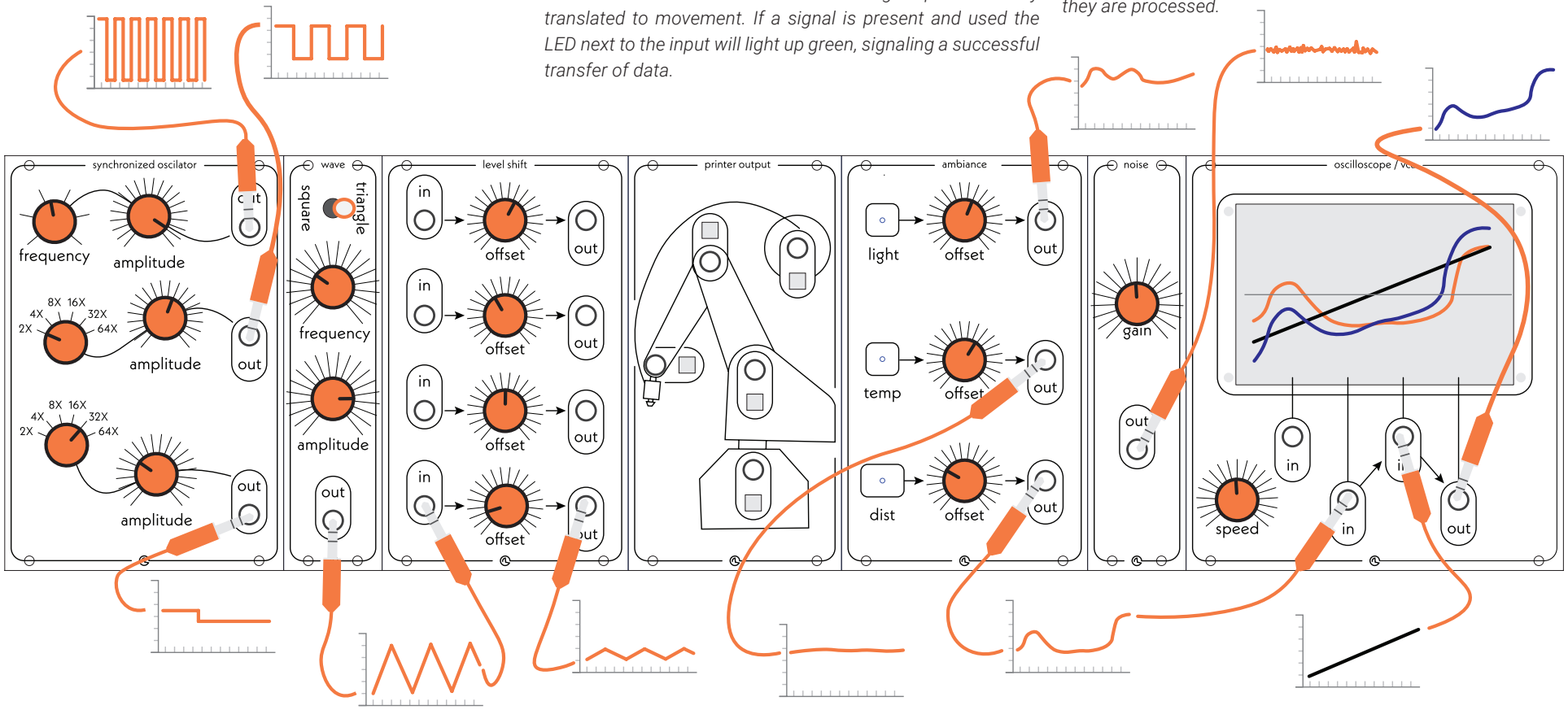
Soundfab is a module which integrates a microphone into the fabrication process, it is generating a signal. The gain and decay of the signal can be set and a switch is used to set if the voltage swings down or up from 1.75V.

The synchronized oscillator generates three square wave oscillations. The first oscillator is set to a frequency and amplitude and output to the jack. The other two are period linked square waves of the first output, the first dial is used to select if the period is 2. 4, 8, 16 or 32 times longer than the first output. The second dial sets the amplitude of the square wave oscillation.

The level shift module encapsulates four of the same circuits and modifies input signals. A voltage is input into the jack, which is "cropped" by a factor 10. Meaning a signal with a full swing of 1V will become a signal with a full swing of 0.1V. The dial offsets the cropped signal which is output to the jack.

The printer output is the central module. It is connected to the motherboard of the 3D printer and every input corresponds with one axis of the machine. The voltage input is directly translated to movement. If a signal is present and used the LED next to the input will light up green, signaling a successful transfer of data.

The oscilloscope/vca has two functions. First it uses a small screen to visualize the signals input and output of the module. And secondly it has a voltage-controlled amplifier this VCA has two inputs and an output. The first input is the signal to be amplified, the second in the amplification factor (0V is maximum negative amplification, 1.75 is no amplification, 3.3V is maximum amplification). And the output is the resulting modified signal, all the signals are visualized on the screen as they are processed.



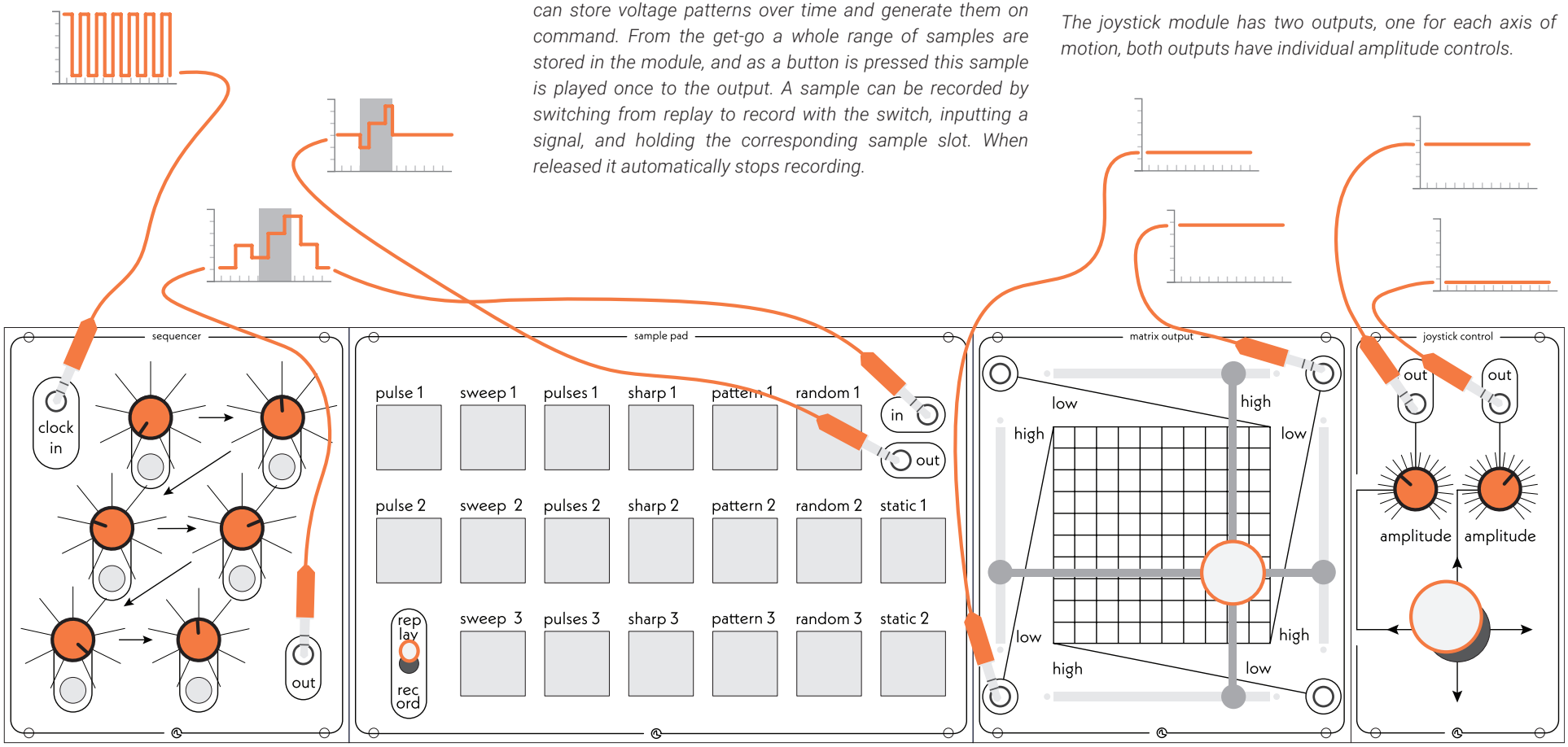
The wave module is a square and triangle wave generator. The switch is used to select between the two wave forms, and the frequency and amplitude can be set individually.

The ambiance module uses three different sensors: a Light, temperature and distance sensor and generates a signal for each. Every sensor is translated to a voltage and an offset can be added with the dial.

The noise module uses an AM antenna with a filtering circuit to capture static noise and generates a signal. A gain dial is used to tune the amplification of the noise signal.

The sample pad, similarly, to the sample and loop module can store voltage patterns over time and generate them on command. From the get-go a whole range of samples are stored in the module, and as a button is pressed this sample is played once to the output. A sample can be recorded by switching from replay to record with the switch, inputting a signal, and holding the corresponding sample slot. When released it automatically stops recording.

The joystick module has two outputs, one for each axis of motion, both outputs have individual amplitude controls.

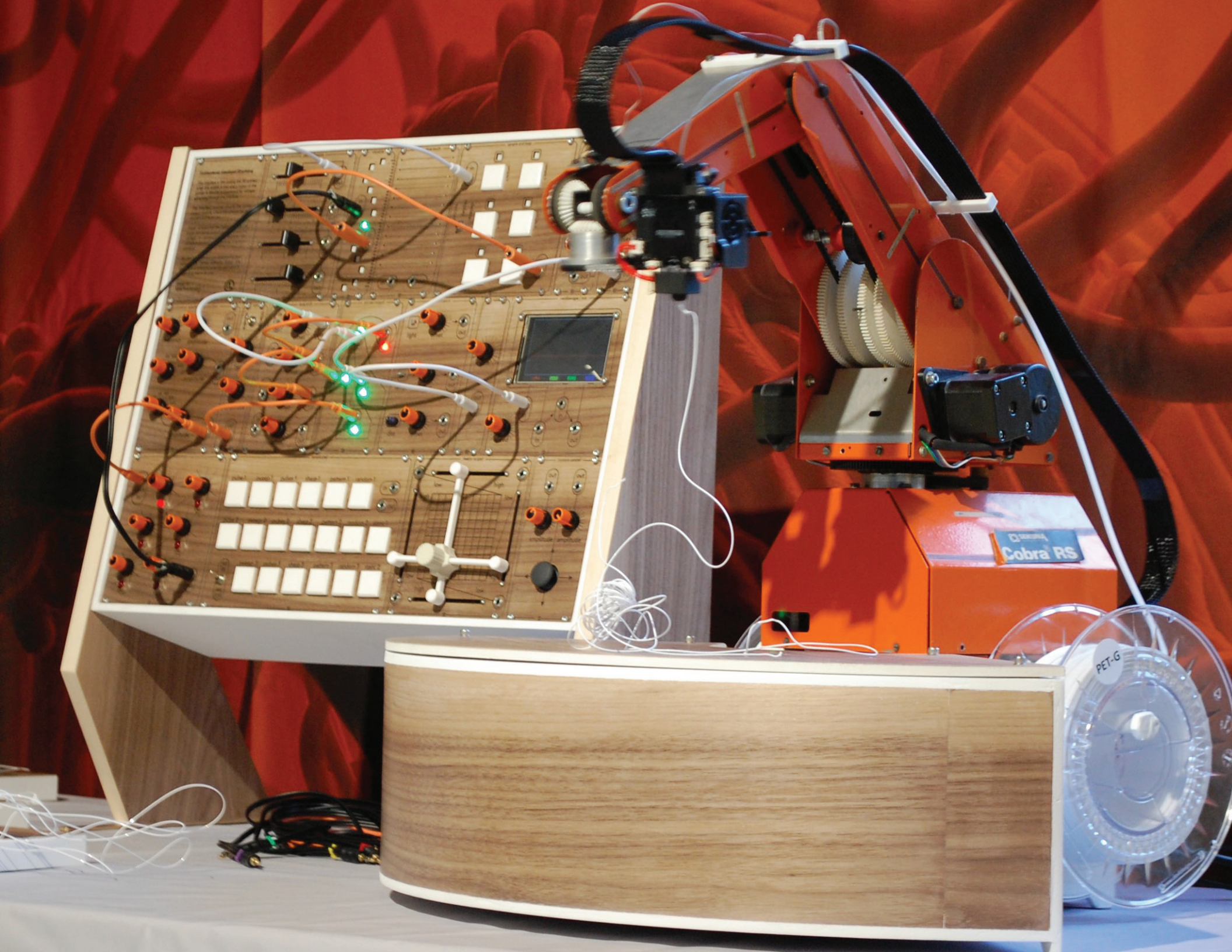


The sequencer takes one input and generates one output. There are six steps in the sequencer, and the voltage of every step can be set with a dial. The input is a clock signal from another module and as the input rises from a low to a high-level input. The sequencer goes one step further in the six-step chain. Outputting the corresponding step voltage to the jack. An LED shows which step is currently active.

The matrix output is a module with four outputs, the two axes are connected with a sliding mechanism and as such the two axes can be manipulated with a single handed input. There are two outputs for each axis, when the slider is on one side one output provides a high signal and the other a low signal.

Final machine

Next follows a selection of images of the machine and some 3D prints. First is an overview of the machine and the interface, second is the machine printing a part, third is a closer view of the interface, fourth is a detail picture of the noise and ambiance module, and fifth is a 3D print made during the final demo day.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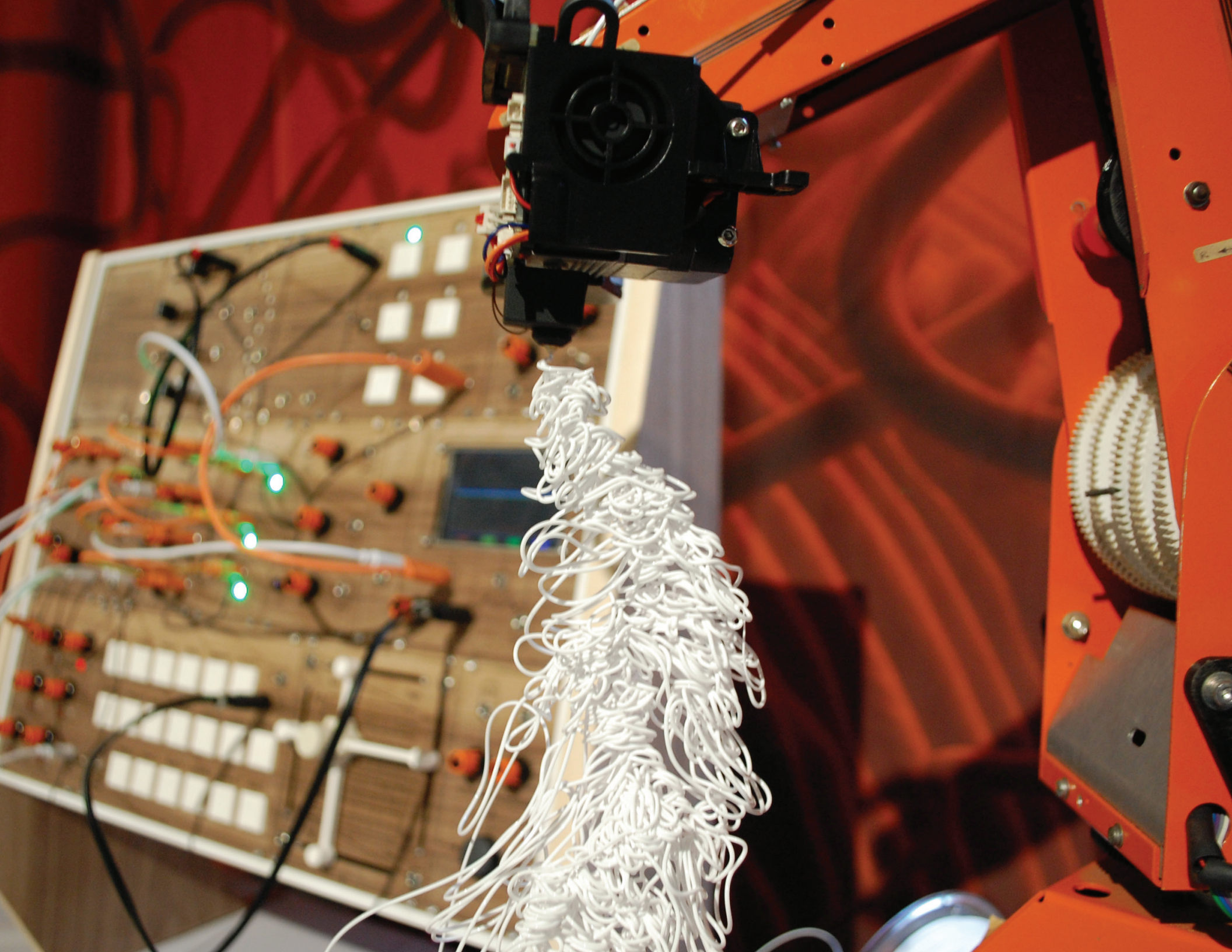

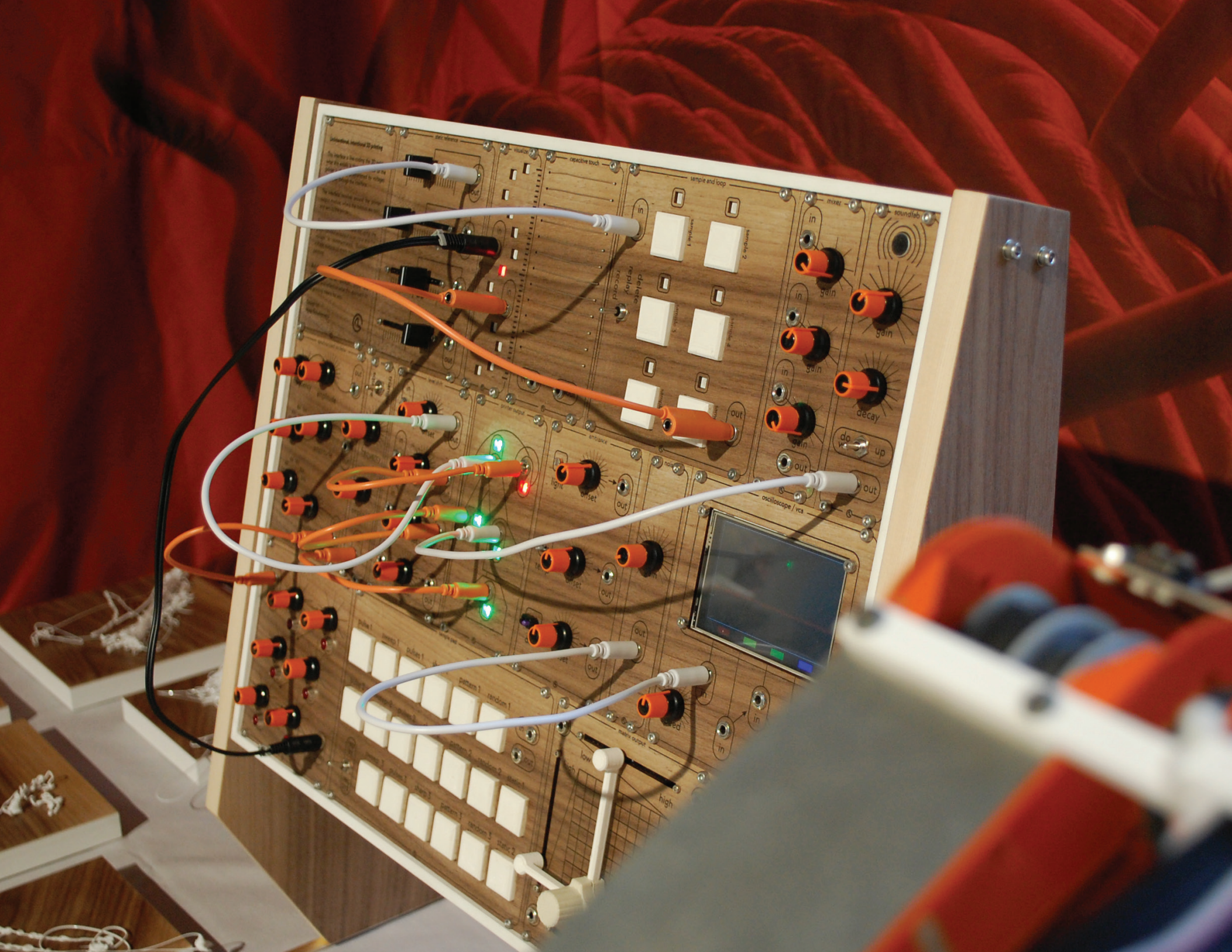
capacitive touch
simple and loop
sample 1
sample 2
sample 3
sample 4
delay
replay
mixer
soundlab
in
gain
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oscilloscope / vca
pattern 1
random 1
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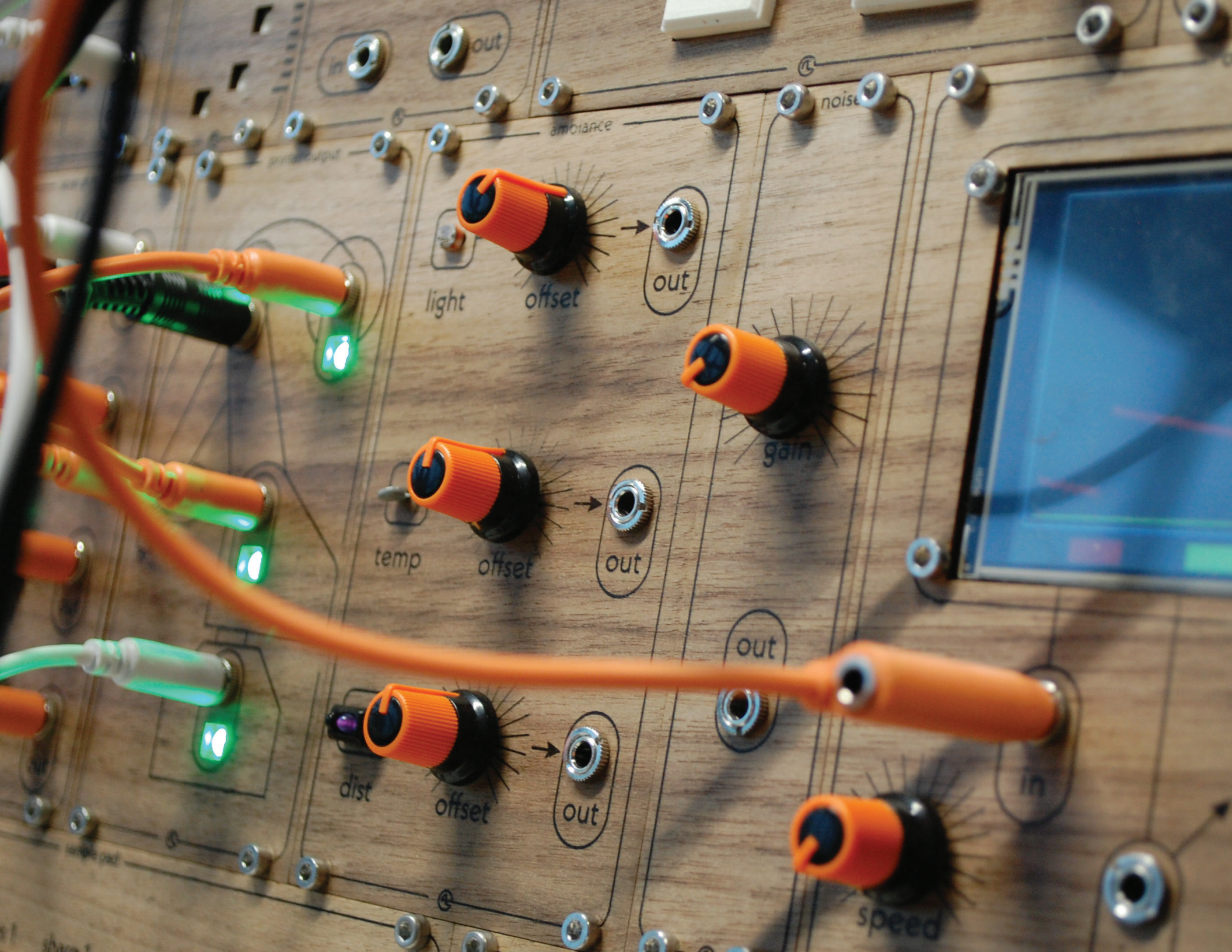
in
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Reflections

Approach

Going through this design process resulted in a 3D printer (amongst other things). As such it becomes interesting to reflect on how this methodology has facilitated the creation of this printer.

At the start of the project, I had a vision of what the 3D printer could look like, but I did not know what it would become. Which resonates with the travelers approach, to let the design activities inspire the next steps in intuitive ways [23]. The way that the modular system facilitated traveling is apparent from the process: I could make a new module without having to pre-determine other future modules or changes. This way of designing an interface for a machine that you do not know yet was very useful. As it allowed me to engage with the serendipitous nature of the process, and enticed me to make to explore.

Designing a tool while working with the tool.

From the get-go the intention of this project was to explore how I make with the 3D printer. And use the 3D printing with the machine to inspire the machine design. I can list examples of how this has surfaced throughout the process. However, interesting things happened when my intentions were not met: for instance when designing the joystick module, I had a clear intention of what I wanted to get out of the module. However, when using it, it did not at all fulfill its intention. Firstly frustrated, I continued printing with it and other interesting uses for the module did arise. This concrete example highlighted for me how bad I am at predicting my interactions with the machine, how much control I have with my hands, and how the agency of the machine is interacting with my intentions.

The anticipation of designing a module, and exploring its use was what made the process interesting and fun. And as such I transitioned from looking for inspiration in the prints to more external inspiration, exploring more broadly instead of attempting to solve a specific solution I encountered.

Designer machine interaction.

Throughout my process of making and designing the machine I've found that I as a designer can have different roles in the fabrication process with the machine. Most frequently I entered a one-on-one interaction with the machine. Where I was changing the configuration of the interface, and the printer would simply act on the voltages. However, during the process different designer machine interactions emerged. When demonstrating the system for instance I entered a different role, I was not actively manipulating the machine to enact on my intentions. I was entering a role of explanation and showcasing, I was actively participating as an expert together with a novice. Open to new explorations and facilitating and interpreting others' ideas and enacting them with the printer. Acting like a translator for someone who doesn't yet know the language of the interface but is able to express their intentions. And lastly when someone was a bit more familiar with the system, I entered a protective role. Where I would not actively participate in the decision-making process, but I would keep an eye on it from a distance. And every now and then I would intervene and prevent damage to the machine.

When printing with a regular 3D printer some of these roles do not exist, like the one-on-one conversation with the machine. However, the translator can be seen as mediating software for slicing or CAD drawing for instance, and the printer firmware acts as an active protector of the 3D printer. Breaking out of the standardized workflow surfaced these important processes and allowed me to explore them explicitly.

Perspective on making

When starting out with the process I had a strong vision on why 3D printing needed enrichment, allowing myself to engage with the materiality of the 3D printing process. I was surprised that the making of the system has contributed to my perspective just as much as making with the system. This act has exposed myself to a lot of different approaches to making, I've made to explore, I've made to build a thing, I've made with little purpose at all, I've made to explain, and I've made for the sake of making.

What I've found is that in all these modes of making lies a richness that is difficult to describe. While making there is an intention, an expectation, an enquiry, and I think that if you are actively reflecting on your making, interesting aspects always surface. Like when engaging with the large press, or when 3D printing to procrastinate. The active participation in the making process is insightful, teaches you something, makes you think. Actively engaging with making is where the richness in making lies, and what Ingold calls to "celebrate" [28:22].

Negotiating intention

When making there is always an intention, in the hylomorphic model these intentions are phrased as fixed ideas before the making process [28]. And to an extent I think this rings true, I intended to make a module with a specific goal, and I intentionally designed my 3D printer with certain goals. I however also found a lot of times that this gets in the way of the enjoyment and serendipity of the process. I've had numerous times where my intentions were not enacted in my making, on the one hand this enforces the materiality of the making process, but also captures frustration. Even though while woodworking I was aware of the materiality of the process, I would experience discomfort when things "failed". Because a "good" craftsman would be able to work with the material to achieve his intended result, and I was not be able to. It feels like you are failing, the material is fighting back and is winning. To surrender yourself to the materiality of the process is something I preach in 3D printing but have trouble with when woodworking. I want to pick when I want to engage with materiality (3D printing), and when I want the material to just cooperate (making the modules). The reality is that you have no choice, materiality is always there, and you can either decide to work with it or against it. Perhaps this is me exploring my own materiality. Exploring my intentionality, frustrations and motivations challenges not only on the thing I design but also how I engage with the act of designing.

Technology shaping practice

Experiencing an alternative 3D printer has highlighted how the machine's intentions are reflected in the process and outcome. I've experienced working with normal 3D printers, which I've watched with fascination during hours of printing. Anticipating a specific move programmed or looking at emergent material behavior. The role you have is that of an observer, noticing what is happening and preparing for the next iteration. With the "live" 3D printer you are doing the same thing, observing, however you are also actively participating. The practice of 3D printing is a conversational practice instead of a turn-taking practice. What this means for the outcomes is that you are a lot freer to experiment. The machine talks back instantly, and you can alter your input directly.

The machine I've made has crafted a different process of printing, with different 3D prints. And as such I find it evident that this tool serves very different purposes when compared to a normal 3D printer. It is off course unrealistic to create a purpose-built tool/machine for every design case, to best facilitate the making in that case. However as a designer you have the opportunity to pick what fits best.

DISCUSSION

Case study

Role of the machine

The 3D printer presented here, with its modular interface, and robot arm actuation is a direct reflection of the serendipitous and exploratory process that designed it. And as such it does not fulfill traditional roles assigned to 3D printers: printing parts [11]. The 3D printer I've designed is not made to materialize a designer's pre-formulated intent. It does however have alternative characteristics, like being adaptable, improvisational and serendipitous. As such its role is not to provide concrete solutions to reconfigure our 3D printers. Similar to "redeform" the role of the machine is to develop a philosophical argument and expand on the machine-designer relationship [11,13]. It highlights how different a 3D printer can become when we are open to alternative goals.

The 3D printing system

This case study highlights how the application of a Modular Synthesizer inspired interface has allowed a serendipitous and improvisational approach to interface design for a 3D printer. The modularity of the system has facilitated the design of very complex and intertwined patterns of programming without having to anticipate this from the start. Every module and their respective interaction opportunities points to potential opportunities to be explored further [24]. The advantage however of using the modular system is that the complexity emerges in the combinations of modules [4], and as such every module opens a door to a whole range of new explorations. Designing a modular system for a 3D printer in this way has also given rise to plenty of limitations. The analog nature of the interface, and the physical patching of the signal cables make the system sensitive to noise, and user "error". With a "normal" 3D printer we want the system to materialize our intent as accurately as possible [11]. The approach to programming this machine live and analog forces the designer to enter a "correspondence" with the material and machine [11,28]. The design of the interface and the machine has a large agency in the prints created, and as such provides an example of a more morphogenetic machine like "redeform" [11].

Reflections

This project describes my own reflections throughout this project and as such are a result of the design context, methods and my vision, they are derived from a first-person perspective [10,30] through the use of auto-ethnography [9,15,34]. As such the reflections are heavily contextualized and qualitative. There is a tension in generalizing and transferring knowledge from first person practices [10]. This makes it difficult to assess the face value of these reflections, it is difficult to synthesize and articulate evidence for my changing perspectives on making. Attempting to generalize them removes the particulars that make it interesting and valuable, but not generalizing makes the insights valuable only to me.

What I'd like to stress is that it is not my aim to provide these reflections for other designers to take at face value. They are contextualized and surfaced in my design process. The goal of these reflections is to provide a perspective of 3D printing that exists and use it as a point of departure, to get inspired or to get critical.

Foster conversations on practice

DDuring this project I have two exhibitions of my work tailored towards an external audience. I've highlighted in my process how the Dutch Design Week, and the Demo Day have contributed to the development of the narrative. A whole range of conversations have inspired me to summarize the following: Conversations with visitors often started with my 3D printer, about specific parts of it that one liked or disliked. I would follow up with critical questions about a "normal" 3D printer, breaking open a discussion on how "limiting" a "normal" 3D printer is. After which a discussion ensued on the accuracy of the statements made, the visitor's preferences in fabrication and the opportunities illuminated by my machine.

I believe that having a concrete example of a "different" 3D printer, helped with finding examples of why it was bad, but perhaps also why it was interesting. And allowed conversation on the practice of 3D printing. It sparked imagination on what a 3D printer could look like and as such provided a starting point for a reflective discussion. The machine here takes a role as a provocative showcase, almost as an art-piece.

On making

Tools shaping practice

When initially brought to market the 3D printer had a large promise: print everything, everywhere, anytime. Increasingly plug and play 3D printers are entering the market, that promise to make it easier and better. The well-known example of the "law of the hammer" [2:73], describes that the overuse of a tool, when perhaps better options are available. We can reflect on 3D printing as such, the tool: "a 3D printer" is being used to solve an increasing number of problems. However, to use a 3D printer, we must follow a very specific design process

and are limited to specific outcomes. The materials are limited, and the parameters to play with are kept within "predictable" boundaries. In practice we see an increasing amount of "standard" digital fabrication workflows integrated into design practice and education [7,25,37], and we should be aware of the implications of these tools.

The prints made by the 3D printer designed in this project highlights how different the outcomes of a 3D printing process can be. This 3D printer is a different tool when compared to the "traditional" 3D printer, and as such it serves different purposes. Devendorf et al. argue for "an expanded view of values in making" where "control-driven and indeterminate systems" are "valuable in different context" [11:177]. Both approaches have their merit in different contexts, and as design researchers it is up to us to balance their merits.

My journey

The auto-ethnographical journey of designing throughout this case has developed the reflections in the previous chapter. Going through the process has allowed me to develop my vision and perspective on making and making with a 3D printer. Engaging with theory and talking about perspectives with other designers has given me the vocabulary to describe these thoughts in words. Using an auto-ethnographical approach to regard my own making practices, and actively relating it to the philosophy of making has given me deeper knowledge of my practices. And has allowed me to more critically look at my tools and materials. During this process I moved through different modes of making. And as such this pictorial describes the reflective act of engaging with design in relation to theory. It sounds obvious but engaging with philosophy to understand my practice has enriched the practice for me.

Going through such a journey is quite an intensive process and is a project. And because the insights are related to one's own practice, a maker might have to go through this process themselves. This project describes my journey throughout a reflective sense of making, and as such aims to inspire others to travel alongside me.

CONCLUSION

This project describes the development of an alternative 3D printer, which was prompted by frustrations with 3D printing. The project is situated in my personal experiences and thus is developed from a first-person perspective, applying auto-ethnographic design practices.

Executing the design activities; designing the machine, printing with the machine, engaging with theory and engaging with designers informed this process, and provided concrete loose ends to reflect upon. Moreover the process of all these design materials coming together has allowed contextualized and specific reflections on what it means to make with a 3D printer. The act of physically designing the machine surfaced reflections on agency, control and frictions. The 3D printing with the machine has shown how alternative configurations of the 3D printer can tailor different modes of 3D printing. The conversations with designers highlighted the broader landscape of making with machines. And the theory has provided prompts for reflective making practice and a way for this project to reflect on its philosophical implications.

As such the main results of this project, are hard to judge on face value, because they are situated in my personal practice. Rather than that I would like to highlight how going through this journey has fostered critical reflection on my own practice. Engaging with the making process itself, actively questioning its purposes and goals has prompted reflection on what it means to make. Experiencing the agencies of making highlighted how important it is to be sensible about the tools and materials you pick in your design practice.

The first-person journey of exploring the design of an alternative 3D printer has enabled me to reflect on the act of making with a 3D printer. Leading to a two-fold contribution: a configuration of a 3D printing practice that serves as a speculative design case. It questions what 3D printing is, and points to an alternative printing paradigm. As well as my changing perspective on making, showcasing how actively engaging with making triggered reflection on my own design practices. The main aim of this pictorial is to inspire other makers and designers to engage with their own design practices, pick them apart, imagine alternatives, all to reflect on how that practice influences their design choices and outcomes.

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APPENDIX

The following pages are the appendix, and contain the ERB form, and the confirmation email from the ethics board.