



Measure of Abstraction: Embodied Fabrication and the Materiality of Intimacy

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Measure of Abstraction

Embodied Fabrication and the
Materiality of Intimacy

A dissertation presented
by
Joëlle Bitton

to
The department of the DDes program
in partial fulfillment of the requirements
for the degree of Doctor of Design
in the subject of Interactive Fabrication

Harvard University
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Abstract

This thesis presents a theoretical and practical research conducted for the last 4 years on interactive fabrication.

Interactive fabrication is an emerging field and takes as a starting point with the numerical control of digital fabrication machines, modulated with parameters of interactivity.

I approach digital fabrication as an ambiguous technology in the ways it articulates the digital with the material, the shapeless with the finite, the abstract with the concrete. As the realm of digital fabrication expands into mainstream culture and maverick machines rise again, there is an opportunity to tamper with expectations of precision and proficiency.

Interactivity is the modus operandi for such experimentation: embracing time, latency, distance and the “decor of everyday life” as conditions. Personal data such as emails, text messages or sleeping data can turn into parameters of control of a CNC-machine, supplanting the typical predetermined file. This is the premise for a human-machine companionship or ‘embodied fabrication’.

3 art projects, *Twipology*, *Rabota* and *Streamline* have been prototyped to enact these possibilities. The fabricated outcomes move beyond functional or ornamental categories, inspiring a mutating and odd materiality, one of intimacy. These objects are objects of a third kind, “born witness” of a moment of interaction with the material world.

This thesis is an ‘undisciplinary’ endeavor, proposing a research method involving art, design, ontology and HCI considerations.

À mes parents,
Rachel et Jacques Bitton

Lumières solaires

“And I
have to speculate”

In memory of my friend Carson Reynolds

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Introduction: Living in the Material World

1. PREAMBLE
2. WHY INTERACTIVITY? (OR MAKING ART FROM DATA)
3. DIGITAL FABRICATION, A PROFOUND MATERIALITY
4. INTERACTIVE FABRICATION, IN SUMMARY

1. PREAMBLE

This research is motivated by the emergence of digital fabrication into the realm of art and design, beyond its original professional premise, and by the discourses surrounding its tools and machines that once again tell more about desires than about the actual capabilities of technologies.

There are also personal motivations at play that should be made explicit. My professional career has been defined by a series of opportunities. It never followed a particular track nor was it constrained to a particular field. I first trained as a historian in a program with strong interdisciplinary approach and methods, inviting me to look into other disciplines such as psychology, anthropology and geopolitics to inform my thinking. This education became a structure for other life endeavours and allowed me to adapt and embrace different vocations, mainly as an intellectual and an artist. I didn't see barriers, or oddness or contradictions between fields of interest, but rather convergence, associations, meeting points, crossings and - in all cases - opportunities for learnings. As the Internet became part of my everyday life in 1996, I found it the ideal medium that could bring many of my interests together, its very own essence inspiring artistic statements. Indeed,

technology is itself the archetypical anchor of an interdisciplinary practice that forces to embrace societal, innovative and cultural aspects. It guided a perspective where art, design and human-computer interaction (HCI) kept crossing paths. After about fifteen years of practice, it felt almost like a compulsion to undertake a long and in-depth research that I considered a convergence of my thoughts and vision and that would establish a discourse substantiated by my expertise, my previous work and my personal journey.

This doctoral research has been providing my career with a strange pause that was never one: the opportunity to look back at the things I learned, the opportunity to learn things I never knew existed, the opportunity to guide my own research and to make a unique statement, on my own terms and limitations, with constant life interruptions. Before making the decision that brought me here, it was a matter of choosing the time and the place to carry the research. The time is never right of course for putting four to five years of one's life at the mercy of re-becoming a student, with little or no income, in a stressful environment, and having to part with an already established social milieu. But I knew that if I waited longer it would have been increasingly difficult to make that change. Choosing the place felt easier. I had known the DDes program at Harvard GSD for many years and it felt adequate for this type of research and at that stage of my life: inviting theory and practice, aimed at professionals, and in a school that is at the forefront of architectural and design innovation. Harvard is also an enticing name, that resonates as something worth putting a life on hold for and getting out of one's comfort zone, worth a move over the Atlantic, a risk to take or a bet to make, hopefully an investment. Evidently something to make parents proud. And as I realised along the way, something to challenge my assumptions of myself, and to aim higher than I thought was possible.

Beyond the scope of my personal journey, this DDes research echoes, at least in part, my DEA dissertation¹, a post-graduate degree in contemporary history pursued in 1998 at the University Paris IV Sorbonne in the

¹ DEA stands for 'Diplôme d'Études Approfondies', a degree in France that could be undertaken after a Maîtrise (Master's), now equivalent to a MA.

department of history of techniques. In this work, I correlated the emerging technology and networks in France and Great-Britain in the 19th century with the emerging ideas of nation and community (Bitton 1999). The drive for this research was the mainstream emergence of the Internet in the mid-Nineties that generated deafening media and institutional discourses. I took that starting point to show that a century before, the technologies of the Industrial Revolution were just as much impacting the collective imagination.

Finally, and in truth to my approach described above I consider this DDes dissertation as an artwork project. Undeniably, this idea was one that kept my motivation high and my doubts in check, and saved me from moments of despondency. An artwork is indeed adaptable, flexible, malleable. It can be revisited and reinvented at any point. There's a lightness to it that is absent from an academic work often perceived as a "life or death" situation - yet, that lightness does not mean that the work conducted is not just as hard and as rigorous. Therefore I'm engaging in this research like an artist with an artwork, uncertain of the final result and rejoicing of the process. This research is an artwork also from the perspective of its dissemination. It builds upon previous work to propose something different and innovative. The final outcome should be engaging and impactful, accessible and shared. It's important that the overall piece can be a pleasant read, both visually and intellectually compelling and not come across as a dry report. In that spirit, parts of the research draw from 'enacted' forms: exhibitions, conferences and workshops. There are sections of this dissertation that can be read as a statement, or manifesto, in particular where I argue for the appreciation of materiality. I perceive my audience as very diverse and multidisciplinary. This is a content that can hopefully inspire artists, designers, HCI researchers alike, and beyond.

2. WHY INTERACTIVITY? (OR MAKING ART FROM DATA)

My art and design practice has evolved around the uses and misuses of technologies, and the ways that technologies strike our imagination, mediate our relationships, shape our understandings of things and reinforce stereotypes or breaks them. Technologies hold a mirror to civilisations, telling at once a beautiful and a dark fairy tale: our “human behaviours challenged by the technological other” (Velonaki 2012).

As an artist working with technologies, I acknowledge that there is an effect of empowerment. Technologies invite to look at things from multiple angles: innovation, design, pop culture, history, fiction, etc. Barriers can be lifted and possibilities are endless. One can escape being labeled. With technologies come playfulness, creativity, and possibly emancipation. At least, in my case, they have helped to constantly reinvent myself, reinvent my future and take authority. Some of my past work, like the project *RAW*, has directly addressed the notion of creativity with mundane uses of technologies in everyday life and ways that it could challenge assumptions (Bitton *et al* 2004).

Aside from power, there is poetry in technology. It’s within this unusual combination that this research thrives. There’s a moving component with technologies. There’s an elusive quality to them, a poetic sensitivity that moves me. And since this research is rather about machines, and machines of fabrication, that poetic quality is even more present. Machines are the figurative entities of technology - their embodied counterpart, or manifestation - and as such, they can trigger the most anthropomorphic empathies. Machines with their *anima*, their sound, their aesthetics and their repetitive mechanisms are ideal instantiations of melancholia and contemplation.

Human interactions with these tools and machines, and the outcomes of these interactions are at the heart of my investigation. Interactivity early

became a quest in my creative process as it allowed to rethink the delivery of content to an audience, the access to information and the staging of narratives. ‘Interactivity’ is also a complex and polysemic word that is used in wide variety of contexts (a later chapter will describe in detail its implications for this research). Briefly, I define interactivity here as:

- an aesthetic experience,
- enabled by a computer program which transcribes into operations the rules defined by the author,
- with the behaviours and inputs of the participants, voluntarily or involuntarily being able to affect the aesthetic experience.

Interactivity has therefore several degrees, where an experience can be *more or less* interactive according to criteria such as the types of users’ inputs, the levels of openness for appropriation, the moments of interactions (included as results or as conditions), the users’ awareness of control and the degrees of immersion (in a black box or in front of a computer screen). I also include generative art, where the code is its own input and is affecting itself. Finally, the degrees of interactivity don’t necessarily infer on the quality or the intensity of the experience.

As an artist, it’s the medium that I chose to explore and dissect. It’s playful, engaging, and it can mostly exist with some aspects of audience participation, the outcome changing from one person to the other. Elements of time can have an impact, while the experience can be further staged with randomness and chance. It’s full of emotional and physical nuances, as the interactive experience can be sensual, bodily, tactile, intimate, performative, phenomenological and perceptual. Interactivity often implies a generous mindset, inclusive of users: it’s “open to evolution and misappropriation” (de Visscher 2012). The relation to the audience is generally crucial in all artistic processes, but it’s strategic in an interactive experience. My work is meant to reach the mainstream and to be made accessible, which is why I create experiences that can happen in casual spaces, in the street, on the Internet, or at home.

Additionally, and less formally, interactivity is a formidable way to address topics that are inherently malleable to that sort of approach, as they have a strong rapport with technology. Notions of identity, memory, connectedness, traces, movement, embodiment, storytelling, everyday life and instantaneity for instance are all part of a constellation of ontological properties affected and reinvented by technology-related tools, uses and aesthetics. These topics hold centre stage in my work - both as subjects and forms, where contents can become the very conditions of the interaction, revealing and hiding themselves in a scheme of interfaces. For instance, I often use the body and its movements as interfaces for interactive experiences that will in turn allow the users to reflect on their embodied presence. The body is the actuator and the interface all at once. In my past work, the participants could reveal scenes with their shadows or record sound as they walked - the body was at the centre of the action. With the movement of the body and gestures, we have interactive inputs readily available and intuitive.



Fig 01. In the project *Abstract* (2007), the shadow of a person would unmask scenes of Japanese gardens. Photo by Joëlle Bitton.

In this research and with a similar approach, I address notions of self and embodiment as modalities for interactive experiences in digital fabrication. My focus is on the representation and expression of the self through its “measurement” with sensors. I look at the eccentric textures and shapes the self can take with technological tools, and if they would allow users in turn to get a different sense of self. For that purpose, the tools of quantified self assess the self in very diverse, endless and abstract ways. Some might say meaningless. Yet, they are elaborate forms of logging, ancient modalities to track ourselves and to establish a sense of control over our body and mind, possibly with a self-censorship and self-surveillance purpose. We have at our disposition ways to measure ourselves more efficiently and more drastically than ever before, and in parallel with our heightened connectedness with the world, we’re increasingly in competition with everyone and anyone. In the context of this research, these logs are showing something else, a measure of what cannot be measured, the elusiveness of our ‘selves’. With the tools to capture and to accumulate data, we’re creating infinite databases which are a formidable matter for interactive processes. Computation makes art from data, measures, notes, lists, and systematisation.

Time is the condition that often allows that data to make sense, to be staged for an interactive experience. With time, come the notions of narrative, storytelling and engagement. We can slow down time, or fast forward it. Of course, we’re not in the movie territory, we’re not totally immersed in a screen or a book, where we suspend disbelief. With interactive art, we’re blending reality and fiction in less subtle ways, using probes, speculation, surprising users when art pops out of the Internet itself, playing with spontaneity, intuition or contemplation, boredom. With time as a condition, daily life becomes a source of fiction. The instant camera from the Sixties transformed triviality into memories and emotion, it fixed time visually in an instant. With computers and their capacity for processing enormous amounts of data, a similar approach becomes even more compelling. In this research about fabrication tools, where time is often considered a problem, I use it as a strength. I’m suggesting to the participants that they could “wait forever”. I’m teasing an infinite patience. I’m forcing a latency that is welcome, taking into consideration that with the waiting and

the expectations, relationships start to form with the machine. Suddenly, you live with a companion that has its own rules and that you're having to deal with instead of a system that completely obeys you.

3. DIGITAL FABRICATION, A PROFOUND MATERIALITY

The contemporary world of fabrication is particularly ebullient, with innovative uses and products often making headlines. It's as if the world was waking up after twenty years of dominance of the Internet and the screen and was surprised and excited by all things tangible. As if we're collectively rediscovering that the world is made of things and that we can even make them ourselves instead of buying them. Computation design, digital fabrication, computer aided-design (CAD) and computer aided-manufacturing (CAM) have been gradually better known to the mainstream public with shapes that have appeared in the public space and that showcase the extravagance of parametric design. It's possibly bringing an awareness of a marvellous materiality, as if we could program and shape the physical world in ways that we couldn't before and in measures that are truly diverse (Gershenfeld 2013).

Following a similar trend in my practice, and after many years of working with visual projections as the main output of artworks, I was looking for more opportunities to play with things. Digital fabrication methods provided me with outlets for experimentation, and an endless list of materials while using computation tools. It's the opposite of adding the Internet to already-made things (Madakam 2015), it's about designing and building things based on conceiving them digitally. From there, I could conceive of things as outcomes of an interactive process. The aspects of tangibility and physicality are determinant. Not only this is an opportunity to give tangible outlets to interactive experiences, it's literally a way to fabricate concepts, to make them physical, to give them a materiality. In a later chapter, I investigate in-



Fig02. Parametric walls used on the renovation of old fabric warehouses in Shanghai. Archi Union Architects. 2010. Image Sheng Zhongha.

depth the qualities of this materiality and the objects that emerge from that interactive encounter. Not necessarily defined by a utilitarian function or an ornamental role, but rather their making process and their ambiguity, those objects are holding traces, seizing moments in time and changing over time.

With this thesis, I thus look into how interactivity and fabrication affect our relation to materiality. By materiality, I mean what constitutes our tangible reality, the physicality of the world, the things that surround us. Not only the built environment but the things that get transformed, natural elements like sand and wood that we use to make things or that are part of our lives, things we walk on, things we touch.

This is as much a statement as it is an exposé of the topic. There's clearly at play in this research a fondness of the material and of the material world, too often considered negatively or despised, especially when it's compared to the "spiritual", the "mind", the immaterial, supposedly too noble to be concerned with trivial and frivolous matters. This cliché is specifically the reason why this work is important to conduct. We're grounded in reality and the tangible things that make this reality do hold meanings, emotions and sensations. Frivolity is serious. It's long been shown, notably in the field of anthropology that there is power embedded in things, that things are more often than not alive (Walker Bynum 2011), full of emotions and humanity. One could indeed argue that all things made are profoundly human: "Rien d'humain n'existe en dehors de l'artificiel"² (Pawlowski 1962). In the same sense, the word 'fetish' that recognises the charming and alluring quality of an object refers etymologically to that of what is being made, fabricated, artificial.

With its playfulness and boundlessness, digital fabrication allows us to point that technology makes us more intimate with materials than ever. Contrary to stereotypes that often oppose humans and machines, the hand and the computer, craft and industry, the digital and the material, the handmade and the precise, I argue that technology can make us more engaged with materials around us, that digital culture is more than ever materialistic, and that digital fabrication outcomes can be as much imprecise, uncertain and elusive as with other traditional processes.

A lot of the aesthetics at play in my work and in this approach as well, is underlining a certain appreciation for minimalism, a care for precariousness, for impermanence and the beauty of the details in the ordinary. I'm finding beauty in what's not supposed to be beautiful: the ordinary, the broken, the forgotten. This perspective has some echo in what certain Japanese concepts describe, like "Wabi-Sabi" that embraces imprecision, mistakes, cracks and accidents as part of creativity, life and humanity. The decor of that approach is everyday life, things that are part of a routine. This can be defined as an

2 "Nothing human exists outside the artificial" (trans. by author).

aesthetic of everyday life. The traces of culture that Benjamin evokes in his unfinished book 'The Arcades project' refer to that aesthetic, at a time where the industrial world had already a rich heritage of debris (Benjamin 1997). Dadaists and Surrealists artists such as Atget and Man Ray would stage those everyday traces for redefining beauty and art.

We are still very much in the ready-made era, we have barely moved from that time in art and design. We're still simultaneously making sense and making art of everything that touches our lives, just like poets. And



Fig 03. Eugène Atget, 'Coiffeur avenue de l'Observatoire', 1926. Albumin print, 24 x 18 cm, The Museum of Modern Art, New York. Abbott-Levy Collection. Digital image © 2008 The Museum of Modern Art.

with the notion of poetry, and its etymological root *poesis*, we are bringing together the different meanings of fabrication: one that tells of making, creating, building something and one that tells of inventing a world, a story, of imagining things.

“La position de Mallarmé à l’égard de la hiérarchie traditionnelle des arts et des genres n’est pas étrangère à cette tendance. À la faveur de la crise des années 1860, le poète découvre que l’absolu esthétique peut se trouver dans un simple bibelot poétique ou matériel, pour peu que celui-ci comporte un ensemble nécessaire de relations entre des mots ou entre des matières, des formes et des couleurs. Chaque genre a, à ses yeux, sa propre perfection et peut produire un plaisir esthétique aussi intense qu’un autre. Ce n’est plus le sujet qui compte, dans les arts et genres mimétiques, mais l’ensemble des rapports nécessaires qui font voir l’objet sous un jour neuf et harmonieux.”³ (Bohac 2006).

The visual poetry of Mallarmé, Ezra Pound, Kitasono exemplify the tangible quality of abstraction, by associating together words, meanings, sounds, and signs. They each created geometries, spaces, objects with words. In a way, this thesis situates itself in similar processes of creating tangible poetry. It’s also a poetic perspective on digital fabrication, and a poetic appreciation of everyday things. This is a way of life, a proposal of a humanistic approach of a sense of self in and with the world.

³ “The stance of Mallarmé in regard to the traditional hierarchy of arts and genres is no stranger to this trend. Taking advantage of the crisis of the 1860s, the poet discovers the aesthetic absolute can be in a single poetic or material ornament, provided that it has a set of necessary relationships between words or between materials, shapes and colours. Each genre has, in his eyes, its own perfection and can produce aesthetic pleasure as intense as another. It is no longer the subject that matters, in the arts and mimetic genres, but all the necessary relations that show the object under a new and harmonious light” (trans. by author).

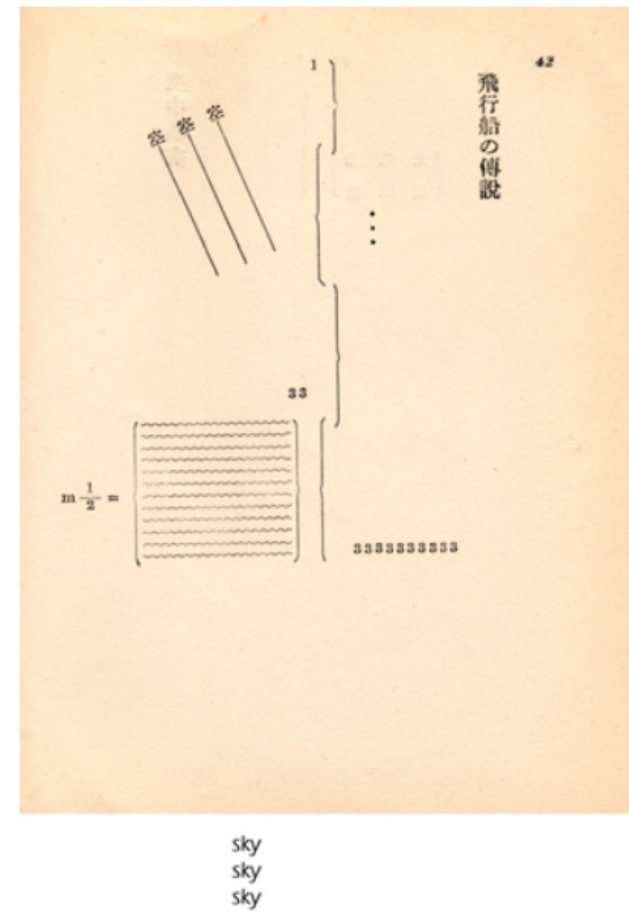


Fig 04. Kitasono Katue, 'Legend of the Airship', White Album, 1929. Excerpt from Young & Solt (eds) "Oceans Beyond Monotonous Space: Selected Poems of Kitasono Katue"

4. INTERACTIVE FABRICATION, IN SUMMARY

I propose to bring together the qualities of interactivity and of fabrication, further exploring the practices of making with digital culture and data. Interactive fabrication is the *modus operandi* for using CNC-machines with the whole range of interactive interfaces, circumventing that way the typical computer modelling software in favour of alternative, flexible and inventive modalities. In light of the definition of interactivity laid out in a previous section, interactive fabrication reads almost as the ultimate purpose of interactivity eventually, finally achievable. This is interactivity that leaves traces, that is tangible, in that an outcome stays. The machine translates the interaction we have with it into a materiality that is the witness of that moment.

The emergence of these experimental practices brings about old and familiar discussions about aesthetics, machines and technology uses, most notably the materialisation of thoughts, of self, of the instant.

While studies of interactive fabrication conducted so far in the field of human-computer interaction have mostly revolved around approaches of accessibility and problem-solving (Willis *et al* 2011, Mueller *et al* 2012), I argue that this is an opportunity for using personal data as parameters for machine control, as an experience of thoughts. I make the case that interactive fabrication can conduce that way to embodied fabrication when a set of conditions are reunited: typically if the data input is based on personal activity or personal physiology, and if other aspects of the experience emphasise the user engagement, such as the use of existing interfaces for interaction, items that the user has available, at hand (phone, body movement, Twitter, etc..) that allow for opportunistic interaction, playfulness, improvisation.

This research is as well an opportunity to make use of quantified self trends, of habits of self-performance and self-reporting to generate traces and forms of inscriptions, be them about our anxieties of evaluation or about

the playfulness of creativity. Using real personal data for creating tangible experiences puts forth a relation with reality: as data interprets reality or decodes it in a biased way, interactive fabrication allows us to modulate our environment according to the life lived.

Chapters in brief

Chapter 1. The Object of Design and research methods

This chapter exposes the methods used to tackle such research, and proposes a methodology for ‘undisciplinary’ studies. It’s also an understanding of the contributions to the fields of art, design and HCI.

Chapter 2 The Digital and the Material

This chapter tells of the relationship at play in digital fabrication, and the concern for joining bits and atoms that is a constitutive drive for research in this domain. One of the implications of this particular study is to look at the geometry within the data.

Chapter 3. Real Machines

This chapter is about the reasons underlying the necessity of such endeavour: there is something about fabrication and machines coming into the mainstream domain that inform much of the experience. As that ‘something’ converges with discourses of emancipation, it enacts an idea of control, which needs to be unfolded.

Chapter 4. The Interactive Paradigm

This is the system of interactivity as applied to digital fabrication, with the operating factors and the parameters necessary for designing an interactive fabrication experience. I'm proposing a framework as guidelines for such experience. As well, implications are addressed that lead to an articulation of embodiment and fabrication.

Chapter 5. Odd Materialism

This chapter proposes to loop back with this introduction and lay out the materiality at play, the outcomes that are the traces. This section addresses more specifically than the other chapters the three experiments I conducted in the research: *Twipology* or the physical ripples, *Rabota* or the domestic enigma and *Streamline* or mutant matter.

Conclusion. Love and the Machine

This section proposes a final reflection and shares more lessons learned and questions of contribution and impact.

The Object of Design and research methods

1. AN UNDISCIPLINARY TERRAIN
2. THE EXCURSIVE METHOD
3. THE FRAMEWORK OF EVERYDAY LIFE
4. THE FABRICATION OF MEANING

1. AN UNDISCIPLINARY TERRAIN

When the architect and artist Didier Faustino presented his work at Harvard GSD in April 2016, he described the approach of his company as such: “[we] have one point very clear to explore: this notion of fragility (...) This fragility appears in many situations, most of the time a situation we can look as intermediary, or in between (...) the work is more to explore a series of fragments to propose something (...) not pluridisciplinary, as was presented, but maybe more undisciplinary.” (Faustino 2016).

Upon its enunciation, the word ‘undisciplinary’ resonated in my mind as a sudden evidence. It echoes a misfit attitude and a resistance to be ‘disciplined’ and to conform to labels. It’s also an acknowledgement that unless the research pursuit is to find a single solution to a very narrow problem, the heuristic cannot be tied to a single discipline. My mindset is to assume that sources and data from disparate origins could contribute to a set of knowledge, that methods and tools can be borrowed and combined from a wide range of disciplines, that new skills may have to be learned to engage further in a project, that views may be broaden and that rules should be broken.

For a long time I thought that terms such as ‘interdisciplinary’, ‘multidisciplinary’, ‘transdisciplinary’, ‘pluridisciplinary’ could express the nuances described above, but they still defend somehow a view that disciplines are fixed and that they can sometimes compromise on some topics for a limited duration. This is the stance that permeates the big discourses that regularly promote a reconciliation between art and science in education, or between design and engineering in curricula. Where I’m concerned, these disciplines never even seemed distinct or “having to be brought together”. I feel exasperated that artists who engage in academia keep having their legitimacy as researchers questioned and their contributions held in contempt and disregarded as frivolous. Even more, I’m surprised that this is still an issue and I feel sympathetic for those that seemed to discover only recently that ‘design thinking’ or ‘art practice’ can indeed represent a chance for societal policies and provide solutions to complex problems.

Barthes thought to restore what the word “interdisciplinary” should mean: “Interdisciplinary work, so much discussed these days, is not about confronting already constituted disciplines (none of which, in fact, is willing to let itself go). To do something interdisciplinary it’s not enough to choose a “subject” (a theme) and gather around it two or three sciences. Interdisciplinarity consists in creating a new object that belongs to no one.” (Bleeker 2010 citing Barthes in *Jeunes Chercheurs*). But this definition has been lost along the years and this is probably too late by now to reassert it. Therefore, the term “undisciplinary”, not yet burdened with too many meanings, is entirely adequate to describe a research that upholds its marginal quality, doesn’t apologize for the range of its inspirations and strives for rigour all the same. The important part in this journey is to not get lost in digressions and to stand by a guideline. In my case, this is done first with pursuing an intuition, then surveying the vast terrain of my topic, assessing the different angles that it could be approached from and limiting the scope to that fragment that is possibly unchartered, or unexpected or elusive.

My research terrain here is digital fabrication. It’s a diverse, unevenly covered and multi-faceted terrain. It has applications in the domains of

architecture, manufacturing, design, engineering, computation, craft and many other domains where it changes workflows or facilitates innovation. It can be examined in order to solve specific technical and structural issues. It can be researched from the perspective of its role in the rise of the makers and DIY culture. It can be assessed for its ways of challenging copyrights and intellectual property. It can also be evaluated as the latest proclaimed societal marker for empowerment. And so on. All those angles are valid and alluring but none of them are the object of this study. The object in this study is the odd materiality that is generated from interacting with fabrication machines, the modality of time in that creative process, and the resulting ambiguous opportunities of engaging with the material world.

2. THE EXCURSIVE METHOD

I realised that there was a research opportunity few years ago, with a series of events happening over the past ten years or so: patents of 3D-printing technologies expired, open-source activists contributed to make these technologies known and distributed to a wider audience, physical computing became increasingly accessible to artists and designers with tools such as Arduino and Processing, media discourses built up a hype around 3D-printers and DIY movements, the makers culture was supported and promoted with a wide variety of resources, from online how-tos to fabrication spaces to amateurs fairs and workshops. Something felt compelling in all this.

When this present study began, it was clear very early that an inductive approach was more adapted than a deductive one for engaging with the terrain (*see above*). This meant that along with the typical issues at play with starting a doctoral research, it was facing an additional difficulty: that of arguing for myself and for others the importance and relevance of a topic when it’s not aiming to solve a specific problem, but when it rather seizes an opportunity. A hinder for a long time, that difficulty eventually became a reward.

The inductive approach means the research method is strongly exploratory and what I would call ‘excursive’: it digresses, moves in different directions, experiments, performs some aspects and eventually exposes meaning. It’s concerned with shedding light on the object of the study and showing that it exists on its own and in a lineage of previous works and theories. It’s apt for a research where new uses and applications of the technologies come out every week.

Another difference with a deductive approach is the question of the evaluation of the relevance of the thesis: is an evaluation necessary when problems are not being solved? And if so, what should be evaluated? This thesis will not answer whether or not digital fabrication changes the world according to a random sample of surveyed people. That would be a vain exercise. On the other hand, what could be named ‘evaluation’ here is a ‘proof’ of the emergence of a materiality formulated by a selection of existing works and the development of further prototypes. Additional contributions take the form of methods, frameworks and guidelines that can be repeated for similar productions. Later sections of the thesis will show more in details the ways qualitative tools were nonetheless used for various purposes, including surveys and users observations and feedback. The outcomes that this thesis foresee are proposals of curious creative processes and challenges for future work.

The excursive method is further relevant in regards to my background and training in history, art, design and HCI, as I’ve exposed in the introduction. Again, part of my perspective on a topic is derived from seeing unexpected associations and envisioning possibilities. I’m both a theorist and a practitioner, with a long and diverse professional practice. Along the way, I’ve created my own methodology that has informed this doctoral research. This excursive method can be defined in different stages that are often conducted in parallel: *investigation, play, everyday, tensions, enactment, dissemination.*

Investigation

The investigation is the process of looking at the literature, of understanding what are the inspirations that colour the overall thesis and of making explicit a number of thought processes: the articulation between the personal and the academic motivations for pursuing the research, the reasoning of how the topic even came about, the choices that are made to constrain the research, the definition of the words that are used to make sure that the words that are used are the ones that mean what is meant, the roles that different disciplines have in the study, etc.

The methods borrowed from various disciplines could each pertain to either ontology, epistemology and heuristic. I’m reviewing them in details in this chapter, in two sub-sections:

- the framework of everyday life with constructionist ontology, semiotics, history of mentalities, and material culture
- the fabrication of meaning with art, design and HCI practices and the role of prototyping for research

The overview of related work let the research to situate itself, and to iterate on what’s existing. The acknowledgment of what allowed for that research to emerge is that way quite essential. Some related work make for a selection of case studies illustrate the discourse in a very eloquent manner. The research advances with other ‘visual’ formulations (mindmaps and diagrams) that are needed at times to get a sense of the whole. But it’s in the writing that the investigation comes together and expands.

Play

Part of the knowledge drawn in the ‘excursive’ method comes from making, designing, prototyping, actions that all define the practice of a topic. Again, this section will be detailed at-length below. In summary, I’m arguing for a research that is ‘testing’ its discourse, that is not only suggesting a possibility but that is experimenting it. In a curiosity-driven research, concrete outcomes are expected, creating interfaces for ‘real’ users are

motivating part of the research and conducting workshops, learning skills and collaborating with peers help keep the research meaningful over time.

Everyday

This research is motivated by the ‘real’ world, it’s meant to be put in effect. It’s also grounded in the popular culture, if just for the way it taps into common references of technology, science-fiction, consumerism. I’m looking at the discourses found in typical newspapers, at the representations of technologies in TV series such as *CSI* (see image below), in books, movies, conversations, that can both illustrate and amplify phenomena. In that sense, I’m not so much interested in the expert or professional terrains as much as I am in the mainstream, the casual, the domestic, the everyday life terrains.



Fig 05. A 3D-printed gun is the murder weapon on the show *CSI New York*. Episode “Command + P”, broadcasted January 4, 2013. CBS.

Tensions

I use both theory and practice to inform the research, there is that way a constant tension between the theoretical framework and the experimentations that I’m conducting. That tension is most of the time productive and at other times can be taking me in different directions. Other tensions appear. For instance, between art and design, the disciplines that I’m prevailing from. Again, this is explained further in depth, but in an ‘undisciplinary’ research, it is a matter of acknowledging the possible contradictions.

Enactment

The research should be practiced, rehearsed, performed and discussed in public settings as early as possible into the process. The shapes this can take are manifold: public presentations with small and large audience, lectures, conferences, publications, submissions to grants, pitches, competitions, social media exposure, online presence with photos, videos, blogs and documentations, etc. The main purpose of all this is to get familiar with the topics at hand, to precise thoughts, to assert arguments and to advance the knowledge. Confrontations with an audience also allow to assess the relevance of the topics, of the angles taken and of the hypotheses drawn. The other important benefit is simply to make the research known, and for the researcher to build a reputation and to be identified as an expert in the field. In turn, the researcher can identify better the audience interested in the topic and the other experts in the field. Moreover if the topic has anything to do with user-experience and social impact, it becomes substantial to bring the research to a public setting.

Other more complex forms of public discussion shed light on the topic, and allow for user feedback and evaluation. They can contribute to foster communities of interest. Those are workshops, classes, exhibitions, symposia, user-studies and surveys. A section of this thesis showcases how the J-term class ‘Self-Fab’ that I co-instructed and the ‘Data Across Scales’ conference that I co-organised helped advance my research and promote the

topic. Surveys and user studies don't produce necessarily compelling results in a qualitative research but they do allow for feedback, expressions of opinions, a 'feel' of what matters, or not. It doesn't mean that the relevance of the research should rest on this feedback, but it means that there is a way to share and discuss matters. Surveys are also useful to gauge what's perceived by an audience beyond the 'hype' of the discourses. The survey I conducted helped me in that sense gather informations on actual practices of people, on their uses of fabrication machines, and their wishes.

Another aspect of 'enactment' is related to the collaborative nature of this 'excursive' method. In technology-related projects, one person cannot master all the skills necessary for production. It's time-consuming to work alone. Working with other people and joining efforts allow for discussions, confrontations of opinions and methods, fights, assertions and compromises. It's also time-consuming to work with others. It could easily be noted among the sources of tension, written above. But it's still one of the best ways to get a project 'out' of one mind's bubble.

Dissemination

In the previous section, I discussed sharing the research during its formation. Its dissemination as it comes to an end is quite distinct even though it can share many similar modes of delivery. The dissemination is about envisioning the legacy of the thesis and making sure that it can keep reinventing itself. Evidently, the main formal outcome of the DDes thesis is a dissertation. But it's only one of the objects, one of the shapes that are actually being produced. There are of course the prototypes and artworks that were created in the course of this research. But as an artist and designer, I consider that the thesis should be strongly disseminated in creative ways. It's meant to be used and enjoyed in its written form as a book or other forms of publications but also fragmented on a website, as an exhibition, a symposium, an installation, a performance, a manifest, a workshop, a course, etc. The thesis can hopefully take part in a corpus of knowledge shared by a community, contributing to it with guidelines, frameworks and online instructions. The work itself is a lively matter, beyond the written piece.

The stages described above define the method and constitute a workflow that give the research a rhythm with beats and interruptions, anticipations and panic attacks. Other aspects of the research workflow are more transiting in between all the stages, they involve meetings with advisors to track progress, discussions with peers for feedback, taking hundreds of small notes, incessant web browsing and bookmarks savings, and finding ways to actually read and process all that information and to keep it organised and manageable.

Regarding that last note, I'm sharing here the main software I used to establish a software workflow, in case it could help other researchers to make choices. In most cases, software tools don't fit a research and academic process. They often cause more issues than they support the journey. I found an acceptable balance by combining a few of these tools. I used 'Scrivener' to organise hundreds of notes and devise an outline, 'Google Docs' and 'Apple Pages' for writing, an ad-hoc system for managing my bibliography and papers, 'Xmind' for the occasional mindmaps and for arranging topics with a different perspective, 'Scanbot', an iPhone app for scanning pages, 'Raindrop.io' and 'Dewey' for visualising bookmarks, 'Self Control' to cut me off online distractions, 'Apple Notes', the quickest way to write down a thought, 'Adobe InDesign' for the formatting of the dissertation (along with other Adobe tools for anything related to images and diagrams), 'Apple Keynote' for all slide presentations and 'Google Spreadsheet' for project management⁴.

And then there's life. Finding a routine amid the life of a graduate student is probably the hardest thing to achieve and it's always elusive. No two days look the same. I found that in the best times, I could maintain a routine for two weeks in a row before it was disrupted one way or another. Life happens all the time and is not suspended where I assumed it would. If you're advanced in age and career, it's likely that existing responsibilities and expectations will still require a lot of the time and attention that could have been, in other circumstances, devoted to the thesis research. Starting with a

⁴ Additional tools and software were used for the prototyping of projects and are cited in the sections describing them (last chapter).

rich professional expertise is a mixed blessing, as it adds to the loneliness of the long distance researcher, in that you don't belong to the faculty nor you can easily build a social life with students that are generally much younger and just starting their professional journey. And of course, it's difficult to accept the subpar status of the "student", when you've been many times over in the situation of the teacher. And for the first few weeks of my program, simple things such as technical words and vocabulary related to the field of architecture that I wasn't familiar with made me feel excluded from the school culture. Of course, money is a permanent concern: I'm always spending time trying to find money, either for living or for research: teaching, applying to grants, taking summer jobs are all strongly beneficial but they end up making half of the time overall that you spend in the program.

Other disruptions have included moving home six or seven times, moving office space a few times as well, breaking a hand and undergoing surgery, breaking up. Then there is the unthinkable, losses and terrible grief. Life is really not suspended at all while you do a thesis. But it's in the midst of all this that I realised that life would have happened no matter what I'd be doing or where I'd be living, and so I feel truly grateful that this happened while I was working on such a wonderful and exciting research, supported by caring friends and kind advisors. And where the thesis is concerned, keeping a purpose, staying on a loose track, doubting healthily and not losing confidence in the relevance of the research, is all that matters.

3. THE FRAMEWORK OF EVERYDAY LIFE

This research draws on a convergence of theoretical frameworks that share a certain appreciation of knowledge produced in the observation and in the practice of everyday life, whether past, present, near or distant: namely constructionist ontology, history of ideas and material culture. As technology is both revealing perceptions people have of themselves and the world around them and creating some of those perceptions, it's particularly adequate to look at a technology like digital fabrication, in the context of its

transition into the mainstream, and thus into the social fabric.

Specific thinking movements are informing the methodological approach of this research. Constructionist ontology proposes to uncover meanings hidden in individual and collective assumptions and to notice the ambiguity and changeability of meanings. Hence, the constructionist ontology supports a qualitative research concerned with context, discourses, uses and creativity. Among the thinkers that have shaped that approach, Roland Barthes, Jacques Derrida and Michel Foucault are references in the arguments that this research is defending. Barthes, in particular, provides guidelines for challenging all discourses as constructs. Semiotics thus constitute an essential tool for questions related to technology and society. Barthes's essay, *Mythologies* (1970) exposes the numerous layers of images, signs and values, often bourgeois, that we associate with mundane ideas and suggests that they can either contribute to our servitude or to our emancipation (his example of inert toys vs building sets is later mentioned in this dissertation about relations to everyday objects). Jacques Derrida with his considerations of words as containing worlds in themselves invites us to ponder upon definitions, associations and metaphors, almost in a playful manner. When historian Christophe Studeny studied the idea of speed in the 18th and the 19th century (1995), he refers to discourses of politicians, intellectuals, writers, testimonies of men and women of their time. Foucault describes this type of sources in *The Archeology of Knowledge*: "[...] the history of those age old themes that are never crystallized in a rigorous and individual system, but which have formed the spontaneous philosophy of those who did not philosophize [...] The analysis of opinions rather than of knowledge, of errors rather than of truth, of types of mentality rather than of forms of thought." (Huhtamo 1996 *citing Foucault*).

French historians Fernand Braudel and Jacques LeGoff, among others, have argued from the Sixties onward for a 'history of ideas' (or 'mentalities') that would uncover social behaviors, materialities and imaginaries beyond mere facts. Thought as a subdiscipline of history for a long time, the history of ideas has now permeated historiography as a whole, as a 'living history'. Derived from the pioneering works of l'École des Annales and the works

of Marc Bloch in particular (1983), this take on history invites comparative studies and turns ‘everyday life’ as a knowledge tool, that leaves in time material or discursive traces to excavate (Braudel 1979, LeGoff 1983).

Again, when considering technology and its uses, this historical approach unfolds as a formidable tool, especially when establishing parallels in time. In *Mechanization Takes Command*, Giedion uses the term “anonymous history” which underlines the attributes of ways of life and ordinary objects. In his attempts to demonstrate how mechanization is intertwined with the “slow shaping of daily life” (1969: 3), he writes a manifesto for anonymous history: “(...) research is needed into the *anonymous history* of our period, tracing our mode of life as affected by mechanization its impact on our dwellings, our food, our furniture” (1969: vi). He advocates as well to seek the links between industrial methods and “methods used outside the industry in art, in visualization” (*idem*). Giedion hints here that the modes of technological production can be regarded as indicators of the social and cultural mechanisms in which they emerge.

Huhtamo applies Giedion’s ideas when he looks of the history of the computer (1996). The anonymous history of the computer is an account of many histories: the social history of the computer user; the history of the computer as a design object and as a source of style and fashion; the history of the computer as a counter culture and a subculture, in its encounter and its gradual merger with the media culture; the ‘mental’ history of the computer as a “machine of dreams”, an intangible object of desires, fantasies, fears and utopias. Huhtamo argues here for an “archeology of media”.

This archeology of media could possibly explain the meaning of *déjàvu*, of familiarity of occurrences that have already happened in different technological contexts. In the title of her essay *When Old Technologies Were New*, Marvin (1988) infers at that sense of *déjà vu*: somehow what we experience today in terms of radical shift in human mediations begins with the invention of the telegraph. And because those machines aroused both sentiments of fascination and fear they constituted a bed for “social experimentation” (Marvin 1988). Thus the history of the uses of these

machines are as much telling as the history of the machines themselves. In the *Arcades Project*, Walter Benjamin (1997) considers the remains of the 19th century culture that are “buildings, technologies, goods, fashion, literature” as “actors of a culture understood as a dynamic construction”. Benjamin took seriously the “debris of mass culture as a source of philosophical truth” (Huhtamo 1996 *citing Susan Buck-Morss*).

These “traces of everyday life” is very much the elements of study of the research field of Material Culture. Established gradually as a discipline since the Eighties, the premises of material culture studies have nonetheless long been discussed first as subsets of anthropology and archeology then as advocacies for looking at materiality as a meaningful subject. Prown gives a definition in 1982: “Material culture is the study through artifacts of the beliefs - values, ideas, attitudes, and assumptions - of a particular community or society at a given time.” (Prown 1982). Within the parameters of our research, the field of material culture would thus address in particular the tangible outcomes of digital fabrication.

The anthropologist Daniel Miller has argued for a materialism demoted from its traditional antagonism of spirituality and has showed that the two actually accommodate well with each other (Miller 2005). And so did Walker Bynum in her essay *Christian Materiality* (2011) that showcases the living nature of objects to which individuals can attribute power, in particular when objects are considered as tangible traces of faith. The human attachment to objects forms a narrative, which in our case is heightened by notions of personal fabrication, creativity, and personal machines.

The theorist Michel de Certeau underlines the role of these everyday life elements of culture: “Creativity is the act of reusing and recombining heterogeneous materials” (de Certeau 1997:49). Tactics of “making do” and “making with” are themselves traces to uncover to bring about the ways technologies are used for negotiation and change (de Certeau 1990). For marxist Henri Lefebvre, the *other* theorist of everyday life, we have an opportunity to transform our daily lives into something else than a consumer’s controlled convenience (1947). Even though very different from de Certeau in his approach as a critique, creativity here again is a mode of regaining control over one’s life (which we’re addressing later in our

discussion of self-sufficiency).

4. THE FABRICATION OF MEANING

This research produces a theoretical discourse and meanings as well as artefacts. The artefacts are not mere supports of the theory. They generate their own set of ideas. To some extent, this research produces meanings by producing artefacts: “Making is ubiquitous, and it is as ancient as culture. In fact, making is the practical dimension of culture. It transforms matter, and it articulates meaning. Making has a cognitive dimension; it makes sense.” (Tin 2013).

Fields of art and design, especially when they relate to technology, provide some insights into how theory and practice can articulate with one another. Similarly, the field of HCI often navigate across methods to produce both a technology and its meaning. These fields epitomise in a sense the notion of research itself, they fabricate meanings within their creative processes.

Research in art

The debate about academic research in art, with art or for art is somewhat out of this scope. I stated my position on the matter in the introduction, underlining notably the artistic values of boldness and curiosity for research. Many researchers have done similar statements in PhDs and essays that support art as a valid and provocative method of inquiry. (Brucker-Cohen 2010, Asempere 2015).

In the context of my studies at the GSD, my artistic proposals were oftentimes perceived as surprising, unexpected and I’ve had informal comments of expert designers saying that they would have never imagined those tools used that way and that it was opening possibilities for them.

One could infer that this was in part my position of novice in the world of architecture that gave me an unrestrained vision of rules. But this is in a brief summary, what art means for research: it proposes unusual scenarios that are uninhibited, that push boundaries, and that shift angles about what a tool is supposed to do or what an artefact is supposed to mean. It’s apt to recall than when related to technologies, art is more often than not a force of innovation. In a brief history of new media artworks as precursors of well-known commercial products, Golan Levin reminded his audience that many artists see their work regularly being rebranded by marketing and advertising companies:

“...some of today’s most commonplace and widely-appreciated technologies were initially conceived and prototyped, years ago, by new-media artists. In some instances, we can pick out the unmistakable signature of a single person’s original artistic idea, released into the world decades ahead of its time — perhaps even dismissed, in its day, as useless or impractical — which after complex chains of influence and reinterpretation has become absorbed, generations of computers later, into the culture as an everyday product. [...] the artists posed novel questions which wouldn’t have arisen otherwise. To get a jump on the future, in other words, bring in some artists who have made theirs the problem of exploring the social implications and experiential possibilities of technology.” (Levin 2009).

With art, the audience is often at the centre of the process, especially with interactive art: “audience engagement with an artwork is an essential part of the creative process. The audience is seen to join with the artist in making the work complete.” (Candy & Ferguson 2014). It means that the research wants to be made public, wants to be shared, exhibited in spaces where a mainstream audience can get access to. It means that ideas can be prototyped

fairly rapidly and tested in informal situations. In that sense, digital art for instance, has been consistently a way for novices to discover professional technologies: with a curated experience, they're introduced to processes that are usually very exclusive (e.g. 3D modelling can take years to learn):

“Especially with respect to emerging technologies that may not have any ‘users’ to study from a social scientific perspective, art and design examples provide valuable empirical evidence that can shed light on complex theoretical questions such as digital materiality. In this way, artists and designers can be understood as a kind of lead user or early adopter of emerging technology, and their experiments with digital fabrication tools are helpful in understanding and specifying the material and aesthetic properties of the digital.” (Forlano 2013).

Finally, it's simply artists that inspire some of the aesthetics at play in this research, as well as epitomise the general spirit of this endeavour. I can cite John Cage's variations on the notion of chance that are reflected in the quality of an interactive piece and that embrace an uncertain materiality. Or Bruno Munari's useless machines and his visionary understanding of everyday art. Or Calder's installations that best express the elusiveness of the material world (see *fig. 6* below). I already evoked dadaists and visual poets that used everyday life as a playground. Poetry in that sense proves to be riveting. The emergence of systems art, influenced by cybernetics, is pivotal - interactive art is in direct correlation with the idea of systems and control. I can also mention the Independent Group that has curated the products of mass culture in immersive exhibitions. And artists who have captured the 'minimalist' expressions of materials such as Lucio Fontana (see *image below*) or more recently Pe Lang. There are many additional references that will be made explicit throughout the dissertation.



Fig 06. Alexander Calder, 'Small Sphere and Heavy Sphere', 1932-1933, Fer, bois, cordes, tiges et objets divers, H.317,5cm (dimensions variables) New York, Calder Foundation.

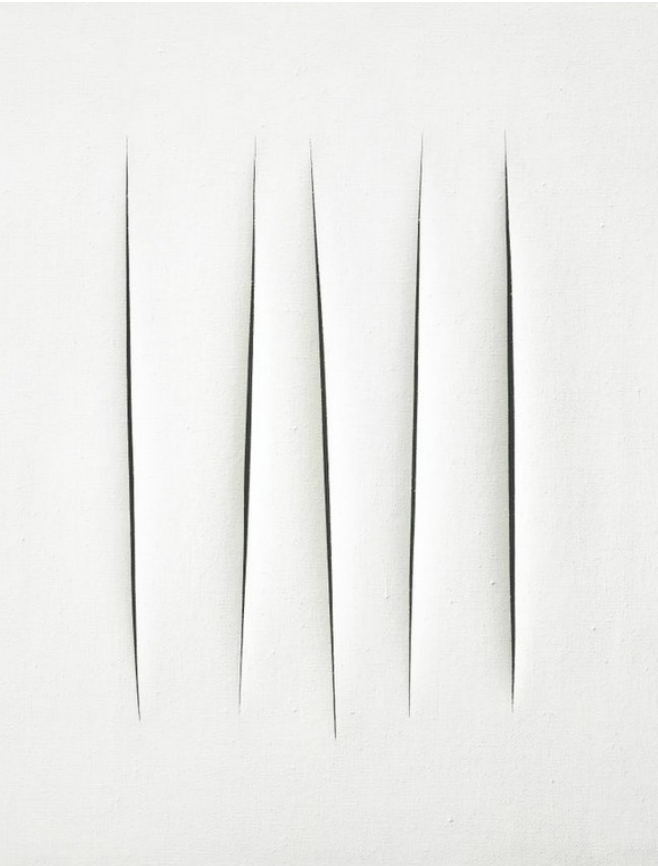


Fig 07. Lucio Fontana,
 'Concetto Spaziale, Attese'.
 Inscribed 'volevo andare a
 Albissola ma il tempo era cattivo'
 on the reverse. Waterpaint on
 canvas, 73.5cm by 60.5cm.
 Executed in 1965. Photo
 Sotheby's.

Research in design

I contend that design, as the modern discipline that we know, is in part an agent of optimisation defined by Leibniz in his "best of possible worlds" and in part a product of the Industrial Revolution and of an era of mass-production and reproduction. Design branched out of craft and other creative practices when it started to think with and about technologies,

all the while making its mission to advance social conditions. This can be reflected in many design discourses and products, since the early 19th century to nowadays, whether the angle is architecture, graphic design, urbanism, typography, etc. My thesis thus situates itself within that history, given as well that it is conducted in a design school.

When I refer to my career, I mention that I'm both an artist and a designer. The distinction between the two is traditionally that of a noble affair for one, and that of a menial trade for the other, or elsewhere the distinction is made that one is whimsical and quirky and the latter rigorous and proficient, or it could be said that art is concerned with aesthetics and design with function. Of course, those examples are just regrettable and pernicious clichés masking the actual assets of practicing both disciplines. Both are creative processes, worlds apart. In my practice, and for this research in particular, I make an important distinction with two aspects. One aspect relates to the term design itself. Etymologically, design looks to the future. It's projecting itself with a purpose, that of being implemented: it needs to be fruitful. The second aspect is that design needs to convince people of that future. It's therefore a missionary with a destiny. Art is much more flexible with the shape it can take, it will insert itself in the world, undetected or in plain view, whether it's wanted or not. Both have the vantages and the dangers pertaining to these qualities.

So if design is a project, it means that it's a joined process of conception and implementation. Design is thinking its action, its 'materialisation', which is a process that this thesis aims to make explicit. Design thinks thoughts and futures, and the shapes, the containers to embed those thoughts, because essentially it's the only way for these futures to become real: tangible artefacts can convince people, can 'sell' them the reality of an ideal. Whether that reality is authentic, that remains to be seen. This scheme is not more blatant than in the field of speculative design (Dunne 1999). In this case, the future, the possibility, often dystopian, are embedded in a design probe, an object that allows people to experience a narrative, a way of thinking when they engage with it. This process can also be defined as design fiction or in other cases critical design. The purpose of these proposals can be at

times to challenge product functions and design processes, especially when technologies emerge in the mainstream public and private domains and disrupt habits. In his study on the domestication of robots, James Auger uses speculative design to “question technological development and its subsequent application in everyday life” (Auger 2012). For him, methods of speculative design consider the “products that could arise as a consequence of the domestication [of emergent technologies]” (*idem*). In that sense, the prototypes that I have formulated for this research are in part speculative experimentations, when they question conventions of digital fabrication, the linearity of the production process and the expectations of the roles it should play for society, whether they’re grounded in reality or in fantasy. If art is about unhinging rules to unlock creativity, speculative design is about reflecting on the existing rules to foresee the future ones.

This research does disrupt indeed the linear process from file to outcome of digital fabrication. It’s proposing to fabricate without a clear understanding of the outcome. This might seem in contradiction to what was stated earlier about the implementation of a purpose. But in this case, the purpose is abandon. In their paper ‘*Paradox of spontaneity of design*’, Erik and Ronald Rietveld frame the “deliberate design of spontaneous interactions”, “an environment [that] provides ‘possibilities for action’ or affordances” (in reference to J.J. Gibson and his essay *The Ecological Approach to Visual Perception*). With this thesis, I set as rules that the body and its data are parameters for machine control, and as “some affordances are more or less predictable”, I create “the framework for people to make their own discoveries and create specific uses” (Rietveld & Rietveld 2011).

This stance acknowledges that digital fabrication technologies are not the precise tools that we could think they are. Errors in the production process happen and there are contexts where instead of being eliminated, they could be welcome. Some materials are known as well to behave inconsistently, such as ceramics. They are “always in a state of becoming” (Freitas 2008), so they should be given an agency in the process. So this is about materials again, or rather the dialogue between ideas, forms and materials: “forms are the containers of models/ideas which are then made into a physical or

material stage temporarily” (Freitas *referring to Flusser*). It’s in the distance between what is conceived (usually made on screen or drawn on paper) and what is finally made that is the moment that is being staged in this research: that moment that goes from an abstraction to a tangible representation. The outcomes or artefacts resulting of that process are beyond the useful/ornamental dichotomy. They could result instead in “forms that can change, morph and move: a new category of objects defined not by what they are, but by the way they change and by the laws that describe their continuous variations.” (Philpott 2013 *citing Carpo 2004:14-15*).

Research in HCI

‘Human-Computer Interaction’ is the field of research that looks at technological innovations, computing systems, tools and interfaces, from the perspective of their uses, either to understand them, to facilitate them, to optimise them, or to identify ones that could be. There’s again here a “humanist agenda” that should be about bettering the lives of users. (Wright & McCarthy 2010) Too often, research in HCI is expected to bring about ‘useful’ outcomes for society thanks to technology: “how will you change the world today?” you could almost hear in the walls of research labs. It’s true that the field comes dangerously close to evangelistic tones when it’s forgetting that people who do change the world, don’t usually set out to do so (unless they’re dictators).

That said, I’m strongly influenced by methods and tools acquired when I was working at Media Lab Europe, the lab that the MIT Media Lab set in Dublin for a few years. Without giving up the iconoclast historian in me, I did acknowledge that naivety was a quality needed for the process of invention, that the world needed to be reduced temporarily for establishing a narrative, that utopias have practical aspects too for making the future happen. The typical creative process at the Media Lab or similar is curiosity-driven: it starts with an interest of the researcher, an intuition, framed by the statement of the research group that hosts the research. In that sense, a lot of trust and autonomy is put in the researcher (most of the time). A

concept is then developed with a top-down or bottom-up approach, or a mix of both, depending on issues: either a design process will involve from the start a community of users, in a workshop for instance, to identify needs or the research is not based on needs but rather proposes experiences which can be tested at later stages. There's an investigation into related work to identify similar endeavours, holes, works that can be reiterated or ones that need to be continued. The prototype phase comes like a reward, possibly the true motivation for all this, it's built often as an interactive device for users to interact with, with the assumption that interaction is the operative factor. The evaluation usually comes with user studies: by setting up the experiences and scenarios of uses and getting feedback with observations, interviews, surveys, etc. The final step and most important one for the recognition of the research is the publication, in a conference or a journal. Throughout the process, the researcher is encouraged to demo the work at all possible stages and to publicise it on various outlets. The timeframe is set on the calendar of annual conferences and thus a project takes about 8 months-a year, depending on the resources, budgets, collaborations, and the support of the lab.

My research didn't follow that track exactly, I borrowed elements related in particular to the definition of the opportunity, the scope of the related work, the prototyping, the user-experience and the dissemination. It's at the Media Lab that I learned indeed the values of prototyping to comprehend a research for oneself and to communicate it for others to appreciate it. It's there as well that I trained to address an audience as diverse as possible, and in an enthusiastic and accomplished fashion. This is generally these methods that have enabled me to establish bridges between the trends of personal fabrication and the expansion of personal data tracking. I devised then interactive experimentations that typically mediate technological innovations to a wider audience.

The question of evaluation

This the question that this type of 'undisciplinary' and inductive research is confronted to with no clear answers: what is the evidence? Vetting *et al* listed four qualities of creative design (as opposed to engineering design): "1) a non-linear process of intent and discovery, 2) design judgment, which is informed by a combination of knowledge, reflection, practice and action, 3) the making of artefacts, and 4) the design critique." (Freitas 2008 citing Vetting *et al* 2006: 524). What then constitutes the premise of the critique?

I used a palette of tools that constituted critique and evidence during and after the research. In a way, the tools can be distinguished as methods for what happens during the research and as contributions for what happens at the end.

Methods of evaluation or tools of critique:

- The "reflection practice", which is the use of practice or making for research, where the researcher can react to mishaps, change directions in a flexible manner and self-assess.
- A set of rules that are established for what the experimentations should address and not address.
- Rules for what are interactive fabrication and embodied fabrication.
- Observations and users feedback when relevant.
- Surveys (that I would use not as 'proofs' but rather as 'gauges').
- Discussions with advisors and peers.

Contributions or tools of evidence of this research:

- The documentation of the experimentations: a report that showcases problems to address, and expectations and flaws and that provides in turn guidelines to be used or referred to, or lessons learned that can be of use to others.
- Exposé of the methodologies used to conduct the overall research that make explicit many of the tacit knowledge and motivations of

the researcher.

- The framework of interactions for interactive fabrication.
- The artefacts themselves, bearing that “the artefacts that result from making are particular, not general; and the meaning they articulate is specific rather than typical. In that sense, making exceeds the scientific paradigm.” (Tin 2013).
- Other contributions include the taxonomy of related work, diagrams for interactive fabrication, scenarios of uses and the expansion of fields of interactive fabrication and embodied fabrication.

Some shortcomings lie in that I intended to draw more conclusions from user interactions with the artefacts, in particular I thought I could impart a typology of uses. I realised that this would have to be the object of future studies, as I didn't address their *usage or usefulness* per se in this particular context. My main contribution in this thesis showcases the ways that personal data could manifest in the physical environment and the types of interactions that can facilitate this process.

The role of the prototype

As mentioned before, prototyping is the essence of ‘undisciplinary’ research, it's the making and practice of the topic at hand. I'm acknowledging here the role of the prototype, of the experiment and their iterations. The practice is not just an excuse to invent things, it's also a learning and discovery process, the heuristic of research in technology: it's knowing by making, by being the first user of the invention. M. Tin defends ‘making’ as a form of research in his manifesto *Making and the sense it makes*: “Making, obviously, is practical, yet we may agree that there is a cognitive potential in its approach as well as its results” (Tin 2013). Freitas argues furthermore that practice is a requisite in design research: “The act of designing (...) is always the primary source of design expertise and must remain the locus of design theory and scholarship”, it's a way to “manoeuvre between the ideal and the attainable” (Freitas 2008). It's worth noting that in the literature addressing the place of the prototype (Vial 2013), the meanings of making, designing,

prototyping and experimenting often overlap.

Known methods have been shedding light on the crucial role of practice and making for the purposes of advancing knowledge (“Reflection in action”), of evaluation (“Reflective practice”) or of taking action (“Action research”). These methods have in all common the practice of a ‘repertoire’, as defined by Donald Schön: “One of Schön's main theories is that educated practitioners have a repertoire consisting of techniques, tools, skills, procedures, theories, and experiences (...) Practitioners see it as something already existing in their repertoire. At the same time they see novelty in a new situation and use the familiar to interpret the new. By using the repertoire, the “toolbox”, in new ways and combinations, according to new situations, practitioners add to their knowledge.” (Hansen 2013).

Philpott notes that these methods are “systems [devised] to record and reflect upon both the pragmatic and the phenomenological aspects of the research without losing the spontaneity of embodied, playful and intuitive design practices.” (Philpott 2013). She explains further how her research was guided by the “development of an exploratory series of small, loosely bounded creative exercises that focused my investigation while still allowing a broadness of scope. These constraints gave comprehensible structure to what had hitherto appeared formless and endless.” (*idem*).

Part of including making and practice in the research process relates to the legitimacy of the discourse that is being produced. It appears that the investigation of a field of study, especially where it concerns the ‘aura’ of technologies, has to include expanding skills, acquiring new ones and learning by doing in order to set a critical perspective. It won't guarantee it but it can be a step towards demystification. It can help to confront the theory to the practice and vice versa. Experimenting hands-on the topic allows for finding issues that were not clearly visible and that could become problems to solve in a research, for instance to improve accessibility. And one could argue that with research investigating materials, practice is in any case unavoidable: “The results turn out the way they have to, according to how the materials and the processing actually behave in action” (Hansen 2013).

Thus, taking a perspective on technologies is not just a matter of being a user or an observer, it can also mean to test ideas and create solutions beyond the conceptual theory.

Then the question prevails of how to consider and design the experiments for this research. What would make sense in this particular case?

Before starting the DDes program, I had already delved into the topic to some extent, while a researcher at Culture Lab, Newcastle University. It allowed me to scope out the field and encounter some of the related work that would drive my motivation, for instance with the works of researchers on interactive fabrication at Carnegie Mellon that open the field (*see image below*). These works gave me a frame of reference for the types of project I wanted to conduct whether to mark the difference of my approach or to underline commonalities. I also ‘practiced’ the topic by building a 3D-printer with two colleagues and created an artwork *White Square Of* that would stage 3D-prints as a visual poem.

Following these first incursions, the DDes program and its timeline gave a tempo for designing and making the experiments: the first year of the program consists in taking classes. In the first semester of the program, I took three different classes at Harvard GSD that each dealt with different aspects of digital fabrication: one about machines and materials, one about general rules of CAD/CAM and one about conceptual architecture and ceramics. They all challenged considerably my assumptions and my skills. It was already late in the semester when I could grasp the tools and the methods that were needed in order to give shape to my concepts. But all the models I did build made for small experiments that started to test ideas about interactive fabrication and odd materiality. I learned what it meant to be a novice in front of 3D modelling and programming tools. I learned a culture, its code, its vocabulary, its rules. I learned that there were immense possibilities ahead of me.

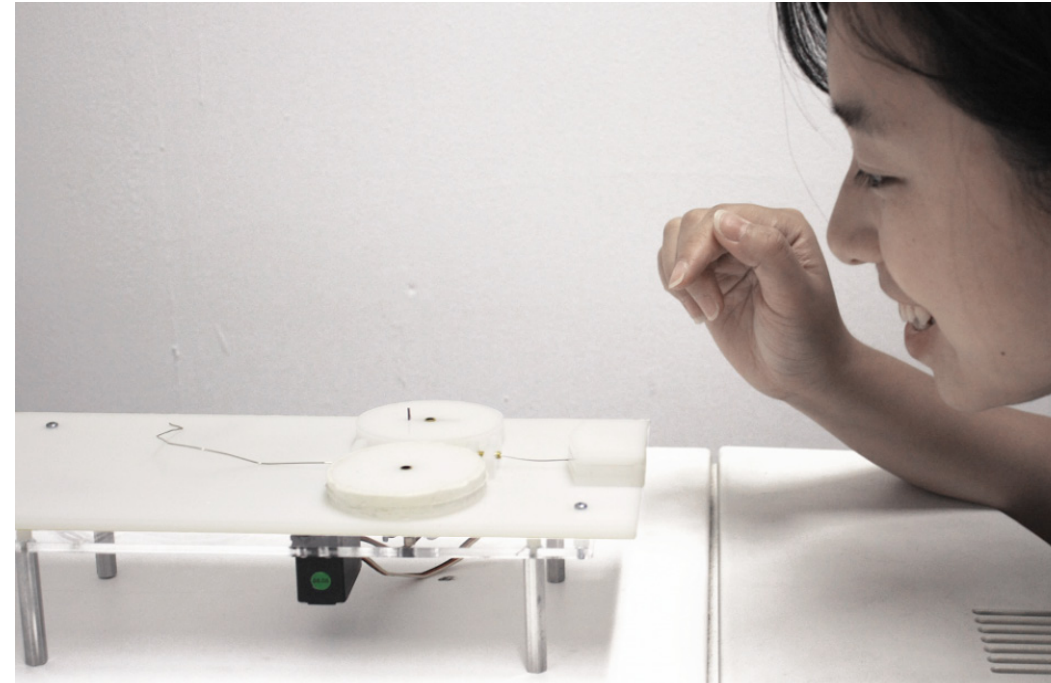


Fig08. *Speaker*, a project by Cheng Xu and Karl D.D. Willis at Carnegie Mellon University. 2010. A machine created to cut the wire shape of someone's voice. Photo sourced at author's website.

In the second semester of the program, I took a break from that intense making phase and took classes that discussed the theoretical framework of the research and helped me pass my general exams. It's only at the beginning of the second year that I came back to fabrication, this time with a more specific aim. The structure of a class would be helpful in order to build the first prototype that was putting to test my vision of interactive fabrication. I applied and was accepted into the MIT class *How to make almost anything* instructed by Prof. Gershenfeld who is an important reference in the cultural context of my research topic. This class and his network of ‘fab labs’ have been instrumental in the democratisation of fabrication tools and in the worldwide distribution of knowledge. For me it was in a way going to the source of the matter itself. The class is set upon the premise that each aspect



Fig 09. Joëlle Bitton, 'White Square Of', exhibited at B&D Studios, Newcastle-upon-Tyne, 2012. 50 objects, printed with a MakerBot over a week, and selected for usefulness and familiarity. Visitors of the exhibition are allowed to keep one of the objects and in exchange write up a title and a description on paper, as well as indicating a new object to be printed off in replacement. Photo George Edwards.

of digital fabrication can be 'handmade', and each week is equivalent to a task for making that aspect: the controller board, the construction kit, the circuit design, the motor control, etc.

A few things prevented my final goal to be fully reached: the intense rhythm of the class doesn't leave much time for reflection, and the weekly tasks might not always serve a final project if it's not very defined from the beginning. It's a class where ingenious concepts cannot be realised every week if the student doesn't already master an important set of skills and therefore one has to settle for showcasing average. But average doesn't work anymore when compared to the productions of other proficient students

that are truly marvellous. The loneliness of the work is horrendous - if group work makes a person feel inadequate, loneliness is making that same person feel helpless, and in that situation it's almost impossible to ask for help, especially when you're made to feel that you should find the answers yourself. When towards the end of the semester, the tasks started to involve heavy programming and debugging, I had little time left to master skills that proved too difficult. Yet, taking this class is an formidable intellectual experience. It doesn't allow much reflection while it's happening, but it certainly does after it's passed. It provides a clear understanding of all functions that are at play within the realm of digital fabrication, and it sets



Fig 10. Initial material research stage for the project 'Pulp Fiction', conducted in the GSD class "Expanded Mechanisms / Empirical Materialisms", Fall 2012. In collaboration with Joe Liao and Sean Canty. Photo Joe Liao.

the path for being innovative and groundbreaking each step of the way. My final project for the class, even though it didn't achieve all I set out to do, taught me the processes I needed to put in place for my future experiments (see details in chapter 5).

Other devices that helped me formulate my experiments are grants applications. In order to build prototypes, I needed money. Therefore I spent a lot of time throughout my program applying for grants. With each application, comes precision. With each rejection, comes disappointment but as well refinement, assertion in the discourse, confidence in the project.

And then came the thesis proposal, where I had to explain why I'm making the prototypes that I'm making. The thesis proposal itself felt like a contrived exercise, forcing a deductive exposé of the topic and a demonstration of its usefulness. It was a difficult process for me to make my reasoning explicit before I started making the experiments. I knew a few things: that I wanted to test human inputs for interacting with a fabrication machine, and correlate them with scenarios. Possible inputs were voice, gestures, movement, physiological data (heartbeat, pulse) and personal data (emails, texts, tweets). I envisioned three large experiments after the small projects I did in my classes that would each test one of those inputs, with a different type of machine, a different level of interaction, a different material and a different setting. The experiences would emerge out of those correlations. Three projects seemed like the feasible amount to showcase the range of possibilities and infer others. By the second summer, after I was done with teaching fellowship work, I could finally have the time and the budget to tackle the first project, *Twipology*. And I was able to conduct two more projects along the way, *Rabota* and *Streamline* (see detailed descriptions and implications in chapter 5 and 6).

Overall, I found that I lacked time and budget to push the prototypes beyond few iterations. I had to accept that they would remain prototypes and not be brought to full completion for public use. I underestimated the resources I could gain with many grant applications rejected. Self-funded research is a trade-off between complete autonomy and project

advancements. It also means that resources for user-studies are particularly limited. Yet I managed to bring each of my experiments to a public setting, sometimes more than once. The prototypes are functional, and can be taken to full public products when the opportunity presents itself.

In general, this note poses the question of the level of achievement a prototype should aim for (Odom *et al* 2016). In some schools that are producing discourses on technology, a proof of concept, a video using actors and staging "what it could be", a model or a probe are just as acceptable and valid to support a theory. While I find these methods meaningful in some contexts, again my position as a designer and a HCI researcher is that the experiment needs to happen, to be 'real', to take the 'possible' to a 'present' for everyday users. But I'm not a scientist nor an engineer, I have to make do as a tinkerer with limited technical skills and with the resources at hand to produce those experiments.

The 'bricolage' stance is a useful one and a creative one, especially for novices and amateurs (Lévi-Strauss 1962) but then it's also not a professional one. A research lab in any case is not an industry nor a start-up environment. The increasing pressure to have for user-studies something good enough to be autonomous and reliable and that can be operated without the constant supervision of the researcher is not on par with the type of budgets or skills that are available in most research circumstances. I expect that this ambiguity will endure for some time in HCI research in general.

In the meantime, the prototypes I built do constitute "part architecture and part knowledge" (Kim & Ibáñez 2015). They're both conceptual sketches and working prototypes. They also suggest "a form of social research to integrate critical aesthetic experience with everyday life" (Dunne 1999). Finally, they made a reality of abstraction.

The Digital and the Material

1. DIGITAL FABRICATION, A POETIC DISSONANCE
2. BITS AND ATOMS
3. INFORMING THE MATTER
4. THE GEOMETRY OF DATA

While the relation between thinking and making can be argued as underlying in all art, craft, design, writing and intellectual practices, digital fabrication infers something altogether of a different nature in its relation between the digital and the physical, where we assume that there's a correlation between the acts of thinking and making and the process of transforming digitality into physicality. Digital fabrication is thus much more literal - something that is hinted at with the term 'rapid-prototyping' used for CNC-machines. It's overall an opportunity to give qualities of time, material, performance, body, everyday life vivid agency and effect.

1. DIGITAL AND FABRICATION, A POETIC DISSONANCE

The expression itself of 'digital fabrication' may offer some indication of a choreography of the digital with the physical. I argue that it also bears some emotional projection at play.

The terms 'digital' and 'fabrication' associated together hold an enticing proposal that superposes a meaning of something usually intangible and shapeless, "the digital" with a meaning of something usually tangible and finite, "the fabrication". Those words are not supposed to go together. But as with most oxymorons, this one has the potential to create beyond the cognitive dissonance, a poetic invitation. 'Fabrication' invites a reliable transformation, a careful process, a workflow, while 'digital' recalls a flexible virtual environment that is typically contained within the realm of networks and screen interfaces, where users are free to imagine and do what they want precisely because this world is not expected to "spill over" into the physical world. Bringing together these concepts is therefore indeed like a dream come true. With the long lost dream of conceptualising things on a computer and see them appear and exist in the real world, in front of us or at distance anywhere in the world, in a relatively short time, and in a revealing process that we can witness, we're a step closer to the fiction within the science.

This chapter invites us to look at the unique specificity of digital fabrication of articulating the digital and the material: the shapeless with the finite, the abstract with the concrete - all the while acknowledging that these notions can be themselves misattributed to one condition or the other. The implications of this articulation are wide and not fully grasped yet, as they renew many classic discourses on technology. In this study, I'm highlighting a few of these implications, brought about by interactive fabrication and related to the interpretation of data with forms, and the geometry of abstract ideas such as memory: how can we apprehend the fabrication and the materialisation of the concepts of distance, time, contemplation? How is abstraction interpreted by digital fabrication? Digital fabrication is a tool for thinking and elaborating concepts and make *some thing* of them:

"The computer has not only transformed the way we design objects, from furniture to buildings. Its impact has proved to be as pronounced, if not more so, on the processes that enable the production of artifacts at all scales. Actually it is the very relation between design and fabrication, and more generally between thinking and making, that is being redefined." (Picon 2014).

The fiction allows us to be carefree, unconstrained and inexperienced unlike with processes akin to ones of a bureaucratic timeframe, where for instance designing and drawing a building is remote from its realisation that is taken care by external contractors over many years.

Yet, digital fabrication is peculiar in its phenomenon. Its wording joins together conceptualisation and materialisation within its understanding. This phenomenon is the relation that this technology allows us to have with the material world. Even more so than with other technologies, this one reveals many things about our constructions of the world (Bitton 1999). Because with digital fabrication, it's again almost a literal condition. Technologies have traditionally been a way to make sense of the world, as they mediate the material world we live in. The specificity of digital fabrication is an opportunity to watch this mediation unfold, to manipulate the real world in more direct, concrete, fast and immediate ways. In her review of the exhibition *Out of Hand: Materializing the Postdigital*, Laura Forlano cites the curator Ron Labaco's statement that takes awareness of the implications: "In the world of art and design, discourse is not longer preoccupied with the technology in and of itself. Rather, interest lies in how technology may be creatively applied in the interplay between digital and analog, natural and man-made, biological and cultural, virtual and real." (Forlano 2013 citing Labaco 2013). The timeframe to conceive, perceive and act is much more condensed regarding the impact of devices and its results. The promise of the future becomes a promise of the present: 'It can happen now'. It's a frontal interpretation of the material world in a sense that digital fabrication is about embracing the physical around us. And now 'it's available at a personal level!'

2. BITS AND ATOMS

Tectonic Bits

Computers gave for a while the illusion that they were not concerned with the real world, but rather with a parallel dimension, a world of bits remote from terrestrial matters - especially around the time that the Internet and the World Wide Web started to become part of everyday life. In many discourses at the time, the 'cyberspace' was then, and still is to some extent, a 'new territory' akin to a uncharted ocean, inhabited by 'hackers', 'pirates', 'trolls' and other barbarians, that needs to be conquered, constrained and controlled; in a publication produced by the Council of Europe, bases on their parliamentary debates, the aim is clear: "[this book] reminds politicians of their new mission: to civilise cyberspace and bind the Internet to the values of human liberty" (Conseil de l'Europe 1998). The 'virtual' territory is still considered dangerous: it's supposedly cutting people from 'reality', from 'real' connections and from 'physical' interactions - the digital world is an illusion replacing the trees, the sky and other humans, fostering loneliness and isolation (Sigman 2009, Melzer 2010).

Without dwelling on the subject, I contend that the separation between the 'real' and the 'virtual' has always been contrived. In 1995, Mitchell was demonstrating in *City of Bits* the extension of the influence of super highways of information on architecture and urban infrastructure. In *La ville territoire des cyborgs* published in 1998, Picon was describing the technological tools that increasingly revealed the cyborg within the human. Others have noted that the boundaries were never there, and it's as if the world of bits has always been lurking about until it was made visible with graphic computing systems. It is also worth underlining the utmost paradox that a software is always bound to a hardware: the computer is a tangible item that damagingly imposes postures and gestures on the human body and that structurally constrains the space that hosts it, even when it's mobile and

reduced to the size of a phone, of glasses, of head mounts or of our future implants⁵.

In his *Material History of Bits*, Blanchette reminds us of all the “processing, storage, and networking stacks [that evolve] as they respond to changes in the material basis of computing resources”. Further, he states: “at their most fundamental, each of these resources deals with bits as physical quantities, whether magnetic polarities, electric voltages, or radio waves. These physical quantities are first abstracted as bits, and circulated up and down the resource stack” (Blanchette 2011). The digital relies on an infrastructure of networks, that when failing is a painful reminder of how much material it is. When a hard drive is damaged, it’s years’ worth of productions gone in an instant - which prompts users now to not only back-up their data regularly, but to double, even triple the same back-up, adding more and more drives to the computer landscape. Cloud services maintain the illusion that the digital is not bounded to Earth - if only with the word ‘cloud’. Their servers are very much down-to-earth though and like all servers, they should never be trusted to be entirely palliative to a data loss risk - not to mention that they are run by profit companies, fated to modify rules on their terms, to censor contents, to delete services as they change ownership or to go bankrupt at anytime (Llewellyn 2010, McDonald 2016).

Of course, there is the question of all the components needed to make a computer, that very tangibly deplete natural resources, as coltan mining in DR Congo and fuel wars and human tragedies. Most of all, it’s power that ties the digital to the material. Energy does need to flow into a circuit so things can operate - the issue of the battery is a favorite of science competitions and of super-heroes comics (Iron Man) or of speculative design (see Auger-Loizeau *AfterLife* project that ‘proposes’ to use human dead as microbial fuel⁶).

There are endless material traces of computation. I can mention another one, possibly the most common of them: the paper printed from computer use, which systematisation has eventually led people to adopt habits against

5 This paradox is of course the very topic of the movie *The Matrix* [1999] that poses that the software [the illusion] takes over the human dimension and yet, the machines are still there in ‘reality’ to make sure the software keeps running, as a diversion for them to draw the energy they need.

6 Auger-Loizeau. *AfterLife*. 2009. <http://www.auger-loizeau.com/index.php?id=9>

the printing of emails. Last, as another detour into etymology, it’s relevant to recall that the adjective digital is itself rooted in the physical world - that of the fingers of the hand on which people would count to ten.

Operational Bits

In this study of interfacing bits and atoms, of fabricating the digital, there is therefore an awareness that the boundaries are not clear to start with. The distance between the digital and the physical is not a given, it’s rather a constant blur, a fine line, an intersection more than it is a bridge, and the blend grows inventive. Furthermore, there are different ways for that intersection to manifest. There are the ‘tectonic bits’ listed above - those that have a structural essence - and there are the ‘operational bits’ taking a more performative part in people’s lives. The ‘digital’ could be accused for instance of proposing a ‘poor’ experience of the world, one that is too convoluted (the body that seats in front of a computer all day) but then it’s also recognized as a tool that enables diverse forms of engagement with the real world and supports communities (Bitton *et al* 2011). The performative condition is growing with a convergence of many uses, innovations and AI research, that distributes the computer everywhere. The digital overflows the physical world that cannot contain it. Drones, parametric architecture and things with Internet are some of the real space invaders (Picon 2015).

That overflow is a familiar topic in the field of human-computer interaction, with research conducted in the past twenty years in ‘tangible computing’ and ‘ubiquitous computing’ among others (Weiser 1991, Ishii & Ulmer 1997). Such fields have worked towards moving usability from the casual graphical-user interface (GUI) of our PCs to tangible-user interfaces (TUI) where the computing system is distributed and hidden: “A good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness” (Weiser 1994). Most of this research thought is only now really starting to reach the mainstream market. ‘Wearables’ for instance or fashion integrating electronic components and computation, is starting to mature (Poupyrev *et al* 2016). Accessible and flexible tools such as Wiring

and Arduino, created twelve years ago for programming circuit boards, have contributed to popularize ‘physical computing’ among designers and artists (O’Sullivan & Igoe 2004). These tools have facilitated the development of projects that could shed their typical ‘computer skin’ and have interactive art. Hybridation is the trend: ‘projection mapping’ uses building façades and built volumes as projection surfaces; traditional board games can be played in conjunction with screen-based versions (Rogerson *et al* 2016, *see also* the hybrid games produced by Les éditions Volumiques⁷); locative and pervasive media turn the city as a playground with GPS, markers and other detection tools (Costanza & Huang 2009). Those are all ways that the digital expands unto the physical, yet not necessarily overtaking it (Picon 2015).

The relation between bits and atoms as such has long been studied at different levels of science and technology, with nanotechnology for instance (Feynman 1960). One of the many actors in the domain, the MIT Center for Bits and Atoms (CBA) run by Prof. Gershenfeld is since 2001 at the forefront of “exploring the boundary between computer science and physical science”⁸, looking at “how to turn data into things, and things into data”⁹. Research includes advances in programmable matters, coded folding and self-assembly systems. What may differentiate the CBA with other research labs with a similar agenda is possibly their educational vocation. The CBA course at MIT *How to Make Almost Anything*¹⁰ has been instrumental in not only setting methodologies for learning and sharing resources, but has also set through the works of students that have taken that class over the last 13 years, many standards, advances in open software, programming languages, circuit board designs, CNC-machines proposals that are accessible online and used around the world.

7 Les éditions Volumiques. <http://volumique.com/v2/>

8 Excerpt from the MIT CBA website statement. <http://www.cba.mit.edu/about/>

9 id.

10 “How to Make Almost Anything” <http://www.cba.mit.edu/>

Another renowned pedagogical contribution of the MIT CBA is the international network of Fab Labs¹¹ that has established a pedagogical and user-oriented approach to the operation of digital fabrication tools (laser cutters, CNC-routers and 3D printers, etc). Fab Labs around the world have supported the diffusion of knowledge of such practices in the society at large, which is an important factor to take into account for this present thesis.

It’s those fabrication tools indeed that make it possible and accessible to shape the physical world, in a very present way. No need for that to look too far into the future. And among those tools, none better than the 3D-printer has enabled us to visualize and comprehend, in an eloquent way, the possibilities of the relation between bits and atoms. The first open source 3D printer, the *Rep-Rap* has in that sense led the way towards the transition to mainstream¹². The science behind the heightened interactions between bits and atoms is leading HCI researchers and designers to envision future applications (Ishii *et al* 2012).

Below is a brief overview of some of the current research in digital fabrication:

Material Growth

One concern relates to the materials that are used, as they ‘grow’ in autonomy and agency: material growth in general, including biomaterials, with the support of computing systems is encompassing many different fields that look to nature as the primary model for growth and sustainability (Oxman *et al* 2014, Diniz & Melendez 2016) (*see images below*). All processes that reinforce the idea as elaborated earlier that there’s a contraction of

11 Fab Lab charter <http://www.cba.mit.edu/>

12 We owe it to Adrian Bowyer and his team at Bath University who have invented in 2005 the first open-source 3D-printer, the *Rep-Rap* and who, as it wasn’t enough, gave it a purpose, that of ‘replicating itself’ - the first machine would print the parts of a subsequent machine and so on (Jones *et al* 2011). This undoubtedly helped the sudden icon-status of 3D-printing and also fomented the demise of the original purpose, with a discourse that was not easy to apprehend [‘a replicating machine?’]. That said, the model is still the reference for most low-cost additive rapid-prototyping machines that are present on the market.

time and of steps between the idea and the manifestation: we could “grow architecture like a plant” (Picon 2014).



Fig 11. The ‘Silk Pavilion’, 2012, by the MIT Media Lab group Mediated Matter, in collaboration with the Wyss Institute and Tufts University. 26 silk-threaded polygonal panels laid down by a CNC-machine and a secondary fibre structure built by 6500 silkworms. Here displayed at the MIT Media Lab lobby. Photo by authors. (Oxman et al. 2014).

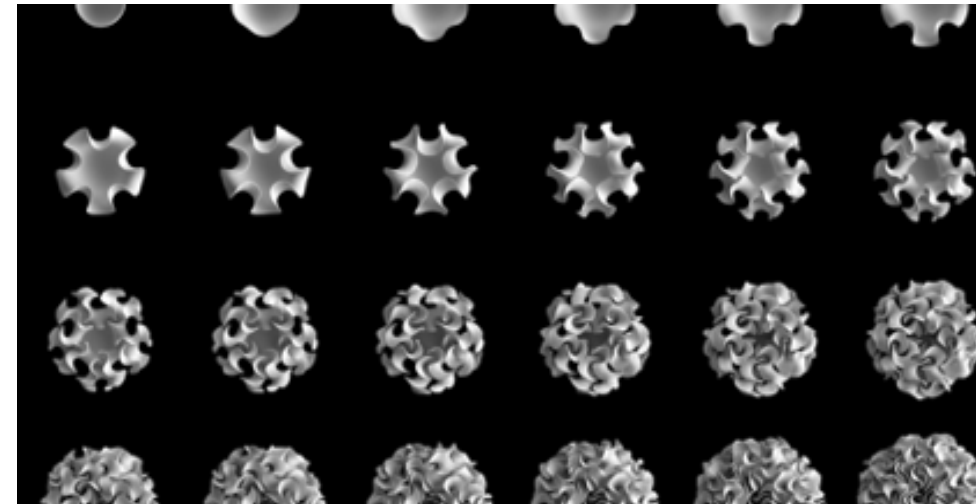


Fig 12. Nervous Systems, ‘Floraform’, 2014. “Floraform is a generative design system inspired by the biomechanics of growing leaves and blooming flowers which explores the development of surfaces through differential growth.” Description and photo by authors.
<http://n-e-r-v-o-u-s.com/projects/sets/floraform/>

Material Properties

Another investigation is the insertion of behaviours in materials *during* the manufacturing process: the project *Steel-Sense* describes the integration of sensors and electronics with additive manufacturing (Vasilevitsky & Zoran 2016); the *xPrint*, a liquid depositing printing system was created to tackle the integration of “multiple materials into one digital fabrication process [...] a challenge with commercially available printing platforms” (Wang et al 2016); the *Cillia* project adds texture to 3D-printed artefacts with a “hair-like structure” (Ou et al 2016) (see image below).



Fig 13. Cillia is a project of the MIT Media Lab group Tangible Media and allows “to 3D print hair-like structure on both flat and curved surfaces”. Description and photo by authors. <http://tangible.media.mit.edu/project/cillia/>

Hybrid Fabrication

Another research field looks at “hybrid fabrication” or “hybrid craft, a method of integrating digital and analog fabrication techniques to augment traditional craft with digital workflows” (Gannon *et al* 2016), applying parametric design techniques to craft (Zoran 2013, Efrat *et al* 2016, Saegusa *et al* 2016) or adding 3D prints to existing objects (Li *et al* 2016). “Existing objects” can mean the body itself, with a robotic tattoo printer or the project “ExoSkin”, a tool for direct on-body fabrication (Gannon *et al* 2016) (*see images below*).



Fig 14. The project ‘Hybrid Bricolage’ conducted at Bezalel Academy of Arts and Design & The Hebrew University of Jerusalem. Traditional embroidery patterns are implemented with a parametric design software. Photo by Daniel Shechter. Retrieved from authors’ paper (Efrat *et al* 2016).



Fig 15. Gregory Petchkovsky's entry in the 'Make It Real' Instructables competition. 2012. A block with a layer of Lego-like bricks is 3D-printed in 'sandstone colour', painted and added to an existing wall. Photos by author, retrieved from <http://www.instructables.com/id/A-sandstone-block-built-from-lego-blending-real-o/>

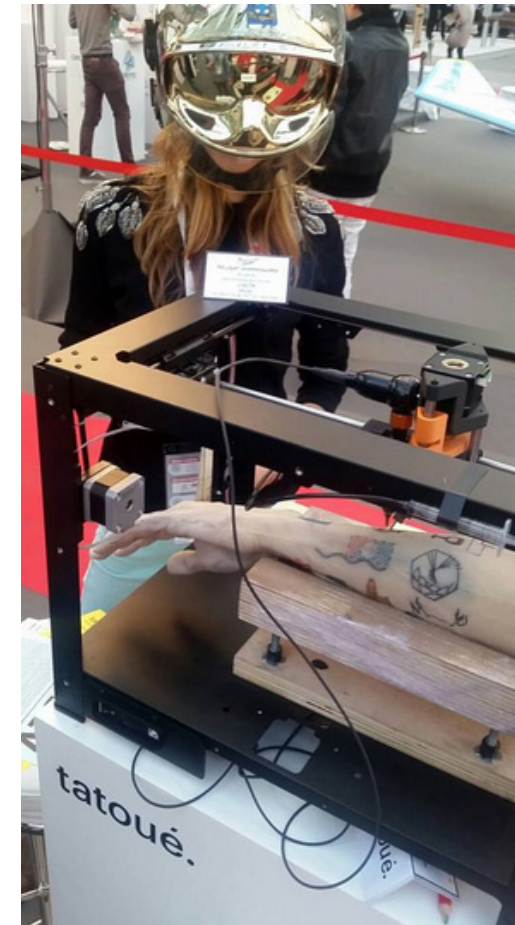


Fig 16. Appropriate Audiences, 'Tatoué', 2013-2015. A MakerBot is hacked as a real tattoo machine. Photo by authors retrieved from https://www.instagram.com/appropriate_audiences/

Transformable Designs

Self-assembly and 4D printing are other fields that look at traditional transformable designs techniques including origami, folds, pleats, weaves, linkages, hinges and shape memory materials to bypass limitations of size, scale, orientation, behavior and costs in digital fabrication (Tibbits 2012, Rosenkrantz 2015, Overvelde *et al* 2016, Ion & Baudisch 2016). Additive manufacturing and subtractive manufacturing are not the only technologies investigated in that matter: laser cutters often prove more creative and accessible and can be used for volumes with flexures, press-fit assemblies and cutting mechanisms (Perumal C & Wigdor 2016).

Machine properties

Machines are studied for their modular property in order to set up a universal system (Peek & Coleman 2016) and mechanisms are explored for their ingenuous dialogue with materials. Andrew Witt's course *Expanded Mechanisms / Empirical Materialisms* at Harvard GSD is unique in that regard, proposing students to conceive of mechanisms in conjunction with materials. Elsewhere, robot arms are consistently tested for the reproduction of the skills and the precision of human gestures such as wheel-throwing¹³ and bending (Bard 2016).

Cyber-Physical Systems

And as an echo to Mitchell's *City of Bits* (1995), cyber-physical systems (CPS) like autonomous vehicle systems and distributed robotics achieve to bring bits and atoms together as a living architecture (Araya *et al* 2012), as an organism responsive to its environment, using for instance swarms system as a model (Biloria & Chang 2012): the "conceptual framework for architecture as an extension of the body is achieved through the implementation of computational tools, sensing technologies, and biofabrication processes"

¹³ The course *Material Systems: Digital Design, Fabrication, and Research Methods* taught by Nathan King and Rachel Vroman at Harvard GSD, Fall 2013, collaborated with potters of the Ceramics Program at Harvard to investigate the range of robotic gestures. <https://vimeo.com/93772684>

(Diniz & Melendez 2016).

This list is, of course, not exhaustive. It's a fraction of the current research related to the increased articulation between the digital and the material. This thesis presents in later chapters other types of work more closely related to the topic at hand. But this selection gives nonetheless an idea of the diversity and richness of the creativity that is inspired by the tools, the technologies and the existing craft.

This thesis is thus concerned with the ways that "properties of software manifest in the real world"¹⁴ - yet in contrast with the specialist research mentioned above, my strategy is to make do with the current tools available and to associate together trivial fabrication processes and personal data: this is a research aimed at the mainstream, the domestic, the everyday life environments. It means as well using familiar tools - quantified self sensors and social networks - and repurposing them as data for CNC-machining.

3. INFORMING THE MATTER

This stance is an opportunity to reflect on the implications of articulating form and matter. Heidegger already established that the hylomorphic outline of Aristotle was overlooking the allure of things, that a thing is not *just, only, necessarily* a function (a form) imposed onto a matter (Heidegger 1958). Simondon went further to suggest the idea of 'negentropy' to explain individuation: it's an energy, a information that transforms chaos into order, hence forms a matter. The outcome is never completely stable because of that movement, that transduction (Simondon 2005). The matter, in the end, could be everything and nothing, and in all the stages in-between.

A popular metaphor used to describe that flux, that movement, that

¹⁴ An expression of HCI researcher Scott Hudson mentioned in a conversation. May 2016.

flexibility of the matter is the ‘fold’. The fold is what makes humans nuanced, what makes nature dynamic and organic, and what reveals the matter. Deleuze defines the fold as the operating mode of the system that Leibniz described three centuries before (Deleuze 1988), a system that acknowledges nuances and variations while finding the least action for achieving the best results, the system of optimisation.

I would argue though that there’s a contradiction in Deleuze’s proposal that would tend to focus mainly on the fold of Leibniz as an agent of ‘baroque’, of sensory experience, of vitality and of tension, a rebellious gesture, while he overlooks too quickly that the system of Leibniz, the purpose of ‘optimisation’ might mean the very opposite of that abandon and instead constitute a signifier of order and harmony, the best of the possible, the chaos resolving to fold and surrender. It’s possible that Deleuze was thriving for an open system and unleashed a closed one instead.

Deleuze’s exposé found a great echo in the field of architecture, adopting the metaphor of the fold (Lynn 2004a). Curves were eventually adopted as the literal graphical representation of the fold process, the inflexion (Carpo 2004), yet they bear the same Deleuzian misunderstanding that they are also an expression of freedom and liberation. But evidently, the opportunity of applying principles of calculus to design and fabrication has been for the most part seen as the surest way to precision and optimisation: “Happy accidents and automatic processes are certainly the precursors to fine grain, detailed, continuous compositions as well as continuously variegated forms. (...)The intricacy of a calculus defined collection of elements in space evokes a particular kind of cohesion, continuity, wholism and even organicity” (Lynn 2004a). In a sense, this quote shows that it’s fine for a society to embrace tension, accidents and vibration as long as we make sure that the end purpose is ‘order’ and that a law of change is still a law of order.

That said, if we forgo the fold as the expression of an organisation with a purpose, it’s still a valid metaphor for that that reveals matter, almost to itself, as a surprise of what it can be and become. The fold as the operating mode of an open system that does not look for a reason could be used as the metaphor of a flux that can determine itself and in the journey be altered by many occurrences: random ones, accidental ones, intuitional ones, technical ones and purposeful ones. An open system thus doesn’t mean absence of

purpose. It could have a purpose or expressively not have one or not state any intention in that regard. The open system lends itself to appropriation and misappropriation and acknowledges that this is not only inevitable, it’s salutary: the intention, the design, per se might be operational to some degree but it cannot control all the aspects.

“En signifiant à l’écrivain de “céder l’initiative aux mots”, Mallarmé a retourné la littérature. Cette formule incite en effet l’écrivain à ne plus se plier à un sens déterminé au préalable pour se laisser au contraire guider par les caractéristiques même du langage [...]. Alors déduit des propriétés formelles mises en œuvre, le sens n’est plus cette autorité que le texte classique se devait de servir”¹⁵ (His 2015)

The flux is then an ensemble of information that operate the system. My thesis affirms the information as the element that mediates the form and the matter, literally the *in*-formation. It makes all the more sense in the context of technologies of information and of data traffic, even more so than at the time that Simondon elaborated his theory, strongly influenced by modern thermodynamics and the emergence of quantum physics. Yet, I don’t see the “information” as a single input coming into the matter as a complete separate entity - the data is only part of that information.

The information is also coming from the material and from its agency (Malafouris 2008). There is indeed feedback from the material as well: how does it want to behave? what does it want to be? And the material changes over time as well, with possible of phenomenons of erosion, sedimentation, decay, etc. Time is part of the information. And again so are chance, intuition, errors. The information is embedded in the machine, in the *techne*: the operator.

¹⁵ In telling the writer to “yield the initiative to words”, Mallarmé turned over literature. This formula incites the writer not to comply with a pre-determined meaning and on the contrary, to let herself guided by the very characteristics of language [...]. Then, deducted from the formal properties implemented, the meaning is no longer that authority that the classic text had to serve” (trans. by author).

There's also the machine akin to the Deleuze and Guattari "slicer", more a mechanism of desire and of drive, than a machine per se: the matter is a continuous flux and it's the machine that gives it shape as it slices into that flux. "*Toute machine, en premier lieu, est en rapport avec un flux matériel continu (hylè) dans lequel elle tranche*". (Deleuze & Guattari 1972-1973:43).

And of course, there's the information that cannot be known, predicted, that one of the human environment that receives the formed matter. About the experience of his artwork, Olafur Eliasson stated in an interview with Caroline A. Jones: "the first challenge is to embrace . . . the kind of stored production of reality that [the] viewer always carries with him" (Jones 2007). Jones comments further on Eliasson's thought: "The contemporary obsession with experience or „relation“ is empty, without attention to the murmur of uncertainty, doubt, confusion, information, and reorientation by which the body summons its representations of the world (its self)" (*idem*).

Finally, there's another category of information, that is not clearly distinct, that hides (Hui 2014), that is not visible yet, not fully intelligible and might pertain to love: the love of things, of details, of textures, of surfaces, the appreciation of things, maybe a perception of their aura.

For Derrida, talking/writing about matter ("la matière"), means also making matter, creating matter, manipulating it, informing it (and I would add - loving it). So when Derrida talks about the paper material, *he puts the paper flat* ("à plat"): he's unfolding its meaning and sets the topic about (Derrida 2001). A process very much at play in this thesis altogether. The *in-formation* of the matter is therefore a process of inscription, of writing, of *graphein*. And by that, I mean that the process of inscription implies the production of a materiality: an articulation of a thought, of an idea, or the narration of a story or the capture of a moment, an event *as it's* being recorded, edited, formatted... leaving a tangible trace that cannot be erased once it's inscribed, written.

"La machine à écrire est une des formes matérialisées de la pensée, elle permet d'automatiser l'écriture estampée sur le papier, sur le cerveau pour

communiquer le mémorable"¹⁶ (Kherbache 2008).

There are of course many forms of writing, of *graphein* beyond text that correlate a thought, an abstraction, an event with a process and with a machine, a technology : *cinematography* writes and records movement (etymologically), *photography* writes with light and records images, a *phonograph* or *gramophone* writes sound, *labanotation* or *kinetography* writes dance movements, etc. They can manifest a narrative or tell a different kind of story of knowledge. They develop a language that expands with grammar uses, trials and errors and repetitions. Investigations into recording all sorts of concepts have led to a countless range of materialities, that keep being revisited. The studies of motion by Marey and Muybridge for instance have been influencing painting, dance, interactive art and recently digital fabrication with *The Art of Motion*¹⁷ and with *ChronoFab* (Habib Kazi 2016).

In another field, the studies of motion by Frank and Lilian Gilbreth have influenced the Taylorist division of labor. And the cinema influenced, well, pretty much everything of our reality and the way we live it too. Artefacts that are the records of these interactions take sometimes the shape of the information: such is the vinyl record. The name in French of the most famous format, "33 Tours" (rotations) exposes the form of the data (33 1/3 revolutions per minute). It's no coincidence that one of the first 3D-printing art projects to gain an iconic status is Amanda Ghassaei's vinyl record, as a self-referential statement to its own origins (*see picture below*).

16 "The typewriter is one of the materialised forms of thought, it enables the automatised writing on paper, on the brain to communicate the memorable" [trans. by author].

17 A work by Saraubh Matre for the Harvard GSD J-term class 'Quantified Self and Fabrication', conducted by Joëlle Bitton & Kevin Hinz. January 2015 (see in later chapter).



Fig 17. Amanda Ghassaei, '3D printed record', 2012. Photo by author. Retrieved from http://www.amandaghassaei.com/projects/3D_printed_record/

With these examples, I suggest that the movement and the energy of that process of *in-formation*, of inscription and its production of materiality can be movements pertaining to the emergence of design, art, creativity. In other terms, the process of *in-formation* can be that as well of making meaning, making sense, making worlds.

As mentioned in the introduction, Flusser considers that design is itself the imposition of form on matter. Myron Krueger sees "the artificial reality, [as] a whole new realm of human experience in which the laws of cause and effect are composed by the artist" (Turner 2002 *citing Krueger*).

"Materialization could sometimes seem incidental - yet materialization was exactly what the artist could bring: a way to make research come alive

as experience in the body of the viewer", Jones says of processes of modern and contemporary art (Jones 2007). She questions Eliasson about his artistic research: "the translation from thinking into doing is the radical thing". She implies in summary that art and science, affected by modern forms of labor and machinery, were able to "reach new planes of conceptualization, and demanded radically new receptive frames. They drew on earlier machinic ways of being (machines for living [Le Corbusier] and readymade desiring-production machines [Duchamp via Deleuze and Felix Guattari]) and became in the postwar period the „large business“ machines of particle detectors (physicist Luis Alvarez), „mechanical means“ for mass image production (Andy Warhol), „executive“ artists' serial modes (Frank Stella), and eventually even ideas as machines for making art (Sol Le Witt). The machine was more than a metaphor. It retooled the producer and the receiver. The concept of knowledge production is thus useful only if it can capture these discursive dynamics, by which the „object“ of art or science is nothing less than the local „subject“ making meaning: of experience, of data, of sensory phenomena, of the broader social field" (Jones 2007).

CNC-Machines should be added to her list.

In this research, it matters to stretch out the ensemble of information that I'm working with and how the components relate to one another. Digital fabrication is unique in that it's already, as presented earlier, a proposal of articulating bits and atoms, the code and the matter. The applications though are usually responses to problems. Here, I'm investigating instead ways that this formulation can capture, write and record things of a different nature.

Abstractions such as 'time', 'network' or 'intimacy' can be 'measured', 'sensed' and 'stored' with a set of tools that transform them as data and 'bits' and fabrication processes can then transform these bits into tangible items. As a synthesis of these notions of 'informing the matter', this research puts forth the idea of '*datagraphy*' as a form of writing, the use of data for datagraphic narration, as data encounters different machines, materials, humans, cultures and a system of chance, intention, knowledge and confusion.

4. THE GEOMETRY OF DATA

Accumulation

The term ‘data’ expresses something rather particular: an obviousness that becomes apparent when labelled. It’s what is, it’s a ‘given’. The etymological root of the term data is ‘given’, and is also the French term for data, ‘*donnée*’. Interestingly, the word ‘*donnée*’ exists in English in the context of storytelling, as a set of assumptions or conditions that informs a narrative. This implies that ‘data’ includes a component of time (and that data gets substance and character over time¹⁸).

Anything can be a ‘given’, it just needs to be acknowledged as such. It’s ‘out there’ but it’s not ‘there’ until we look for it and capture it. As Richard Feynman elaborates: “Nature does not know what you are looking at, and she behaves the way she is going to behave whether you bother to take down the data or not.” (Feynman 1963). Data is usually noticed when it’s plural, an accumulation of itself: a dataset that has formed furtively, such as weather records for 100 years or thousands emails collected over the years, or terabytes of files that fill up a hard drive. Or possibly, we consciously register the first occurrence of an event and it’s the beginning of a collection, like our daily steps. In either case, data makes sense when it’s measurable, assessed, mined. Patterns can then emerge. And maybe it will tell a straight story. More likely it will relate a fiction, a fallacious interpretation. The logging tool that we use for recording the data will play a role in that matter, it often comes with its own interpretative bias, whether it’s a notebook, a spreadsheet or a fitness tracker.

The term ‘*data*’ thus come to infer an ensemble that comprises notions of collection, measure, registration and storage - an operative factor in the case of this research. It’s also now assumed that the data is always digital: recorded and/or measured and/or stored by computer means (something

that we still need to specify in French for instance: ‘*données statistiques*’, ‘*données numériques*’, etc).

Datasets and databases of all kinds have long been mined to correlate habits and behaviours and to ‘predict’ the future. Sumerian and Egyptian mathematics, among the oldest forms of mathematics, are said to have been invented for the management of land partitions, trade and taxation, and thus for anticipating agricultural fluctuations. Today, data is the new currency upon which companies like Google and Facebook flourish (Eggers *et al* 2013). It’s our data that we trade as a currency for being able to use “free” services. But we’re oblivious to the algorithms and to the results that process and interpret the data, and to who makes use of it. It’s become an instrument of power: the data that is accessible by all citizen with open data programs, the data that is kept hidden, the data that is sold, the data that is leaked...

Of course, with the increasing capacities of computation, the more we can capture and store data, the more it accumulates. We’re now overloaded with data. This accumulation tends to exceed our capacity of measurement (well, we build more efficient computers for that, and in an infinite loop, we can capture, store and mine more and more data, more efficiently).

The data doesn’t take *that* much space yet - at least that we can apprehend at an individual level. On the contrary, it seems to be even less apparent with smaller, thinner instruments and cloud services, and with unassuming data centers hiding among us (Wiig 2015) (*see picture below*). Yet, as mentioned earlier, the data spills more and more over the physical world: the data centers are growing, now constituting autonomous provinces. The data is also blatant in how it’s used in our daily lives for monitoring ourselves, our friends, our society.

18 The etymological root of ‘given/data’ is also ‘date/time’.



Fig 18. A data center in Philadelphia. "A closed United States Post Office on the back-side of the Terminal Commerce Building. (...) The transmission of information in and out of the building has always mattered, even when that movement was paper-based and involved the post office. February 2011." Photo and description by urban geographer Alan Wiig. Retrieved from Wiig's research blog <http://www.everydaystructures.com/>.

In this complex context of data collection implying forms of currency, surveillance and accumulation, my research is in part a proposal for users to take notice of the data they produce and make use of it in a creative and playful way. But my research also acknowledges the *already existing* forms of creative uses of data. When users 'curate' content on their Instagram page, or Pinterest wall, or Soundcloud list, they do relinquish the ownership of the data and the choice of the visualising interface to the operating companies, but they most certainly tell stories as well in the process of mining and

selecting their own data.

Making sense

Making sense of data is indeed a process of logging, collecting items and curating a list. The logging sets the condition for the curation. For Dietmar Offenhuber, researcher on accountability design, "data collection holds implicit meaning" (Offenhuber 2015). A list is a composition, a rhythm, a narrative, a way to organise the world, to keep life under control. It puts order in the chaos (akin to the Simondon's negentropy), it states the ontological categories of things in our world. A list can be generative, descriptive, a collage, a classification in order of importance, etc. It's a cataloging interface, and a process of writing, inscribing, accounting at once (Bitton *et al* 2004).

Such is what Eco describes and praises in *The Infinity of Lists*, itself a list and the catalogue of an exhibition he curated at the Louvre (Eco 2009). Eco underlines that the list can be both an instrument of control and an instrument of knowledge, at the heart of civilisation. He dismisses casual lists too quickly though, those that are shopping lists and "practical lists", too 'finite' in his view. He favors the poetic lists that are boundless and endless, possibly out of concern for 'open systems' (Eco 1989) - but he fails to notice that a shopping list can be just as poetic and open as any other. He may also have too literal an approach to what constitutes a list when he excludes sculpture: "It is hard to imagine a statue that conveys an '*et cetera*', *ie* one that suggests it may continue beyond its own physical limits.» (Eco 2009:37) It's surprising that he overlooks the subtleties of *gestalt* or monadology, or other ways of looking at a whole as made of infinite parts.

But the art of looking is everything indeed. In her book, *On Looking: Eleven Walks with Expert Eyes*, Horowitz shares a walk with field naturalist Charlie Eiseman as he quotes his tracking teacher: "Half of tracking is knowing where to look, and the other half is looking." (Horowitz 2013).

In a raw dataset, looking often means selecting an angle and representing what is seen. This is how the field of data visualisation makes sense of data, by revealing patterns. The issues pertaining to data visualisation are not our

focus here, but it's worth underlining a couple of points: for the most part, data visualisation *adds* information in the process of representation. It can add complexity to understanding the data, or facilitate it (or both at the same times), or not care at all. The second point is that visual metaphors will be used as a way to engage viewers. The London Tube map was designed for instance after an electric circuit and since became the standard for us users to navigate a transport network.

Graphic standards have been set over time, aiming for a common visual understanding, vaguely universal (even though there's no guarantee that the standards are followed). In parallel, the rise of computation has triggered a very rich and unconstrained graphic language, that can attribute any sort of visual meaning and value to data.

This consideration matters in the case of this research: it brings about the correlation of data with geometry. It's not exactly the same concern that data visualisation has, bounded that it is by the usual 'placard' mission underlying it. With digital fabrication, geometry is the expression of a relation. Diagrams in that sense are possibly the closest analogy. They have a long history in the field of architecture of encompassing meaning with the representation of data in a drawing. It's become its own craft, a way of contemplating complexity and appreciating it at the same time. But diagrams and data visualisation outputs are still each time their own statements. It begs the question of the geometry *within* the data: what can the data reveal of its own geometry? Does it have one to start with?¹⁹ The experiments I conducted all faced that issue, but the project *Twipology* in particular was a direct comment on it (see image below). Usually, in digital fabrication, purposes of precision will guide the choices and the shape grammar (Stiny 2006). With *Twipology*, on the contrary, the space is created through some "intuitive parameterization of the data by the designer"²⁰. The resulting "imprecise use of the space" could explain "why *Twipology* is a seductive landscape"²¹.

Gramazio and Kohler note an opportunity of a resembling nature: "[the computer] motivates a designer to exploit the human potential for associative thinking in order to discover new organizing principles, and establish new relations with the built environment. (...) *Digital materiality* leads us from the design of static forms to the design of material processes. In doing so we give up geometry, whether drawn or modelled, as architecture's actual

19 The study of writing systems, with graphemes, alphabets, logograms presents an infinite range of explanations for each representation: sound of words, ideograms and pictograms (Hanzi) management system (Braille, Morse), etc.
 20 Comment made by Jonathan Gringham, peer in the DDes program, March 2016.
 21 id.



Fig 19. Electric draughtsman Harry Beck for London Underground designs a Tube map based on electrical circuits diagrams. 1933. Transport for London.

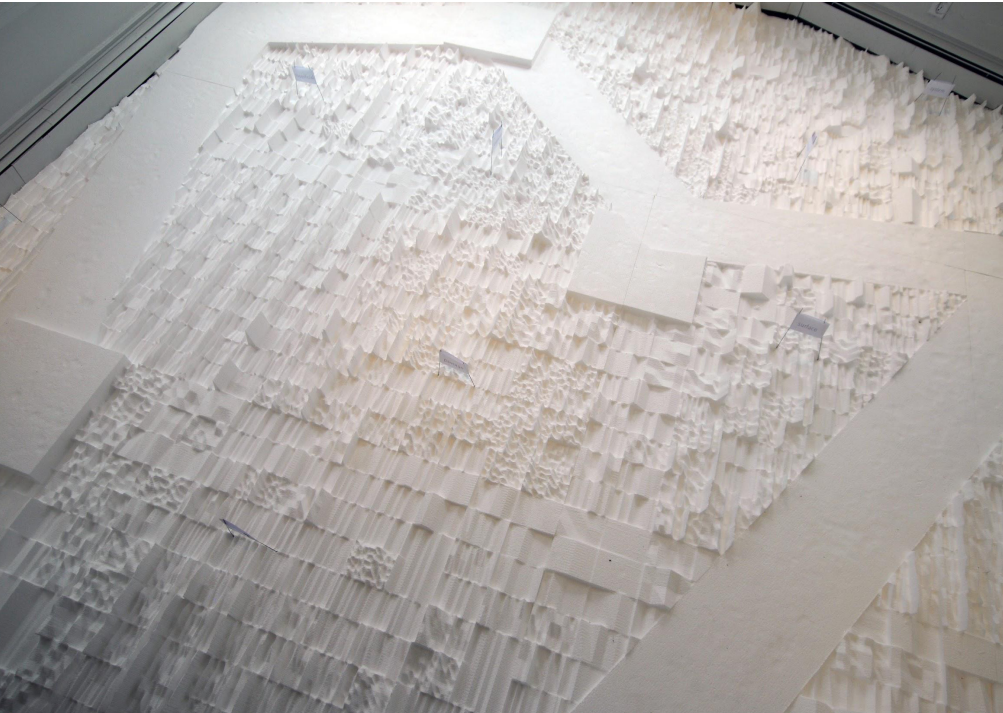


Fig 20. Joëlle Bitton, "Twipology", 2014-2015. Exhibited at fortyk gallery. View from top. 1000 Twitter feeds are collected according to 12 different hashtags and generate together a 'garden' landscape.

building plan and its primary basis for design decisions. Instead, we design the relationships and sequences that inhabit architecture and that emerge as its physical manifestation" (Gramazio & Kohler 2008). Yet, I would argue that if there's indeed a possible desertion of geometry, it's a mere illusion. The design decisions made, how unrelated they are to geometry to start with, end up having to be reduced to it, just like in a diagram.

A Measure of self, a care for self

Data enables action. The visualisation mentioned above, the making sense are often driven by assessing a situation for the purpose of changing it. It's a process of optimisation which relies on measures of reference to decide "what's best in a set of constraints" (Radford & Gero 1988:309), often with nature as a model to emulate. It's providing rules so that compromises and decisions can be made according to the data. Computation systems can enable some of these changes more or less in real time, which make things 'smart': a temperature sensor could change the heat in a room immediately, a basic feature among many more complex energy strategies.

Monitoring is thus an incentive of change, a measurement for a mutation of sorts. Possibly, a phenomenon akin to the 'observer effect' in science, where observation affects the observed. In his conversation with Ackermann at the *Data Across Scales* conference, del Castillo y Lopez pointed that in quantum theory, "the act of measuring a particle changes the particle" (Ackermann 2015) : it's the premise/promise upon which quantified-self tools are permeating the market. Ackermann reminds us of Socrates' statement, that "the unexamined life is not worth living" which we can now take at its word (Ackermann 2015).

The newfound accessibility of tools that used to be restricted for medical use and neuroscience studies, adapted for the general public and made available 'off the shelf', is only starting to show its potential for the re-appropriation of one's health and of one's journey in life. Evidently, this aligns with tendencies for assessing ourselves as performers in a competition, where we give ourselves good points and bad points, reinforcing assumptions we may have of what a good behavior is, internalising "the carrot and the stick mindset" (Ackermann 2015). With our self-tracking and self-surveillance systems, we keep ourselves in check indeed, accepting and even assisting the multiple and diverse forms of external surveillance and regulation imposed on individuals - the repeated enactment of "docile bodies" that Foucault described (Foucault 1975). Not to mention the tacit surrender of the data with the companies that sell the products.

On the other hand, that mode of "*subjection*", the capture of self

sensory data, is most enticing for exactly the opposite, as a process of “*subjectivation*”, the constitution of one’s identity that Foucault sees as the ethical path to freedom. At the root of the ethical work is the “care for the self” - in French “*le souci de soi-même*” from the Greek *epimeleia heautou*. The “care for the self” is threefold:

“- *premièrement, le thème d’une attitude générale, d’une certaine manière d’envisager les choses, de se tenir dans le monde, de mener des actions, d’avoir des relations avec autrui. L’epimeleia heautou, c’est une attitude : à l’égard de soi, à l’égard des autres, à l’égard du monde.*

- *deuxièmement, l’epimeleia heautou est aussi une certaine forme d’attention, de regard. Se soucier de soi-même implique que l’on convertisse son regard, et qu’on le reporte de l’extérieur, sur... j’allais dire « l’intérieur ».*
(...)

- (...) *L’epimeleia désigne aussi toujours un certain nombre d’actions, actions que l’on exerce de soi sur soi, actions par lesquelles on se prend en charge, par lesquelles on se modifie, par lesquelles on se purifie et par lesquelles on se transforme et on se transfigure. (...)*²² (Foucault 2001).

22 “First, the theme of a general standpoint, of a certain way of considering things, of behaving in the world, undertaking actions, and having relations with other people. The *epimeleia heautou* is an attitude towards the self, others, and the world; Second, the *epimeleia heautou* is also a certain form of attention, of looking. Being concerned about oneself implies that we look away from the outside to... I was going to say «inside.» [...] (...) The *epimeleia* also always designates a number of actions exercised on the self by the self, actions by which one takes responsibility for oneself and by which one changes, purifies, transforms, and transfigures oneself.” (trans. quoted from Foucault, *The hermeneutics of the subject : lectures at the College de France, 1981-1982*, Palgrave Macmillan, 2005).

Foucault underlines very well in the exposé of the ‘care for the self’ how it’s too easily perceived in our moral society as an expression of selfishness and narcissism - something that current judgements passed on the practice of ‘selfies’ for instance show adequately. But the care in question takes work that induces transformation. And it operates with actions and practices, various techniques of self-investigation. Foucault names them “technologies of the self” (“techniques de soi”). They are “technologies of the self, which permit individuals to effect by their own means or with the help of others a certain number of operations on their own bodies and semis, thoughts, conduct, and way of being, so as to transform themselves in order to attain a certain state of happiness, purity, wisdom, perfection, or immortality.” (Foucault *et al* 1988:18).

Among them, are *hypomnemata*, written notes, accounts, records of memory: the very same logs that were addressed earlier in this chapter. In that sense, logging is marking the first traces of oneself’s presence. In the context of this research, it’s literally a conjoint process of form-finding and form-making (Laiserin 2008).

Traces

Foucault’s *hypomnemata* are of course creative acts. They’re techniques/ arts of self/of life, something to make one’s life a work of art. The logging, collection and mining of our personal data are invitations for creativity. This research suggests that we can play and experiment with our own personal data other than using it for evaluating our performance *at* life. There’s something intimate and intense about using the data that we generate ourselves, that comes from our daily activities and our own bodies. It’s also data that we have at hand, now, immediately. That we should visit and explore the same way we explore places.

Recent research projects invent novel tools and systems for exploring the data that we’re producing without being fully aware of it: genomic data (Shaer *et al* 2016), work breaks, time spent on internet (Epstein *et al* 2016),

archives forgotten in stockage (Daisuke & Odom 2016), etc. The quantified-self tools become themselves objects that we live with and that we abandon over time (Kim *et al* 2016). And objects are now more than metaphorical extensions of our selves - embedded with computing, they're alive with information, they can be tracked, and become "accountable artefacts" (Benford *et al* 2016): they may "serve as memory objects, helping us construct our identities and self-histories, or as narrative objects, enabling us to tell stories. Their records will enhance their economic and social value, support provenance and extend their utility" (Benford *et al* 2016).

As opposed to the intent of data visualisation and the purpose of optimisation that we've seen earlier, there's an opportunity here to keep and highlight, at least in part, the abstraction nature of the data material that we're sensing - embracing the absurdity of it. Emails or Twitter feeds are thus peculiar entities. The web itself is a bizarre collection, the database of all databases. And the APIs that allow anyone to have access to those sets of data and to mine them unleash infinite possibilities. Other examples than *Twipology*, the '*Pulse Project*' uses pulse reading for a drawing performance (Lewis-King 2016); the project '*Metadating*' made use of personal data as a way to have people actually dating (Elsden *et al* 2016). These projects and others announce very inventive ways that data sensing is interpreted in the material world. With CNC-machines, the opportunity is clear: since the machines are controlled with numbers, it's as well that the data that's used for that could directly come from human activity, in a staged interaction. It's a feedback loop on subjectivity.

Real Machines

1. L'IMAGINAIRE
2. DESIRES OF FABRICATION, DESIRES OF AUTONOMY
3. A TECHNOLOGY OF THE SELF
4. MACHINES IN THE DECOR OF EVERYDAY LIFE
5. THE ART OF CONTROL

1. L'IMAGINAIRE

As described in the previous chapter, digital fabrication is unique in its proposal to interact with the material world. It encompasses in its meaning both a technology and a process. That of machines controlled by a computer system (CNC-machines) and that of what is related to the act of thinking, designing, making, bringing tangibility to our imagination.

Part of this research consists in unfolding what is at play in that synergy. When thinking and exposing technology, it's necessary to take into account the projections that are made onto it, because since the scientific revolutions of the 17th century, there is a bond between the 'destiny' of humans and the technology. In a feedback loop, science fiction exposes a world with "problems that wait for 'real' scientists to resolve"²³. As if technology was always bound to be the expression of a human project. According to Heidegger, technology becomes itself the manifestation of metaphysics in that it determines the conditions of our being and of our becoming (Besnier 2014). Often misunderstood, as an applied science that we can use without having to know how it works, technology invites ambiguities. And

even when its 'mystery' is revealed, it keeps some of its magic. Discourses, uses and inventions are intricate in the assumptions we have, for each one is made to say something about our society, our culture and our identity. Innovations come to challenge our habits and methods, as annoying or welcoming tricks. But in the first place, technology is an object of transition between freedom and imprisonment: it often escapes control - at least in its premise - and therefore it often possesses within it a proposal of freedom... that is until it's crushed by external forces of authority such as a government or a corporation. That evocative power of technology is demonstrated and reinforced by most storytelling of genesis and liberation from the myth of Prometheus to the modern superheroes. Technology talks to our imagination at all levels of our desires and anxieties. It's evident that thinking the 'radicality' of these technical objects is also thinking the imagination that these objects develop (Besnier 2014).

What do I mean by imagination? In French, the term is 'imaginaire', a word that reads more like an anthology of our cultural references. It differs slightly from the common use of 'imagination' in English, more related to notions of 'creativity'. 'Imaginaire' can include thoughts, desires, dreams, assumptions, visualisations, associations, popular culture references. For instance, if I write the word 'Timbuktu', what comes in the mind of the reader? Possibly about a dozen meanings that don't belong together in the same world, that may be contradictory with one another, with some that are not grounded in the reality of Timbuktu itself or even related to it at all. The direct translation term in English to 'imaginaire' is 'imaginary' and is used as an adjective, meaning 'fancy' or that 'that does not exist'. It's thus unsatisfactory to use it as a noun. 'Imagination' and possibly 'imagery' are still the best options for translation as they can refer to the projection of our mind onto meanings.

The impact of a technology can be very real for an individual but also triggers a general collective impression that may conflict with it, as literature will reflect, as in the writings of Jules Verne. Imagination can be indeed a collective attribute that opposes an individual project and vice-versa, a regular feature of technological tales. A technology can comfort, disappoint

23 Comment made by science-fiction sociologist, Julien Wauquez, April 2016.

or disrupt the imagination according to the contradicting expectations that a community has and that the engineer, the inventor, the designer, the users, the regulators have (Besnier 2014). As mentioned earlier, there is the human project at stake. What are the expectations that we have for our human condition? The ‘imaginaire’ as reflected in discourses tells in the end much less about the technology itself than reveal the human project of their authors. This in part can explain why technologies are so polarized within the hope/fear passionate rhetoric.

When I use ‘collective imagination’, it means that we share these cultural references as a society. I infer that the society of this study is mostly Western as it shares common foundation myths and literary references, although they’ve been evidently influenced at all stages of history by stories and philosophies brought from all over the world and have as well been absorbed by other local cultures. The relationship between technology, philosophy and craft in a country like Japan is for instance both a major influence in pop culture as well as an exposé of global exchange (with the story of *Godzilla* for instance). I have dedicated a specific study to the relation between technology, networks and the construction of nations and communities (Bitton 1999). Similarly, even though I won’t address that topic directly here, the geopolitical stakes behind innovations, the competitions between countries, the uses of technology for imperialism and colonialism and the considerations of postcolonialism are always hiding in the background as staples of such discourses.

Then, one of the main drivers of imagination is the fascination itself that exists with all technologies (again the use of an applied science that we don’t need to understand and that awes). As we’re investigating the imaginary quality of digital fabrication in particular, we’re reminded that as with the Internet twenty years ago, we are faced with a technology that impresses. Technologies that impress are akin to magic, and often promoted as ‘miracles’ as a way to garner attention and funding. Long before Steve Jobs, Thomas Edison would present his work in wonder shows (Nadis 2005). These technologies are things that we read about in science-fiction tales, that we hoped could become real, but that are not supposed to become possible,

and one day they are. For a while, we are not used to them yet and they keep impressing us... until we use them casually and we’re accustomed to them ‘being there’ and the next generation is not even aware of a time when they were not around. Trains, electricity, telephones, cars, computers are now part of the everyday decor (Noiray 1982), we are *blasé*, taking them very much for granted.

For the ‘digital natives’ generations (Palfray 2008), it’s hard to imagine the types of fantastic headlines that the Internet made not so long ago, just like 3D printers do today and have been for the past six years in a repetitive mantra. The term itself “3D printing” is itself an enchanting expression: it’s printing in 3D! Somehow, the terms ‘laser cutting’, ‘CNC-milling’ and ‘CNC-routing’ don’t have the same miraculous imagery, even though these processes are likely to be more diversely used by makers and more impactful over time. The term ‘3D printing’ is also a useful metaphor for conveying meaning and process to a non-expert audience by associating two very familiar terms together. It infers the notion of ‘realness’ (3 dimensions as opposed as the flat 2D stuck behind a screen) and the notion of ‘instant marvel’ (“it’s happening”, “it’s coming out from somewhere”, “it’s just as easy as using my inkjet printer”,). The 3D printer is set if just by its naming convention to be an icon, a tip of the iceberg for a much richer ecosystem of fabrication technologies. The fact that ‘real’ things can be produced from a digital file yet presented as if they were coming out of the computer belongs to the domain of miracles that rely on instantaneity and substantial apparition. It relates to the domain of superheroes and witch powers with abilities to control the physical world, to manipulate and extend the physical properties of objects, bestowing them with behaviours. Not to mention the powers of creating and shaping things. The *Star Trek* reference of the replicator is that much a reference for 3D printing because it depicts the immediately granted wish of receiving an item, it’s the wish that just thinking about something makes it happen (*see image below*).

There is of course a link that cannot be ignored between the audience of these sci-fi shows and superheroes comics and the inventors and users of these technologies. There is an affirmation of the geek identity that permeates both that is instrumental in staging the fictional and the technical ways that wishes and dreams are reinforced or crushed. Pop culture will then

act as the cautionary tale, as with the TV show *CSI* portraying 3D printing with its infamously gun as the murder weapon. We can now intervene in our everyday life environment by redefining the objects around us and as we know, “with power comes responsibility”.



Fig 21. *Star Trek Replicator malfunctioning in Star Trek: Voyager, episode “The Haunting of Deck Twelve”. Broadcasted May 17, 2000. Paramount.*

Eventually, the power of fiction does wind down in favor of use and habituation to the devices and their abilities. Digital fabrication is too on a path of becoming an everyday occurrence, having to face in that process the typical ways society absorbs technologies, especially since the beginnings of the Industrial Revolution: government control, legislation, copyrights settlements, corporation acquisitions and competitions, knowledge

transfers, warnings of technophobes and cheers of techno-evangelists (*on the history of copyrights, see Atkinson 2014*).

2. DESIRES OF FABRICATION, DESIRES OF AUTONOMY

Currently though, the mainstream use for digital fabrication is not clear, beyond the uses of hobbyists and the trio ensemble of artists, designers and makers. Again here, discourses found both in the media and in academia are mostly wishful thinking rather than reality. They announce a “new era” of production as personal fabrication ‘rises’ (Mota 2011). Micro production, mass customisation, lightweight factories, factory at home: fabrication becomes personal, the same way computing did one time. It might not be useful yet, but at least it’s personal. In the same vein, news articles in mainstream publications “have not only contributed to a growth in the number of adopters, but also drawn attention to this confluence of trends and the promise it carries to revolutionize the creation, production and distribution of material goods” (Mota 2011).

Then of course, it’s the empowerment of making that is celebrated above all and the creativity that comes with it. The values of making for individuals are branded almost as a therapeutic salvation. The benefits of DIY have been heightened in much of the literature on the topic (Ramocki 2008, Williams & Gibb 2012) and digital fabrication is taking centre stage in that rhetoric. Beyond self-realisation, the main benefit seems to be a counter-balance to consumerism and the dominance of corporations. Making is then a form of activism and designers are seen as agents of social change (Clarke 2011:56-57). Allan Ecker, the founder of Thingiverse, the website that provides resources for easy access to digital fabrication writes in his blog on May 13, 2009: “designers leverage the power of personal fabrication to improve the world, by improving the way things are made”.

According to a study run by the Institute of the Future, communities of

makers build a new world that is relying on itself: “a self-motivating, self-educating, and self-organising sector of society is emerging that may define an alternative economy. This sector [is] preferring to have a more active hand in shaping their own goods, environments, and experiences in conjunction with relatively small groups of like-minded people” (Mota 2011 *citing Institute for the Future 2007*). ‘Users vs the industry’ is the new paradigm of consumerism (and not ‘the individual vs the corporation’): “User-centered innovation processes offer great advantages over the manufacturer-centric innovation development systems [...]. Users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often very imperfect) agents.” (Mota 2011 *citing von Hippel 2005*). Of course, the correlations made between technologies and the construction of alternative communities building a new world are not new. I could cite Saint-Simonism as one of the many examples of such premise (Picon 2002).

Through the modern discourses, the message is to make everything we use ourselves, from home, homemade, DIY, free, etc. Manufactured products are tainted with the evils of passivity, consumerism, underpaid labour, toxicity, waste, human exploitation, pollution. Making is thus tied to the cultures of hacking, repairing, upcycling and repurposing. The collectives F.A.T. Lab and Sy-Lab define reverse engineering - or the action of unlocking the way an item works - as a ‘civic activity’ when they create the *Free Universal Construction Kit*, a set of 3D-printed adapters for 10 popular construction toys that can be downloaded by anyone (*see picture below*). Similarly, a critical engineering manifesto has been issued that advocates a political awareness of how things are made and used (Oliver *et al* 2011). The designer ‘libre’ Christophe André invites us as well to resist to the planned obsolescence of manufactured products and the marketing orchestrations of corporations that make us replace things before their time (André 2011).

The theorist Illitch is one of the main references of this cause, as he encourages the design of “convivial tools”, fashioning our own ways of life and not delegating its design to others (Illitch 1973). The freedom of determination is acted within all details of life, down to one’s own cup of tea (Illitch 1973:13). Conviviality directly opposes in that sense the alienation of

the consumer society (Debord 1967).



Fig 22. F.A.T. Lab and Sy-Lab, *Free Universal Construction Kit*, 2012. “A matrix of nearly 80 adapter bricks that enable complete interoperability between ten popular children’s construction toys.” Description and photo by authors. Retrieved <http://fffff.at/free-universal-construction-kit/>.

The prime users are often the inventors of their own tools and machines. The machines don’t necessarily carry an explicit agenda other than to serve a personal use²⁴ but there are cases of a global intention, especially when items are cared to be developed in an open-source fashion. The open-source 3D printer *Rep-Rap* was clearly invented with the intention that it would replicate itself and swarm the world with mini-home factories so we could get rid of industries (Jones *et al* 2011).

Finally, there’s a nostalgia at play, a reasoning for ‘claiming back our

world', longing for a time when people could repair their cars themselves (Crawford 2006). A possible response to the *made in 'very far away'* where people have lost the connection with a local manufacture culture.

All the above tells a very strong narrative of empowerment, of resistance, of standing for oneself. I could assess whether any of this is grounded at all in reality. Some of it may be, and some of it is just very volatile. Many people who do use a 3D-printer don't necessarily see it as a way to replace their local store (*as a general survey I conducted in April 2016 showed*). So far, the desktop 3D-printer, or the laser cutter from the shop have been handy and creative rapid-prototyping tools for architects, designers, hobbyists. This is a much more "boring" and casual reality than the transformation of the realm of production. A critique to technosolutionism is emerging as well that challenges the utopian views of making, very American-centric as well (Lindtner *et al* 2016).

3. A TECHNOLOGY OF THE SELF

Things are not really happening at a grander scale, although they might some day - yet things are happening still. CNC-machining might not be celebrated for the reasons it should be the most. Digital fabrication is indeed unique in its phenomenon. As presented in the previous chapter, digital fabrication is contributing to a renewed perception of materiality and to a consideration of data as a creative input. Its wording joins together conceptualisation and materialisation within its understanding. This phenomenon is the relation that this technology allows us to have with the material world. Even more so than with other technologies, this one reveals many things about our constructions of the world (Bitton 1999). Because with digital fabrication, it's almost a literal condition. Technologies have traditionally been a way to make sense of the world, as they mediate the material world we live in. The specificity of digital fabrication is an opportunity to watch this mediation unfold, to manipulate the real world

in more direct, concrete, fast and immediate ways. The promise of the future becomes a promise of the present: 'It can happen now'. It's a frontal interpretation of the material world in a sense that digital fabrication is about embracing the physical around us. This chapter thus shows that digital fabrication might not realise all the dreams but it's still manifesting an anticipation of desire, a desire of design, which is itself a form of self-realisation.

The material world encompasses the wide range of actual materials that are what stuff is made of: the built environment, artefacts and all things tangible including our own bodies and selves - as they manifest themselves in the world. So when digital fabrication mediates our material world, it's mediating our perception to our own presence in the world. And because this is a technology of fabrication, it is also about our self realisation as creative, productive, meaningful individuals. It's a technology of the self and a rhetoric of validation. Because of that or aside from that, it has the potency to generate the forms of *hypomnemata* I described in the previous chapter, the tangible records of memory and identity that again contribute to the care for ourselves (Foucault 1982, Foucault 1983).

Technologies are tied to the idea of the self as processes of transformation. They offer multiple opportunities to assert ourselves via uses, misuses or transgressions, or to surrender our time and habits. With fabrication technologies, this is even more literal as they might make the individual even more incarnated. Making is then a making of self, driven by constant differentiations, variations and interpretations. I already alluded to the geek culture, where individuals are affirming themselves by what they are making, producing and can assert that identity as a global one with no frontiers but the tinkerer's. Of course, this is where the status gets limiting and exclusive. In the great paradox of a fight for more democracy and knowledge sharing, people who are not makers and who do not code are regarded as useless and unfruitful, and not contributing to society. Open source movement puts tools in the hands of people so they can be free but mostly if they know how to free themselves too. Beyond just a reaction to a society of consumerism, this is a determination of the individual that is at stake.

Thus as we acknowledge the link between fabrication machines, making and self-realisation, we should read between the lines what tale of self-sufficiency it tells. Self-sufficiency is before all an agent of freedom: if we can make everything we need for our personal use, if we're resourceful then we don't need anyone else; and if we don't need anyone else, then we're free. 'We're free from government control and surveillance, we're free from money and the need for money, we're free from corporations who decide what we should consume, when and how, we're free from contingencies of time, and distance. We're in control of our environment, we're the masters of our lives'. Of course, this is in theory. But the discourses that surround digital fabrication put forward the ideal of making ourselves all we need, because that's how we realise ourselves in the process, otherwise 'we're not ourselves, we're not our own, we're others'. I already mentioned how the the DIY culture acts sometimes as a supporting background in these discourses of resourcefulness (Ramocki 2008, Roberts 2001).

Resourcefulness in everyday life has been associated with ways of asserting freedom, especially in the context of oppression, as an expression of pockets of resistance [Certeau 1990, Lévy-Strauss 1962]. The unique point that Certeau makes though is that consumer culture can be a source of resistance as well, as a study on his work affirms: "en s'interrogeant sur la production quotidienne de la culture, [Certeau] cherche à saisir les mécanismes par lesquels les individus se créent de manière autonome en tant que sujets s'exprimant dans le processus même de la consommation et dans leurs pratiques de vie quotidienne." (Proulx 1994)²⁵.

Lévy-Strauss is more concerned with the position of the 'bricoleur', the tinkerer who makes do with what's available, a non-stop productive individual if we take the word of Deleuze and Guattari (1972-1973). Yet, as brought up in the methodology section, the tinkerer is always somewhat falling short of professionalism, and if the choice was given of better resources, it's not sure that the tinkerer would continue to accept ad-hoc or poor conditions of making. The association between resourcefulness and

25 "Pondering the daily production of culture, [Certeau] seeks to understand the mechanisms by which individuals are created independently as subjects expressing themselves in the very process of consumption and in their daily life practices" (trans. by author).

freedom has also been challenged as an illusion for the forces of control are too powerful and shrewd (Foucault 1975, Bourdieu 1972). Yet the illusion, if it's one indeed, does function in the collective imagination and the activity of making is all the same a learning process, a practice is arguably a path to education and knowledge.

We could wonder if the self-sufficiency and emancipation project resonates particularly well in the American culture. There are of course narratives of self determination and individuation in France and other countries, but the French philosophers that have laid them out have found a particular strong echo in the American narrative of the self-made man, the pioneer, the independent individual, distrustful of institutional control, that went from being grounded in nature (Thoreau 1854) to being expressed in technological supremacy (Pursell 2007). For Tocqueville, a 'modern' nation is made of what he notices in Americans: a will, an ability to master one own's becoming (Tocqueville 1835-1840). As geek culture, the MIT fab morale, the Hollywood superheroes and the Wired-supported utopia permeate a general pop culture, it's the mainstream society that is on its way of adopting a unique blend of ideals. The practical freedom supports the political freedom.

Ever since the Industrial Revolution, technology and machines often play a major part in the theatre of emancipation, for better or worse: the humans are at the centre of the relationship, masters or slaves. I'm focusing here on the discourses presenting technology as supporting a brighter future for humanity and individuals. The Saintsimonian economist Michel Chevalier would, in his opening speeches in his classes at the Collège de France, tie sociopolitical cohesion to the development of infrastructures, with the example of the communication networks in the United States : "ces communications multipliées et rapides contribueront au maintien de l'Union, plus encore que la balance de la représentation nationale"²⁶ (Chevalier 1843). Saint-Simonism in general supports technology as a vector of social change, that transforms the nation into a big manufacture, where

26 "These increased and rapid communications will contribute to the preservation of the Union, even more so than the balance of national representation" (trans. by author).

everyone works without hierarchy for the common good (Picon 2002).

Frédéric Passy, a pacifist politician, was deeply confident and positive about machines: in two speeches he gave in 1866, they're the tools of progress, freedom and equality. The machine completes the human, without which he would be an animal. Passy looks towards the future and opposes the vision of the past as the golden age of humanity: "le retour à l'état de nature est une pure fantaisie"²⁷ (Passy 1866).

Since the machines in this study are about personal fabrication, making, artefacts, and materials, they are even more so agents of self-realisation. If we add to that the promotion of the 3D-printer as the ultimate self-sufficient machine which can "replicate itself" (Jones *et al* 2011) or the ambition for the "machine that makes almost anything" (Gershensfeld 2012), we're going full circle. Therefore making "machines that make" become almost the highest point of the narrative: making the tools if they don't exist, every time there's a need, and sharing them with others. The maker of the machine becomes what the machine allows her to be, powerful and productive. Chevalier wrote in 1836 in his "Lettres sur l'Amérique du Nord": "il n'y a pas de paysan du Connecticut ou du Massachusetts qui n'ait inventé sa machine"²⁸.

4. MACHINES IN THE 'DECOR OF EVERYDAY LIFE'

In most of the polarising discourses, the machine again often either liberates or dooms the human. Yet, I would suggest to look at the machine as a partner. There's little view on the everyday companionship that is happening between a human and a machine, the intimacy and the empathy arising from living with the machines, using them on a daily basis. The use habit could be perceived as the channel towards doom (dependance, addiction, enslavement) but familiarity is generally overlooked for its

27 "The return to the state of nature is pure fantasy" [trans. by author].

28 "There is not one farmer of Connecticut or of Massachusetts that hasn't invented his machine" [trans. by author].

own quality: the recognition of the machine as a distinct presence, as an independent "other" (Hwang *et al* 2016). That presence is not necessarily obvious or blatant, it can be more or less *there*. In his study on robots, the speculative designer James Auger pointed out that domesticity is the operating factor in our adoption of them (Auger 2012). Furthermore, in a paper on the familiarity of technology, Hwang *et al* have shown that in Eastern philosophies as Taoism and Confucianism, technologies are included in the index of "non-human agents" along with nature, animals, immaterial entities and spiritual beings with which humans have very real ritualized relationships and are interdependent. They give the example of the Japanese notion of '*mitate*' that characterizes computer interaction in *Device Art*²⁹: "a method to present and read hidden meanings behind what is shown or written" (Hwang *et al* 2016 *citing Kusahara*). Similarly, they cite Deleuze and Parnet who observe that in Japan the "arts of Zen, archery, gardening or taking tea, are exercises to make the event surge forth and dazzle on a pure surface" (Hwang *et al* 2016 *citing Deleuze*). The authors deduce from that that "(...) these ritualized activities present opportunities to contemplate the entangled connections that exist as part of our interaction with nature and non-living - often technical - entities such as the bow and arrow, the tree, flower or tea." (Hwang *et al* 2016) The awareness of technological objects as 'others' and of the reciprocal 'place' that things can have would then enable us to shift our perspectives towards our own practice of daily life.

There are traces of that awareness in literature and popular culture. At least, it's been acknowledged that the machine can trigger emotions, especially when they are personal tools used for work, craft, art, and at home. They're imbued with personalities. In the popular literature of Jules Verne and H.G. Wells, machines are famously powerful characters often with a 'mind' of their own. The historian Jacques Noiray described the personalisation of machines attested in the novels of Zola, Verne and Villiers

29 Device Art is a Japanese art movement, defined as "a form of media art which draws together art, technology, design, entertainment and pop culture" [Arrighi 2016]. "Device Art is often made of objects which are able to connect to each other crossing long distances and to start a sentimental correspondence among the people who own the objects themselves; the way these devices work may seem to be curious, but it can be assimilated to the dynamics of magical practices" (*idem*).

de l'Isle Adam and how we co-exist with them and their increased presence in the “decor of our daily life” (Noiray 1982). The machine can be seductive for instance. In *Typewriter Ribbon*, Derrida remarks that “Rousseau lingers complacently over the description of the machine that seduces him into dangerously close contact: «I looked at the metal rolls, my eyes were attracted by their polish. I was tempted to touch them with my fingers and I moved them with pleasure over the polished surface of the cylinder» (Derrida 2002:156 citing Rousseau, *Les Confessions*).

Anthropomorphism evidently has long been including the machine in its realm. Even the myth of emancipation can pertain to the machine. In a study on the behaviours of objects for the research group *Reflective Interaction* at EnsadLab (Bitton 2013), I pointed out that the machine too is in a submission or emancipation rapport with its creator and it comes alive when it takes its autonomy from its creator, when it's outmatched her, when it's affirming its singularity, as what the computer *Joshua* attempts to do in the movie *War Games*.

Conversely, the machine has been used as a way to describe the human as well (see Descartes, *La Mettrie*): “the human becoming (...) one of the cogs in a larger machine (for Marx) or becoming himself a machine, exploited for mass production” (Bitton 2013). The productive property of the machine is also why Deleuze and Guattari would use it as a metaphor for human desire (Andoka 2012). Humans and machines have thus been exchanging or borrowing attributes from each other for a long time, as mirrors of each other's dimensions.

One of the reasons for these human-machine conversions could be imputed to movement: “Movement is likened to the concept of living and life in origin myths (...) Hence the famous phrase from the movie *Frankenstein* when Dr. Frankenstein exclaimed on his creature “Look! It's moving. It's alive. It's alive”. (...) Epimetheus (or his brother Prometheus depending on versions) shapes humans from clay while Athena intervenes to breathe life into them and to give them a soul. They've become “animated”. (...) In this way, which is animated (endowed with motion) is alive or rather the movement makes it believable, with just enough of a likeliness to envisage



Fig 23. The computer *Joshua* learns an important lesson from playing tic-tac-toe against itself in the movie *WarGames* (1983). MGM.

the plausibility of life.” (Bitton 2013).

There's something ‘moving’ in a relationship to a machine. Sound is another element of confusion. And feedback, responses of all kinds can reinforce the affective and intimate role we attribute to technical objects, especially when they're perceived as autonomous, and able to entertain a dialogue (I cited already the computer *Joshua*, now we have *Siri*).

This entire ecology of shared characteristics has contributed to establish a personal emotional bond that is inferred by the German concept of *Einfühlung* used by Victor Basch in his essay on the *Aesthetic of Kant* (1896). *Einfühlung* indicates an empathy, or a “psychological projection of the self into the objects of perception” (Rosenblatt 2001). The designer Victor Papanek, in his study of Inuits refers to an “*Einfühlung* for things electronics or mechanical” to describe the Inuits’ “amazing mechanical aptitude” (Papanek 1995). This empathy for things mechanical are best illustrated by the machines of kinetic sculptor Arthur Ganson, that intensely move the

audience, even though the machines are completely abstract and are not humanoid.

The machines seem to be forever stuck in-between familiarity and strangeness. The state of inbetweenness is represented in arts and movies, capturing the motion of life, yet with an artificiality that could look natural but is never quite right. When Fred Astaire dances in a ship's machine room in *Shall We Dance* (1937), the music and the dance emulate the rhythm of the



Fig 24. Arthur Ganson, 'Machine with artichoke petal (#1)', Undated. Detail. An artichoke petal moves over a spinning wheel: "A failed attempt to cook an artichoke uncovered in a microwave oven resulted in this little withered petal that caught my heart. It moves carefully and with determination." Description Arthur Ganson, photo retrieved from <http://pietmondriaan.com/2010/06/21/arthur-ganson/>

engine, which becomes a partner in the dance. It's with a choreography as well that Chaplin shoots the machines of his film *Modern Times* (1936). And if Fernand Léger attempts to capture the mechanism of life in his paintings, he ultimately stages it in his experimental film *Ballet Mécanique* (1923-24). Generally, Léger is interested in the sudden pause of the movement: "Léger's ambition, expressed in his artwork and in his writings on the modern spectacle, was to incorporate the "shock of the surprise effect" experienced by the automobile driver, the urban pedestrian, or the consumer suddenly transfixed before the shop window into the formal features of his artwork" (Rosenblatt 2001). I should also mention more generally the arts movements *kinetic art*, *op art*, *pop art*, *electronic art* and *new media art* that have along the 20th century until now engaged specifically with this in-betweenness. It's possible that these illustrations invite us to simply embrace the posthumanism that announces itself, where humans and the non-human agents mentioned above live together indiscernible from each other. After all, again, as Gaston de Pawlowski wrote in his "antinaturalist manifesto", the novel *Journeys in the land of the fourth dimension*, "rien d'humain n'existe en dehors de l'artificiel"³⁰ (Pawlowski 1912). For him, the fourth dimension, time, allows us to define the known world and experiment with the idea of what our scientific knowledge could become.

CNC-machines are unique in that landscape of empathy and confusion: they are not only machines that move, make sound and respond, they're foremost machines of production, fabrication, creation. Digital fabrication strike the imagination both as an impressive technology and in its promise of creation. Heidegger is often cited for his invitation to appreciate technology not just as a tool and a function, but also as a *techne*, a way to create (Heidegger 1977). And since technology encapsulates a mixture of emotions, wishes, fears, pleasures, disappointments, opportunities to learn, opportunities to be frustrated, companionship of impermanence, it becomes also a *phronesis* (Tin 2013), a way to be in the world, to be in the moment and a way to navigate the world. CNC-machines tell us all about living in the material world.

30 "nothing human exists outside the artificial" (trans. by author).

What is ascertained in this dissertation is the ambiguity that lies within the cracks of the association of ‘digital’ and ‘fabrication’, a discreet quality that is almost out of reach. As these CNC machines insert themselves into the realm of the everyday decor, they have the potential to suggest an aesthetic experience in a daily, casual context, almost insidiously, without advanced warning. I’m proposing to experiment with processes of CNC-machining, to play with forms and shapes, to fabricate unexpectedness and other abstract notions such as dreams, thoughts, insecurity, emotions. As I challenge the linear and expected workflows of fabrication, transformation and materialisation, I look at ways that CNC-machines can modify or alter our view of materials, the world and ourselves. I’m setting them up to be possible social tools, or tools of connectedness (Agamanolis 2003, Ilan 2011).

Moreover, I postulate that these machines and their interaction with users and materials can create art and if not art, a way of living, and if not that, a way of surprising ourselves. And maybe in the end, as a nod to the doomed emancipation dream of the maker alluded to above, I argue that embracing imprecision, abstraction, playfulness, broken things is our true liberator (*see image below for an example of the Japanese art of Kintsugi, or repair*). Emancipation can be minimalist too. Therefore, the usual “issues” of CNC-fabrication like latency and imprecision that are meant to be addressed and ‘solved’ by innovative iterations can become the very same precious attributes to value, in an aesthetic context and in life.

An endorsement of the flaws and cracks might seem ironic in a context where the condition itself of digitally controlled machines is about a precision-driven process, but again the opportunity to expand the scope of the association of ‘digital’ and ‘fabrication’ is too tempting.



Fig 25. Kintsugi art, where cracks are highlighted. Photo retrieved from <http://www.amusingplanet.com/2014/05/kintsugi-japanese-art-of-fixing-broken.html>

5. THE ART OF CONTROL

Domesticity

We are looking at a technology, CNC-machining, that is not new in its existence but is novel in its mainstream emergence, as it's going through its lengthy transition from “*inventio*”, invention to “*usurpatio*”, application (Braudel 1979).

A brief historical overview could take us to the 18th century with textile manufacturer Basile Bouchon who, inspired by the crank organ and music automata, adapted perforated paper for supporting the automation of a loom (1725). Further improvements and adaptations by Vaucanson (1747-1750) and Jacquard (1805), among others, eventually led to the punched card in a continuous tape as the standard for machine programming for the 19th century and well into the next.

The use of this form of ‘numerical control’ (NC) was implemented with modern manufacturing machines operating with servomechanism in the early 1950s. Servomechanism is a system of control of motion, where information usually about position, velocity, acceleration of motors is used for the system to adjust itself - it's a feedback loop akin to the process of optimisation mentioned in the previous chapter.

The applied research of electrically-powered servomechanisms at MIT under the direction of Gordon S. Brown and in collaboration with the US Army, led in 1952 to the first numerical control fabrication tool in 3-axis. The ‘numerical control’ eventually became ‘computer numerical control’ (CNC) with the rise of computation and the consequent phasing out of punched tape.

‘*gCode*’ is the computer language which started to be developed in the Sixties that became the standard since the late 1970s for instructing CNC-machines. *gCode* is not usually ‘handwritten’ the way other programming languages are used. Rather, it's a series of instructions that are generated by a

software that would transform a CAD file into a CAM file (basically a set of X, Y, Z numbers for each geometrical point of the artefact to be fabricated).

The current workflow is thus generally: the drawing/modelling of an object on a CAD software (*ie. Illustrator, Rhino, AutoCad*), or programmed with languages (*ie. Grasshopper, Python*), then exported unto a CAM software (*ie. MasterCam, MakerWare*) that interpret the model into *gCode* and operate the CNC-machine. These interfaces are more or less complex to use, depending as well on the type of machinery that it is intended for or associated with. They are the interfaces responsible in part for maintaining the technology in a rather exclusive status. This is typically the workflow that this research is disrupting and challenging.

The transition of these machines to the mainstream could be the process of domestication that is so determinant in tinting the relations to come between the users and the technology (Auger 2012). The term of ‘domestication’ refers as well to various notions all at play here: the idea of welcoming a ‘wild’ foreign entity at home, the adaptation of that entity to the home and the taming and control of that entity. Home as such is not always intended as the final destination of the machines - but blurry spaces in between the home and the factory could also be substitutes for personal unthreatening spaces: the design studio, the community woodshop, the makerspace, etc.

In this transition, something like size matters: where a smaller scale, a portable, adaptable format fits better with the surroundings. In that sense, Rayner Banham recognizes the superseding influence of trivial and domestic machineries: “the reduction of machines to human scale” (Banham 1959). It's what the phenomenon of ‘personal fabrication’ entails.

As a subset of the larger “digital fabrication” field, the notion of personal fabrication is emerging and is still unclear to the modalities of its implementation (see section on ‘desires of fabrication’ above). Also called ‘desktop manufacturing’ (Gershenfeld 2007) or ‘personal manufacturing’, these terms refer to former groundbreaking transitions as they borrow the same vocabulary: ‘personal computing’ (the revolution of the PC) and the ‘desktop publishing’ (the revolution of the ink-jet printer). As said, this

increasing accessibility of desktop-size digital fabrication machines, and notably that of the 3D printer further popularised by media coverage, play an immense role in the anticipation of uses. Just like with desktop publishing, the user is now able to create or download a file on her computer and send it to 'print' or to 'cut', etc in a fairly heedless way. In the field of HCI, as overviewed in the previous chapter, many investigations into overcoming current constraints of size, quality, time and materials are on-going which will further accelerate the transition.

Crowdfunding platforms such as Kickstarter feature regularly new machines iterating on similar principles at cheaper costs or increased performances (*Form1* by Form Labs, *The Other Mill* by Other Machine Co.), with formats adapted to the human body (*3D Doodler* by WobbleWorks, an extruder pen for the hand), and with functions that imply more familiar uses (the *FarmBot* for planting seeds, the *iBoardbot* for writing messages - see chapter 'Odd Materialism' for a more detailed description of these two references).

Mavericks

Most of these efforts consist in adapting to 'human scale' the machines that became standard and universal: additive manufacturing into desktop 3D printers, large router machines into smaller mills, and the laser cutters and robot arms into ad-hoc solutions and open source versions. But the domestication of technology can find its way in adapting something else than standardisation, rather a character of sorts, a virtue possibly.

In technology in general, a standard machine is not a given, there are those that failed to become standard, those that were invented for a very niche purpose, others that suddenly became useful or playful to society-at-large even though they were not intended to leave the professional world, those that were never meant to be used by anyone except by the inventor, those that are essentially art statements, and also those that were very popular and mainstream but are hardly ever used anymore and thus become iconic objects of curiosity and fantasy, etc.



Fig 26. 'The Marvelous Wondergraph', sold by Sears from 1907-1908. Manufacturer: E. I. Horsman Co. ©The Strong, National Museum of Play. Rochester, NY. Photo retrieved <http://www.museumofplay.org/online-collections/1/45/109.1340>

All of them together compose an exotic family of machines. Those have a queer identity that make them almost an intelligence. There are many examples of them in history. I referred to some of them in the previous chapter that were invented to trace and record all sorts of things, usually bearing the suffix '-graph'. Many of them draw mathematical figures using pendulums, linkages or gears ('*spirograph*', '*cyclograph*', '*integrator*', '*harmonograph*', '*pantograph*', etc) - Sears started to sell one of those mechanisms as a toy from 1907: *The Marvelous Wondergraph*.

There are the photo-cinematic machines that play with light and motion, or with light and space such as Moholy-Nagy's light-space modulator and Hirschfeld-Mack's *Farbenlichtspiele*. These two examples announce machines that do no longer belong completely to the world of efficiency, function and productivity: they start to slide down a path towards experimentation, design, art. They are machines freed from usefulness, a type of machines that's not profitable, that's not transporting, communicating, nor even entertaining: 'independent creatures' with which we 'cohabitate'. They can still manifest one or more attributes of their useful cousins: the mechanical repetition of a task for instance can be repurposed to signify gesture, persistence, exhaustion or violence, as in Rebecca Horn's painting machine *Kleine Malschule*, Liz Larner's *Wall Scratcher*, and Roxy Paine's *SCUMAK 2*. Repetition makes Gordon Pask's *MusiColour* 'bored' and capricious: "the system 'directs its attention' to the potentially novel" (Pask 1971).

As art statements, these machines were always meant to be singular³¹. Pask calls them 'mavericks': "mavericks are machines that embody theoretical principles or technical inventions which deviate from the mainstream of computer development, but are nevertheless of value." (Bird & Di Paolo 2008:1 citing Pask 1982:133). The value comes as a framework that make the creation of an aesthetic environment possible, supported by the co-creativity between humans and machines. The low-tech sonic machines of the STEIM group are in that sense 'ecstatic' (Montgomery 2013).

Systems art

The presence of machines, systems and technology in art is a large, well-documented, diverse, dense field. It should be nonetheless mentioned here as a source of related work, as a source of inspiration and as a context for situating this thesis. Art is in a permanent feedback loop with technology:

31 I'm disregarding the term 'bachelor' here on purpose: the numerous meanings pertaining to sex and gender, often stereotypical, that have been superposed on Duchamp's original intention, itself rather unclear, would need its own study for them to be unraveled.

"C'est effectivement en présence des ouvrages de la machine que les artistes modernes ont vu se transformer leur champ de conceptualisation et d'action, « leur répertoire de formes et leur outillage matériel et mental » comme l'écrit Franca Castel."³² (Legras citing Franca Castel 1956). Thus art is both a tool for experimenting with technology on its edge of mainstreamness and a process to capture the aesthetics of technology.

The references cited above and the following ones are relevant as they help make explicit the two postulates that has guided my theories and experimentations:

1. The machines are real. The Futurist movement understood that fact as what made a major difference with any other myths. Machines are not vain wishes or dreams. They happen:

*"Where can we look for more contingent inspiration than among the new symbols which are no longer the creation of the imagination or the fantasy but of human genius?
Is not the machine today the most exuberant symbol of the mystery of human creation ? Is it not the new mythical deity which weaves the legends and histories of the contemporary human drama ? The Machine in its practical and material function comes to have today in human concepts and thoughts the significance of an ideal and spiritual inspiration.*

The artist can only pin his faith to the realities contingent on his own life or on those elements of expression which spiritualize the atmosphere he breathes. The elements and the plastic symbols of the Machine are inevitably much nearer to us

32 "This is indeed in the presence of the works of the machine that modern artists saw the transformation of their conceptual and action scope, "their repertoire of forms and their material and mental tools" as Franca Castel wrote". (trans. by author).

(materially and spiritually) than any symbol of the past can be : symbols as such as a god Pan, the taking down from the Cross or the Assumption of the Virgin, etc. The logic, therefore, of aesthetic verities becomes self-evident, and develops parallelly with the spirits of the times which seeks to contemplate, live and identify itself with reality itself.” (Prampolini 1922)

2. Each machine is an inquiry into the notion of control. Machines give us the opportunity to reflect, test, and simulate our understanding of control. For the artist Richard Hamilton, humans attempt “to assimilate the disruptive experience [of technology] to the balanced fabric of thought and feelings.” (Hamilton 1982). System theorist Jack Burnham announces *systems art* as art that puts people in touch with reality: “*Part of systems theory stems from cybernetics with its emphasis on elements of control between animals and machines. Most systems have some means of control which determine the goals of the system, or it can be a separate function with a hierarchical assembly such as the human brain and the nervous system. (...) If systems thinking does nothing else, it makes us realize that we ourselves are on-going, self-organizing systems that need to resonate with the systems around us.*” (Burnham 1969). Gordon Pask elaborates further “*Man is prone to seek novelty in his environment and, having found a novel situation, to learn how to control it. Let us develop and qualify this cybernetic statement. In the symbolic domain which constitutes the most important aspect of the human environment, 'novelty' inheres in events or configurations that appear ambiguous to a given individual, that engender uncertainty with respect to his present state of knowing and pose problems. 'Control', in this symbolic domain, is broadly equivalent to 'problem solving' but it may also be read as 'coming to terms with' or 'explaining' or 'relating to an existing body of experience'.*” (Pask 1971).

Among the many occurrences that have marked the history of technology and art, I can cite three exhibitions: Richard Hamilton's *Man, Machine, Motion* at Newcastle's Hatton Gallery in 1955, MoMA's *The Machine* in 1968 and E.A.T.'s PepsiCola Pavilion at Osaka's Expo '70. Not only have those exhibitions reinforced the posture of the machine as an art object (and subject), they have emphasised that the “decor of our daily life” was the main stage of operation for machines. For Pontus Hultén, the curator of the MoMA's 1968 exhibition, “only the machine can allow us to escape our fate” (Pontus Hultén 1968). In that regard, it's worth noting that Cartier-Bresson's photography work ‘*Man and Machine*’ commissioned by IBM that depicts scenes at work or in life of a proximity that is not threatening anymore, it's just there (Cartier-Bresson 1969). More recently, the exhibition *Ghosts in the Machine* at the New Museum (2012) has restituted traces of the aesthetic heritage of movements as the Independent Group that had prefigured Pop Art in conceding mass culture its sensorial irresistible attractivity: “a recognition of the fragile boundaries between specializations in the plastic arts” (Morphet 1992).

The relation between art and technology has thus been the most articulated in systems art, cybernetic art, new media art and interactive art, for the past fifty years, and most prominently since the mid-Nineties. Each system-based artwork is its own expression of presence and control, that can only be repeated with the set of rules that has been defined (“it's alive!!”). The *Floats* of Robert Breer appear in the E.A.T pavilion as autonomous entities, minimally marking their territory with their ethereal quality (*see picture below*).

“An art committed to the machinic ought to be looking for those moments, those forms, those planes of consistency where auto-production emerges of its own accord. Or rather, constructing such zones, watching and waiting for it to happen - the way it can happen on the dance floor, or on a listserver. Not pure chaos, which tends in the end to be rather

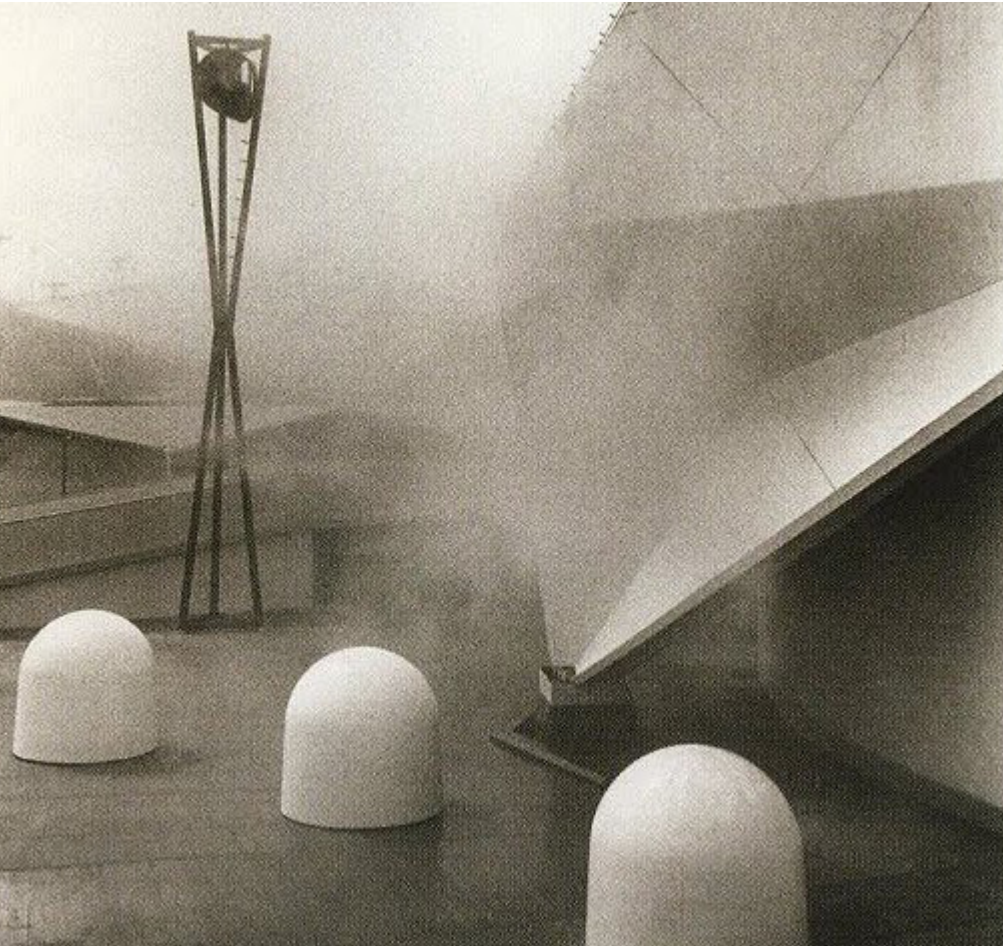


Fig 27. Robert Breer, *Floats*, exhibited at E.A.T. Pepsi-Cola Pavilion, Osaka, Expo '70. "...I thought of grass and then these objects "semi-obscure" that were alive, but my thinking was not anthropomorphic or biomorphic in terms of shapes or in terms of content. I was thinking, Sculpture, strangely enough. This was pretty corrupt as I was coming from centuries of art consciousness to arrive at what amounts to a motorized mollusc..." Robert Breer. Image and excerpt from Robert Breer: *Films, Floats & Panoramas*, Editions De L'Oeil, 2006, retrieved from <http://stoppingoffplace.blogspot.com/2011/07/everything-goes-not-anything.html>

uninteresting, but chaos articulated on a plane of consistency, selected and articulated, so that complexity arises of its own self-organising accord" (Broeckmann 1997 citing Wark).

Making mavericks that make mavericks

With machines of digital fabrication that explicitly put forth the idea of control in their function mode ("Computer numerical control" machines), this is particularly resonating. Machines that make are hence doubly self-realising: "something that makes itself while we watch it" (Gioni & Carrion Murayari 2012:101 citing Eco). Making those machines that make is therefore an opportunity to orchestrate the control in the real world.

The course *Expanded Mechanisms / Empirical Materialisms* taught by Andrew Witt since 2012 at Harvard Graduate School of Design illustrate that opportunity as an investigation of possible pairings between machine and material, one transforming the other, not necessarily guided by design needs and thus practically limitless in terms of possibilities. Such machines made in that class and other experiments elsewhere are taking a wide variety of shapes for different uses with an ever expanded range of materials. machines that transform hot coloured wax into coral structures (del Castillo y Lopez et al 2013), machines that transform in-situ desert sand into glass (Kayser 2011).

It's a craft of its own and an art of its own to make machines, especially when they're articulated with a material. There is something powerful about setting our own rules, without asking for permissions (Ackermann 2012). The next chapter investigates the process in detail - for now it matters to realise that the design encompasses not just the mechanism, but also the data input that controls it, the materials that are used, the geometries that are generated, the transformations at play and the human interventions in that system. It's a design that should embrace the ambiguities of that orchestration, for fear of becoming prescriptive and authoritarian. There also should be an awareness that the design of a system could become a

tool (Ackermann 2012), for which users develop methods, languages, uses, a whole framework (*see the project RAW*, Bitton *et al* 2004). It's generally a perceptual experience, an experience of oblique thoughts: one where we are surprised by the outcome of a material transformation, by our interactive agency in that outcome - one again that I would argue is the true agent of freedom.

The Interactive Paradigm

1. A SYSTEM OR THE EMERGENCE OF ART
2. INTERACTIVE FABRICATION, A *MODUS OPERANDI*
3. DESIGNING FABRICATION EXPERIENCES
4. IMPLICATIONS
5. EMBODIED FABRICATION

In our introduction, I have explained why interactivity mattered in the context of this research and what I meant by interactivity. To restate some of that account, Interactivity is the *modus operandi* that allows this research, it's the system by which art emerges, it's pushing the boundaries of the opportunities of digital fabrication, it's making them more meaningful, it's allowing for a series of bold and radical experimentations.

The notion of 'interactivity', as used in Human-Computer Interaction research generally requires that a system: 1. receives an input from an analog or digital source and 2. translates it into an output for a human-centered experience (Stern 2013). An ensemble of parameters can reinforce the user's engagement (Candy & Ferguson 2014). In the case of this research, these parameters could be all or some of the following:

- A collection and sensing of personal data related to the body (gestures, movements, physiological information) and to traces of daily activities (eg, a commute journey on the subway, emails, etc). The use of personal data reinforces the personal engagement in the experience.
- Notions of control and intervention: The user is at the center of the process within the constraints imposed by the designer. From there,

possibilities emerge of storytelling and narration, as the control becomes a form of live editing.

- Openness and Scenarios of use: the role of the designer is to frame the experience playing with notions of time, scale, location, situation, multi-participation, social interaction, distance, etc. The consideration of time is possibly the richest component to play with: interaction can happen in real time, or can be staged over a longer period of time (a week, a month, a year). Generally the more 'open' a system is - where the user is not prescribed an emotion or an outcome, the more appropriation and creativity occurs.

1. A SYSTEM OR THE EMERGENCE OF ART

Interactivity is a troubled term, there are many definitions that are used in different contexts - many of these definitions establish a checklist, notably in regards to users input (Rafaeli & Ariel 2009). Here again, interactivity is meant as an input and an output, a computation system that operates according to rules, with one of those rules being an input from an external user. I use this term specifically as a creative agent for art, although similar understanding has been formulated in design and HCI as well.

I showed in the previous chapter the influence of system theory in works of art that included technology. At the heart of this, is the notion that the system allows the emergence of art (Cage 1976). A quote from theorist Stafford Beer inspired Brian Eno's experimentations: "Instead of trying to specify it in full detail, you specify it only somewhat. You then ride on the dynamics of the system in the direction you want to go." (Dayal 2009 citing Beer, *The Brain of the Firm*). Peter Schmidt, the system artist who collaborated with Eno on the generated *Oblique Strategies cards* project explained his process: "the point of working this way is not at all to achieve a pre-conceived result, it is to allow an unexpected one" (Dayal 2009 citing

Schmidt, exhibition artist statement).

When Lushetich discusses the works of Blast Theory, pioneers in locative interactive art, she deduces that "the artist *shapes the conditions* for the work of art or artistic event to arise". She quotes one of Martin Flintham, one of Blast Theory collaborators on the right system to find: "too much freedom may result in the participant's bewilderment and retreat into inactivity. Too tight a structure may do the same. It's all about orchestration." (Lushetich 2007:12 citing Flintham). A system itself can let art emerge but is not a guarantee for interactivity and user participation. It should strike the right balance: I've underlined the importance of open systems for appropriation by the user. Richard Sennett reminds us that Karl Popper defined 'openness' as a correlate of freedom, and 'closeness' as one of tyranny; disruption, chaos and noise come as salutary markers (Sennett 2013). Yet as Flintham suggested (*see above*), open system doesn't mean that there are no constraints at all - there is still a system in place. Openness thus is *designed* just the same for Sennett: with a balance of systems theory and poetry that favors 'seed planning' rather than 'master planning'.

Sennett proposes a set of indicators for open systems:

1. Parts in an open system have distinct characters
2. Simple rules can generate complex results
3. Known and determinate beginnings can produce unforeseen or unpredictable results, which is the meaning of chaos in complex systems
4. In a complex system, a relatively small scale event can trigger massive changes.
5. Past dependency, small turn reorients a whole system
6. Complex systems can self-organise (*autopoiesis*), responding to tipping points and chaos. (Sennett 2013)

Of course, open systems are generally advocated as a social posture, and this dissertation argues for a similar awareness, through the investigations of the implications of interactive fabrication. Interactive open systems that

invite appropriation can readily pass for tools of civic engagement: “Blast Theory use interactivity to foster engagement and care, and, to resist the indifference engendered by the proliferating spectacular practices of the contemporary society.” (Lushetich 2007:47). Interaction generates meaning (Dourish 2001) and “can support more reflective ways of knowing” (Wright & McCarthy 2010 *citing Bolter and Gromala 2003*). This approach could constitute the method of an ‘aesthetics of existence’ pruned by Michel Foucault, an ethical proposition for selves to ‘make life a work of art’ instead of looking for a deluded universal moral truth. Lushetich suggests that the urban collaborative experiences of Blast Theory are just that “a process of conscious form-giving to the smallest everyday actions, reactions and relationships with others. Interactivity, as practiced by this ensemble of ‘digital situationists,’ [Blast Theory] is essentially a contribution towards an aesthetics of existence.” (Lushetich 2007:48). It’s plausible that interactivity can be a formula mimicking life itself.

There’s no possibility to determine a strict framing of interactivity, a checklist to cross off, as each system is formulated differently according to contexts and subcontexts and can thus be more or less open. Examples abound: it could be an application for facilitating teamwork in software design or an augmented reality social experience in game design or a body to speaker interaction in an interactive art installation, etc. I proposed a definition (*see introduction*) that acknowledges that perceptions of what is interactive can differ among authors and among users. In addition, the situation of an experience (the room, the time, the place, etc) is part of the system and can alter these perceptions.

Instead, I propose to underline the attributes of interactivity that are effective in this research. I already touched on the notion of control, with its multiple degrees. There are others: the possibility of collaboration between users, the interaction as human to machine or as human to other humans via the mediation of the machine, the role of metaphors and scenarios for setting up user experiences, the question of interface, the use of the user body as an interface and the expectation that interaction produces results, whether in real time or with a delay. Within that, there is an opportunity for

human behaviour, movement, personal data, gestures, everyday life routine, habits, relationships, presence, absence, familiarity, emotions, perceptions to become the actuators, modulators and inputs of an interactive system. “As an art form, this is unique. Instead of an artist creating a piece of artwork, the artist is creating a sequence of possibilities. Conversely, the audience is not looking at a piece of artwork. Instead, they are actively involved, sharing in the creation of the art.” (The Digital Age 2009).

2. INTERACTIVE FABRICATION, A *MODUS OPERANDI*

How do these considerations fit within the realm of digital fabrication?

Interactive fabrication is thought here as a *modus operandi* that invites users to make things in a distinct way compared to most formal and professional contexts: meaning not in a linear process that requires a pre-designed digital file to be fabricated. With this premise, the outcome is not the primary purpose. Considerations such as the use of personal data or real-time or perceptions of user control are the guidelines for the fabrication process.

The affordances of interactive fabrication have several implications to take into account in the design process: from acknowledging the human body to the manipulation of materials to the narrative opportunities that emerge from these experimentations. In a short paper that introduced the term ‘Interactive Fabrication’, Willis et al presented early conclusions from a set of experiments at Carnegie Mellon, evoking mainly a process akin to craft-making (Willis et al 2011). The authors of the paper acknowledged that theirs was a study that “only scratched the surface” of the field, there was opportunities for “a range of new creative possibilities for early stage prototyping, experimental form, improvisational fabrication, and many others” (Willis et al 2011).

Plainly, this is the possibility for all these human-based inputs to be materialised, physicalised, to bring physical action and physiological reactions into processes of making, emphasizing proprioceptive senses. It's an opportunity to intervene more tangibly in the physical world, to affect materials and transform them for the experience itself. As I've laid out, it redefines the relationship between code and form, it goes beyond data visualisation, it's turning the bits of a human-computer interaction into atoms.

At the source of the formulation, there is a concern for the interface, that which mediates the input with the output. CAM software are exclusive, they are built for a GUI world that is not easily accessible: "In many cases software for digital fabrication is merely an output method from existing CAD applications, without specific consideration given to interface design" (Willis *et al* 2010). The HCI research team at Carnegie Mellon first addressed that concern with the goal to bring a "wide audience" to "the fabrication of real-world entities." In a 2010 research, Willis *et al* implemented a tool for "spatial sketching", inspired in part by the project *Sketch Furniture*, by the Swedish design company FRONT: "We believe that embodied interaction techniques utilising body movement and the physical attributes of our bodies offer one approach for designing interfaces for digital fabrication. If our physical movements in the real world can be mapped directly to digital fabrication, we can establish an immediately understandable relationship between the interface and real-world output" (Willis *et al* 2010). The implementation of their original concept did not go without challenges, possibly because the activity of sketching is after all a very 'GUI gesture' to start with and has already a strong relation to the drawing hand. Yet, this allows the research team to pursue further edgier experiments under the umbrella of 'interactive fabrication' (Willis *et al* 2011) and to take the vision of virtual reality pioneer Myron Krueger of an "unencumbered full-body participation" to actual reality (Willis *et al* 2010 *citing Krueger 1991*).

Tackling accessibility to technologies is traditionally a superb vector for creativity: tools such as Processing and Arduino that were built for bringing larger audience to programming, electronics, physical computing, have led

the way for new objects, new methods, new systems and a galaxy of creative outputs. Quoting Andrew Witt in a conversation, "it's a precious thing to have a problem that resists solution".

In the case of digital fabrication, a user-study I conducted at Culture Lab, Newcastle in 2011, revealed that novice and amateurs users were facing two particular challenges when engaging with digital fabrication: the first one had to do with using a 3D software and the second one with finding a use or a purpose for the technology (Bitton 2012). Regarding 3D modelling and 2D drawing, which prove to be the strongest limitations, several strategies for inclusiveness have been set up across the board: access to mentorships in Fab Labs (Gershenfeld 2007, Insley 2011), customization of pre-determined shapes (Rosencrantz 2015), simplified software interfaces (123D Make, Google Sketch Up), and a combination of the above (Posch *et al* 2010), etc. Aside from the example above of the research of Willis *et al*, other researchers and designers have investigated interactive fabrication as a facilitator: at Hasso Plattner Institute (Mueller *et al* 2012, Eickoff *et al* 2016, Ion & Baudisch 2016 among others), at MIT (Pinochet Puentes 2015), at Ars Electronica FutureLab (Ogawa *et al* 2012), etc.

Another issue is that first-time users or recent users often wonder how to design for the technology or how to understand its usefulness. Examples of tactics exist, especially with workshops to guide users towards the fabrication practice (Makerversity). Newcomers problems are being better understood (Hudson *et al* 2016) and innovative solutions keep being proposed every year for various limitations (Jones *et al* 2016). The project *On-The-Fly Print: Incremental Printing While Modelling* proposes both a way to get around the latency issue of the 3D printer and a novel approach for rapid-prototyping (Peng *et al* 2016). And there are the investigations of assembly processes and '4D printing' that address the size and scale of CNC machines platforms (Tibbits 2012, Rosencrantz 2015).

My approach is neither functional or utilitarian, as I'm not investigating precision and optimisation. I look beyond the problem-solving method, which I find limiting and narrow in the answers that it provides. Some of the experiments mentioned above are thus overlooking the scope of implications for the users and the field itself. I argue that customisation for instance is

not a creative process if it's about choosing between a few pre-determined options - it only gives the illusion of freedom and control. As well, some of the issues such as latency or lack of purpose are not necessarily obstacles.

That said, this research does look at inclusiveness and engagement as clear inspirations and motivations. My experiential interactive approach invites to bypass the need of drawing on a software altogether and to seek a sense of purpose that emerges from the process itself, taking the focus away from the end-product. This is a premise for involving users with fabrication in a playful, intuitive, direct and affective manner. It is not meant as a precise and a systematic design method although notions of control and intention are still addressed and very much part of the process. Accessibility and engagement can be heightened by taking these processes in unconventional settings: for instance at home, or in a public space, with materials that are not sourced for the machine but that are already part of our physical environment, on location or at distance, in real time or over 1 month, with generic machines or machines that are designed for that single purpose. It also has implications for expert users, not just newcomers.

The *modus operandi* in question can thus allow *all* users to control or converse with machines in a creative, original manner. The point is more evident when the interactive experience is set as embodied interaction (Dourish 2001) with non-GUI interfaces that put emphasis on controllers that are related to the body (movement, gestures and habits) or that are related to cognitive traits (intuition, memory, sensory perceptions and behaviour). The aesthetic experience of control can be reinforced by using what are typical parameters of interactivity such as variations of time, latency, distance, location and endless range of data inputs: physiological data, personal activities data, community data, government-surveilled data, non-consented data, etc. In addition the shape and form factor of the devices that are interacted with can have agency in the quality of the interaction. A machine doesn't need to stay on a "desktop" or conform to the assumptions we have of about how it should look or where it is located. Any of these conditions can be applied in the interaction between humans and CNC-machines thus generating a substantial and expressive relation between the two. Besides

the HCI research, artists and designers have been contributing to these observations with their work on generative code, as the software artist Lia, and on data materialisation, as the artist Luke Jerram with his work, *Tōhoku Japanese Earthquake Sculpture* or as the collaboration of Lucas Maassen and design studio Unfold with the *Brain Wave Sofa*.



Fig 28. Lia, 'Filament Sculptures', 2014. Lia wrote code for a MakerBot to explore during few weeks the properties of the machine. Photo by artist. Retrieved from <http://www.liaworks.com/theprojects/filament-sculptures/>

Each of these endeavours have different purposes depending on the authors' intents as shown: tackling accessibility to 3D modelling, inventing more flexible tools, testing the affordances of the medium and producing eloquent data sculptures. The scope of this research is again to understand the meanings that interactive experiences can produce and their implications for our relation to the material world.

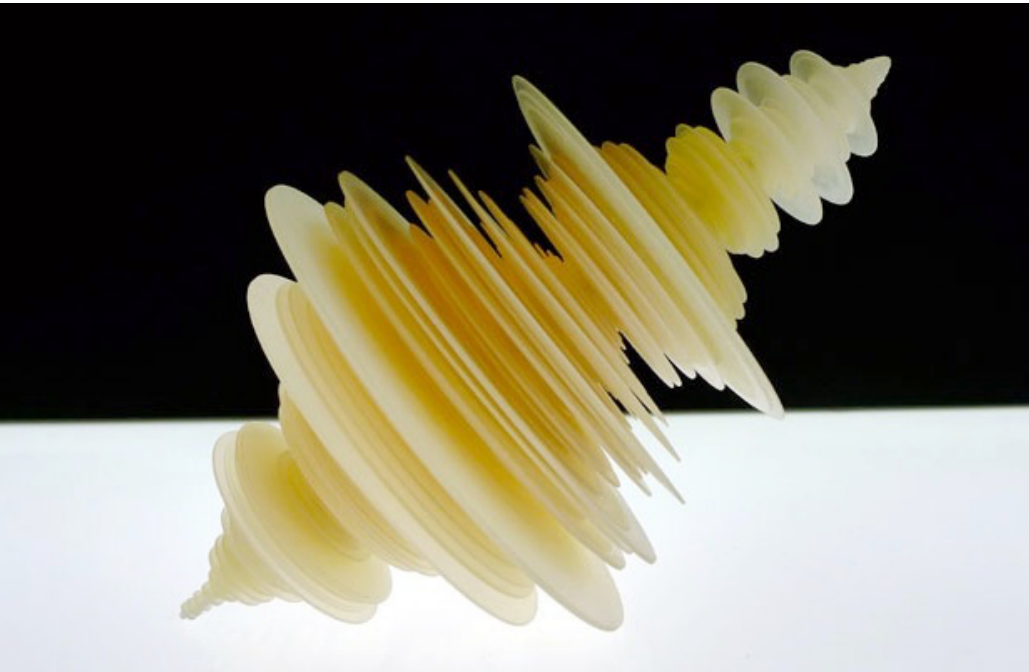


Fig 29. Luke Jerram, 'Tōhoku Japanese Earthquake Sculpture', 2011. A sculpture generated from a seismograph sample of the Tōhoku earthquake. Photo by artist.

These interactions do produce actual artefacts and because exactly that, they also produce something else: objects of a third kind, neither really functional nor really ornamental. They are materialisations of thoughts and concepts and they engage users in a different relationship between the physical and the digital world.

In his lecture-essay, 'Typewriter Ribbon' from 1998-2001, Derrida makes this idea of correlating the thought process with the machinic process an impossibility within his present and conceives of a future that could happen only by making the idea happen:

"Will this be possible for us? Will we one day be able,



Fig 30. Lucas Maasen and Unfold, 'Brain Wave Sofa', 2010. A sofa is generated from a sample of a brain-wave graph. Photo by artists.

and in a single gesture, to join the thinking of the event to the thinking of the machine? (...) If one day, with one and the same concept, these two incompatible concepts, the event and the machine, were to be thought together, you can bet that not only (and I insist on not only) will one have produced a new logic, an unheard-of conceptual form. (...) That is why I ventured to say that this thinking could belong only to the future - and even that it makes the future possible. (...) It would be an event that, this time, would no longer happen without the machine. Rather, it would happen by the machine" (Derrida 2002).

Derrida is troubled by the idea that repetition and predictability (the machine) are not compatible with the singularity and the unforeseen (the event). Further down, he reiterates the question but almost without expecting an answer : “In a word and repeating myself in a quasi-machine like fashion, how is one to think together the machine and the event, a machine like repetition and that which happens/arrives?” Venturing on digressions in a playful manner, it’s only until his very last words that he possibly gives us a clue, answers can be found in superpositions of temporal dimensions and perceptions of realities: “Sooner or later and virtually already, always, here now” (Derrida 2002).

It’s in another of his essay that we can find an additional answer: the khôra, an undefined space, an interval, an ‘other’, could be the necessary condition for abstraction to take form and shape (Derrida 1993). I interpret this as the staging of time, space and perception that computers can allow in an interactive experience.

I could differ with Derrida in retrospect that the idea was not a future possible but it had already happen, long before 1998 at the time of his lecture. Yet, it’s apparent that interactive fabrication does bring more than any previous technologies the event and the machine together, the instance within the iteration.

This approach is quite unique compared to typical linear design processes, even though Flusser defines the role of design in general as “giving material shape to concepts” (1999). Antoine Picon hinted that digital fabrication as such is putting forth the idea of superposing different notions of time:

“The computer and the various numerically controlled machines it communicates with are today redefining the nature of this intersection [between thinking and making]. Such redefinition is often presented as a radical departure from industrial modernity as we knew it. In terms of fabrication, it now seems possible to reconcile singularity and repetition, advanced customization and generic methods of production. The unique object and the series no longer appear irreconcilable.” (Picon 2014).

I would argue though that beyond digital fabrication in general, more specifically interactive differs by bringing the event on par with the machine, on equal terms. With this perspective, I’m putting forth that the elusive sense of uncertainty is as much a drive, if not more, than being purposeful.

3. DESIGNING FABRICATION EXPERIENCES

Taking into consideration the typical linear workflow of digital fabrication, which starts with drawing a file on a computer, prepping it for a CNC machine and waiting for the result, a start point is to see where the artist can intervene, where the chain can be disrupted, where interactivity becomes meaningful. There are multiple points that it can happen in the interaction between humans, data, machines, materials and the produced outcomes.

Operating factors: mechanisms, materials, machines, data

Below is an overview of the components that constitute considerations in the design of an interactive fabrication system. They are the operating factors that pertain to digital fabrication and data inputs.

Fabrication techniques (mechanisms)

Fabrication and transforming modes of materials are very diverse and may be related to the properties of the materials themselves, they may be natural or artificial, or reproduced artificially from natural processes. They can also represent the various stages of a lifecycle. This is a non-exhaustive list of such modes.

In addition, some of these techniques can be used in conjunction with others, in different steps of transformation (making molds) or with existing artefacts (adding material to existing objects, modifying and repurposing existing objects, repairing broken objects).

Erosion / addition / subtraction / attraction / explosion / affliction / denting / annihilation / formation / sedimentation / hardening / softening / melting / liquifying / cutting / engraving / piercing / embossing / sanding / forming / shaping / sculpting / folding / bending / molding / stretching / weaving / sewing / blowing / inflating / drawing / burning / heating / thermoforming / cooling / freezing / drying / pulverising / spray drying / freeze drying / milling / building / assembling / superposing / moving / shape shifting / dissolving / bonding / casting / lubricating / abrasive machining / grinding / vacuuming / screwing / glueing / welding / scanning / copying / pasting / erasing / pulping / colouring / blending / mixing / texturing / polishing / fermenting / breaking / roting / expanding / growing / squashing / compressing / squeezing / extracting / juicing, etc.

Materials

Materials can be natural, treated, composites, raw, recycled, repurposed.

Wax / metal / tin / souder / soil / sand / depositions / cement / plexiglas / plastics / polymers / wood / chipboard / cardboard / paper / paper pulp / cork / concrete / plaster / fluids / viscous materials / glue / hydrogels / collagen / silk / minerals / ceramics / chalk / limestone / oils / gaseous materials / living organisms / moss / bacterias / food / sugar / flour / salt / fabrics / rubber / styrofoam, etc.

They can come in different states:

- raw material (eg. sand)
- treated material (eg. clay, abs plastic, collagen)
- existing components (eg. metal sheet, wood sheet, fabric piece, brick, wire frame)

I also consider built, formed artefacts as materials for fabrication: floors, furniture, walls, landscapes, objects that exist in the environment.

Materials can be fed to a CNC machine or treated *in-situ*, as with the *Solar Sinter* made for the desert sand.

All materials have a different history as to craft, local traditions and techniques of transformations that influence as well the way they are used and perceived, especially for woods, metals and ceramics.

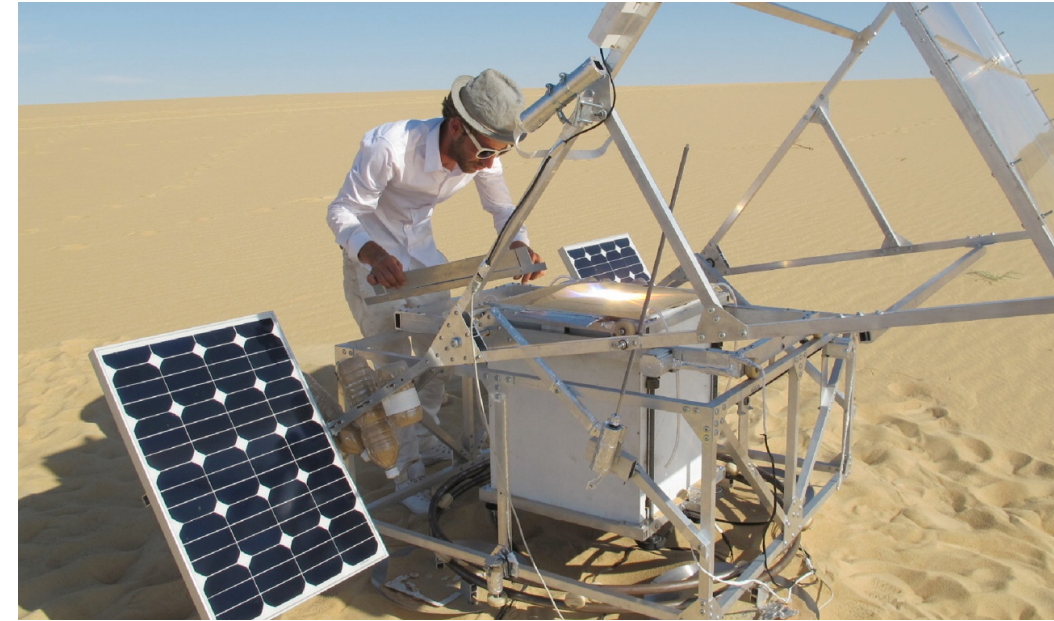


Fig 31. Markus Kayser, 'Solar Sinter,' 2011. A CNC-machine using the sun for power to shape sand material into glass artefacts. Photo by artist, retrieved from <http://www.markuskayser.com/work/solarsinter/>



Fig 32. Thing Thing, 'Tabula Rasta', 2012. A 'self-manufactured' plastic extruder is used for recycling plastics into custom shapes that reveal. Photo by artists retrieved from <http://www.thingthing.us/tabula-rasta.html>

Machines

There are many machines already existing that are set to shape or modulate particular materials with particular techniques. They are standardised and have existing software that interface with them: laser cutter, additive manufacturing printers, sintering printers, stereolithography printers, milling machines, routers of various sizes, vinyl cutter, etc.

Other machines as shown previously are made and invented for specific uses, they are illustrations of an idea. They are what I'm calling 'situated machines', that interact with a material on location rather than being fed with it. Other than *Solar Sinter*, another example of that is *Satelliten*, a drawing machine operated by the route of satellites.



Fig 33. Quadrature, 'Satelliten', 2015. "In a square of approximately 10cm², the machine traces [the satellite] lines in real time until the far away object leaves our horizon again. (...) Satelliten uses its own position as starting point and old maps of the area as a base for its drawings". Photo and description by the artists. Retrieved from <http://quadrature.co/work/satelliten/>

The form factor and the scale of the machine can also participate to the user interactive experience, especially if its physicality means that the user can get 'closer' to the machine. A portable machine or a small machine invite a closer proximity, a domesticity and possibly a higher level of intimacy, as it's been noticed with the laptop computer, and then the tablet/smartphone formats.

Personal Data inputs

There are many sorts of data inputs, especially the ones that are 'personal', from the body itself, to the activities we perform. It depends on the ways that the data has been recorded:

- *Body inputs*
 Movement / gestures / human presence (accelerometer, orientation, sonar, vibration, magnetic field, motion, infrared, force/loading, image/video, step, light, temperature sensors, etc)
 Type / touch (mouse, keyboard, switch, temperature, step sensors, etc)
 Voice (microphone)
 Face (AI analysis)
- *Physiological data*
 Brain Wave activity
 Weight, body fat, calories intake, bmi, size, steps, distance traveled, movement
 DNA / genomics
- *Life statistics with apps*
 Accountancy of our lives: life summarised, evaluated, interpreted in numbers
 Books we have read, movies we have seen, papers we publish, wealth, etc.
 We now have tools and apps that can track the data of 'living': hours we work, sleep, have sex, drink, eat, etc.

- *Computer activities*
 What we do on our computer and devices leave traces that are automatically digitised: photos, texts, emails, SMS, videos, Internet activity: sites we search, sites we visit, Facebook status, blogs, Twitter feeds, Instagram posts, Skype conversations, Google maps searches, You Tube videos watched, Facebook Likes, Facebook friends, GPS signals, passwords, crash reports, junk mails, etc..
 Smart buildings, vehicles, homes store now quantities of data that can recompose the life of a person through numbers.
- *Administrative services we use / public traces we leave*
 In addition to the public traces we leave using services such as Google or Facebook, we generation numbers and digits for countless operations: bank, social security, passport, medical records, phone numbers, addresses, age, fingerprints, customs, immigration papers, photos, visas, biometrics, taxes, pension, salaries.
 This is in addition to the data that we provide to companies, to governments without being aware of all of them: GPS routes, video surveillance, communication surveillance, facial recognition, public transport commute journeys, shopping customer information, credit card expenses, marketing information, etc.
- In addition, there are the databases that we may contribute to or use - examples are:
Databases that are produced: radio, tv, music, libraries
Medical databases: organ donations, sperms
Society stats: finance flows, traffic, laws, amendments, employment rate, taxes, crime, GIS, city planning, maps, global health, demography,
 And more data that affect us: weather, astronomy, sea levels, extinction of species, earthquake reports, etc.

Interactivity thus brings to the workflow a perspective of user-experience, a comprehension of it with metaphors, an appreciation of the human engagement with the machine and the process. At the same time, it's also

giving machines more space, more intimacy, more autonomy, more agency to be part of our lives. Thinking an interactive system is therefore a story of disrupting a technology, finding different uses than what is expected of it, in order for that technology to be possibly friendlier, kinder, more approachable. In that angle, machines are our friends, our weird friends.

The way to achieve that is to set up a system, set up the conditions that define the interactive experience. One of the findings of this research led to identify specific conditions and select some of them for experimentations. On one end, there are the operating factors as seen above, and on the other end, there are conditions, rules and contexts that can stage and enhance the interactive experience. The articulated ensemble creates a scenario for an experience, that should be as casual to implement as possible (e.g. the form-factor of the CNC-machine articulated with the notion of time, the notion of control and a user interface). Through this investigation, some user interfaces showed to imply different forms of engagement, as the description of the conditions below is exposing.

Conditions and rules of an interactive experience

The other elements at play in the elaboration of an interactive experience contribute to define what the interactivity is about. They can determine an overall 'level' of interaction, and invite more or less appropriation. Some of these components are common with aesthetics of interaction and with questions of user engagement in general (McIver Lopes 2015). Some others are more specific to interactive fabrication, and even more so to heighten the intimate character of interactive fabrication. All of these traits are in echo with one another. Here's an overview of the rules and conditions that modulate the experience and that were considered for this research:

Time and latency

Time is short for the 'time response' of a system, as in 'real time', as in evaluating the performance of a computer system by its ability to respond

more or less instantaneously to user commands. 'Real time' can be just as staged for an experience as other distortions of time. Most interactive installations tend to react immediately to user input (the classic image of 'push button - get result') while others invite users to wait or to appreciate time differently. In the case of digital fabrication, where latency (the time of waiting for an operation to end) is considered a problem to solve (until we arrive at immediacy), time can be a formidable experiential tool. It could mean for instance that an object can be built over a week or even a month, or longer, as my project *Streamline* shows, or as a potentially never-ending process, like with my project *Rabota*. Metaphors of growth or decay can be introduced as well.

Space

The location of the interaction, the surrounding environment can be greatly influential: the experience can happen in other places than the typical fab lab. Home is where things change from distance to intimacy. Bringing a machine home, domesticating it has all the possible implications of living with technology, that is that 'other' familiar (Auger 2012). Generally, taking technology that is usually expert-based or professional to mainstream public spaces can make all the difference: on the street, in shopping malls, in regular office spaces, etc. Museums and galleries constitute another variation of spaces that can connect non-expert users with proficient technology, even though the expectations may be different: things are expected to be unusual, surprising, and the curation can shed light and give aura to daily objects and techniques, like in my project *White Square Of*. Other qualities of the space can be determining depending on various purposes: size, structure, light exposure, ambient colour, texture of walls and floors, occupation, sound resonance, temperature, geographical location, smell, etc.

Participants

Similarly, the participants can be defined by the type of space used. In the case of this research, the participants are not specific. They're casual users of technology and could also be experts. They can live anywhere, be of any

age, gender, etc as long as they're wanting to participate in an experience of fabrication. In the experiments I conducted, there's an assumption that users would use Twitter or use quantified self tools such as the Fitbit. In past works, I aimed the experience at users in a relationship, separated by distance for instance, or at users in a particular cultural environment, or at 'flâneurs' of a city.

Individual/Collective

The experience can be addressed for an individual or for a collective audience. Generally, if the piece is on the Internet or in a gallery, it's made to be addressed for a large audience, unless it's expressly set up for one or for a couple or for a specific number of people (technical constraints can be the reason for that). In the case of *Twipology*, the data was collected from 1000 different users. And the outcome, a landscape was an invitation for all visitors to step in, although the setting was designed in such a way that only three people could sit at once. In the case of *Rabota*, the machine is entirely personal. It could be replicated to fit other users. And the outcome, the result can be enjoyed by other people. The project *Streamline* could be used by one individual or could be set up for two for instance, where one person communicates with another one by sending her 3D printer instructions to be printed.

Context

These remarks relate as well to the general context for interaction and can reinforce notions of intimacy and embodiment. And I mentioned the location and other elements pertaining to context. Data is of course primordial. If it's data from typical daily activities like sleeping, moving, breathing, this would make the experience probably more personal and emotional, same if the data would be our own heartbeats and pulses.

There could be a wide variety of contexts guided by a research agenda if the experiments are conducted in HCI (on accessibility and inclusiveness for instance). There's also a strong potential for social connectedness in

all my experiments, as I assume that technology is often a mediator of relationships. I cited *Streamline* above for connecting at distance - *Twipology* in a different way brings 1000 users together in forming a collective landscape. This study could be an investigation of modes of surveillance via the data that is collected, or it could be a comment on DIY culture, with notions of hacking and repurposing. I chose though to root this research in everyday life and convivial contexts, with an emphasis on the traces we leave that can become objects of memory. Everyday life and everyday use of technology are excellent premises for 'opportunistic interactions' (Freitas *et al* 2016) where people can just use the devices they already use for other purposes (as a smartphone) and allow them access to experiences in a very ad-hoc informal way.

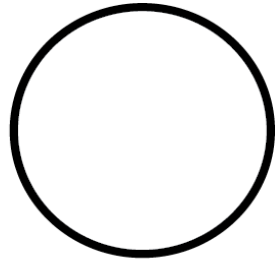
The Interface

By interface, I mean the system that will interface the user with the machine or the fabrication workflow. Evidently, in an interactive fabrication system, the idea is to correlate a user's personal input with an object being made. Drawing from observations of related work and of the experiments I conducted, I suggest three ways of user engagements with an interactive fabrication process. They are more or less direct, and depend as well on the constraints and situations evoked above:

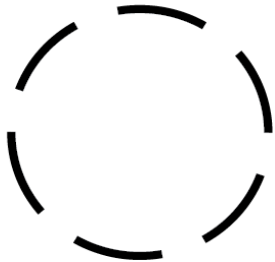
1. "Seamless": The user interacts directly with an integrated system. The fabrication process in this case is seamless. Machines need usually to be invented for that purpose, as with the projects *Speaker*, *Rabota* and *Streamline*.
2. "Broken-down": The user is involved with all the steps of a broken-down process. The fabrication happens in multiple interactive steps: the data is collected and processed first with a software and then fabricated typically with a standard CNC machine. Projects such as *Waveform Necklace* and *Fabricate Yourself* belong to that category, as well as my project *Lamp* (see pictures below).

3. “Partial”: The user interacts only with the data collection or a software interface. Fabrication happens at a later stage, the user is not involved with that part. Instead, the user’s data would be collected for a specific purpose, and the results would be presented after they’re fabricated. Projects like *Twipology*, *In-Flexions* vases, *Beautiful Modeler* and many others are in that category (see pictures below).

Seamless



Broken Down



Partial

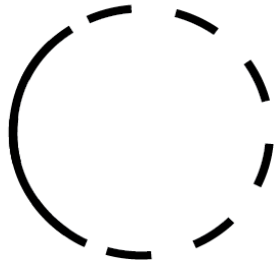


Fig34. User engagements in an interactive fabrication process. Diagram Joëlle Bitton.

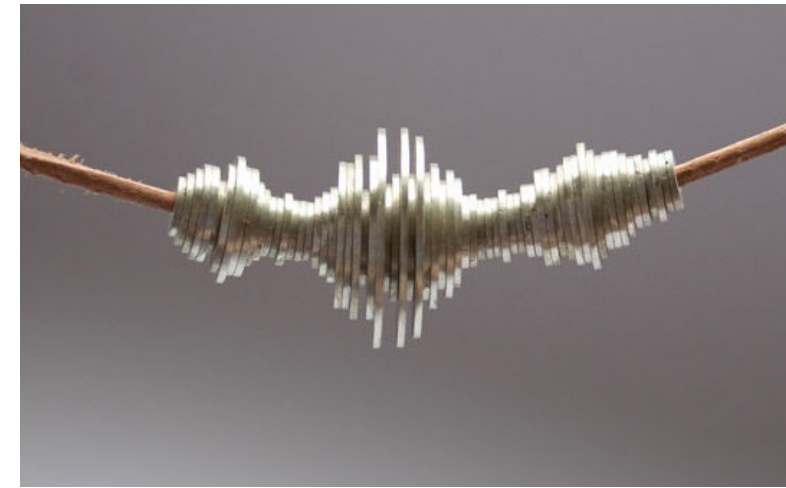


Fig35. #bzabiz, ‘Waveform Necklace’, undated. Item produced with a sample of one’s voice. Photo by author. Retrieved from <http://www.instructables.com/id/Waveform-Necklace-Bracelet/>



Fig36. Joëlle Bitton, ‘Lamp’, 2013. Sound excerpt laser cut on translucent paper over wood. Photo by artist.



Fig 37. *In-flexions*, 'Vases#44', undated. Vase shapes generated from voices and later 3D-printed. Photo Véronique Huygue. Retrieved from <http://in-flexions.com/#/vases44>

Level of participation

All the elements listed above have a direct impact on the level of participation and interaction. They're not necessarily in a cause/effect relation but they can make the user feel more or less contributing to the interaction. The user can be an operative at different stages of the experience (*see above*). The role that is given to the user can determine as well if the result will be completely different and singular each time or will have only slight variations between each user input. The former is very rare, as after all, a program proposes a limited number of variables. Even in the case of a generated design - say for instance a program generates drawing based on a few mouse clicks (*see image below*), the result will indeed never be

the identical between two users, but in the end, the aesthetics are just about the same, and render the user input anonymous. In the case of the project *Twipology*, even though there were constraints in the tweets that were gathered, and other would have produced different results, the overall general impression is the same. This doesn't mean though that the process is less interesting or less qualitative than an interaction that is completely singular.

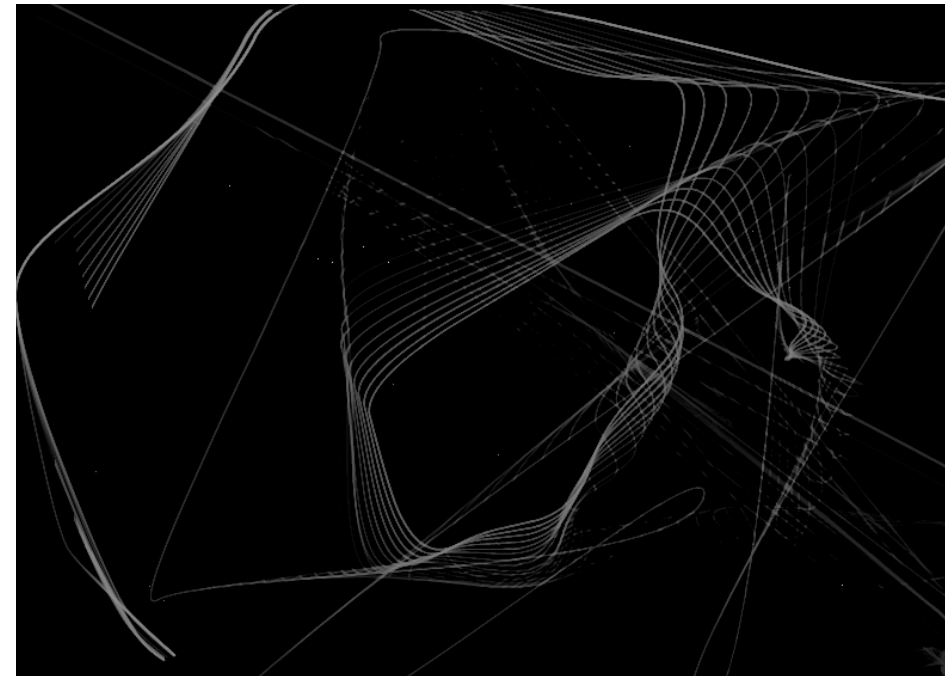


Fig 38. Raphaël Meyer, 'Streamliner', 2001, inspired by Levin & Snibbe's *Streamer*, programmed in Director. The user clicks on random positions on the screen and lines are generated in-between points. Work featured on [Superficiel.org](http://superficiel.org). Screenshot retrieved from <http://superficiel.org/temp/streamingtrails/index.html>

Awareness of Control

This relates of course to the notion of control. Where this research is concerned, the notion of control is furthermore determining: it's the tacit link between 'digital' and 'fabrication'. It's there in the 'CNC' acronym. Computers are controlling machines and humans control computers. It's in the staging of that 'control' that we can construe all the creative and aesthetic possibilities of digital fabrication. And this precisely is the core disposition of interactivity. Interactivity in relation to digital fabrication appears as an evidence, bringing about the perfect components of appreciating its significance: notions of control, embodiment, materiality, performance and tangible trace. In the interactive experience, the user can be given higher or lower level of control, or made to think she's given control. Interactivity is often accused of being an illusion of control although all the components listed above can insure that user control can be acknowledged. Here, in the end, it's somewhat the ideal of interactivity that is questioned. The inclusion of the user in the process, the participation, the shared authority and power (or the surrender of it) by the author are aims and ideals that can be sometimes touched upon in interactive experiences, but they're often elusive. Many external factors interfere: lack of budget, lack of time, technical constraints, user-studies and experiences run in privileged contexts (Western countries with an audience that is financially stable, has facilities with technology, is college-educated, is used to visit museums and galleries, is sensitive to innovations, is willing to participate to workshops and public events). That said, these aims remain guidelines to work towards.

Feedback

A correlate of control, the feedback is two-fold: it's the direct results of an interaction and it's the visual/auditory helps that guide the user in the interactivity (a button is pushed, and it makes noise or light). The staging of the feedback overall supports the user understand more or less clearly what the effects of her input are. Again, it's not necessary to have immediate or clear feedback in all interactive experiences. There are settings where the

user can do without understanding causes and effects or where visual and auditory helps can confuse the user. User effects can be intuitively learned (the user tries different things and observes the result) or instructed. That knowledge invites repeated uses and iterations to check all possibilities. Changes of behaviors and habits could ensue in order to produce different outcomes. Similarly, notions of storytelling and editing could emerge as the user could foresee a series of action instead of a standalone one. In a previous work of mine, *RAW*, the system allowed specifically for forms of editing as participants were recording sound by taking pictures. In the case of interactive fabrication, the system could lead to repeat making objects over time, in series and as an ensemble.

The Decision-making process

In order to understand the implications of interacting with CNC machines and elaborate on some ideas that were brought up by early research, I needed to conduct experiments and make prototypes of interactions. With all the components listed above, there are endless possibilities for orchestrating them and designing experiments. Constraints of budget and time, opportunistic options and intuitions help narrow down the possibilities. There were a few components that I estimated relevant to implement in order to reinforce intimacy and familiarity:

- Real-time fabrication
- Direct seamless interaction with a machine
- Use of the body including voice, gesture
- Use of readily-available interfaces such as the mobile phone
- Use of a sensual material such as ceramics
- Use of resources easily available in stores or repurposed from things already at home
- Original, innovative designs

As explained in the methodology section, it may not be possible for experiments to implement all the components at once or for some not at all.

Each project I conducted though, small or large, tested some of these aspects. I realised that each time, the choice of materials, outputs, mechanisms, data is necessarily a comment on the overall experience and that it was often guided by metaphors.

For instance, early experiments in classes offered some leads. In the class '*Architecture of the Envelope*', I was able to test out the use of ceramics for repetitive shapes, as units for structures. In the class '*Digital Manufacturing*', I made my final project about mixing one 3D-printed connector with components available in a hardware store or at Ikea. And in the class '*Expanded Mechanisms / Empirical Materialisms*', I could test the design process of envisioning a singular machine in correlation with the behaviour of a material. The team work in that case pushed for the system to have a useful outcome - a structural quality - which led me to realise that in addition to the challenge itself, a driving purpose was possibly not letting the interaction of the machine with the material emerge with its own meaning. In the class '*How to Make Almost Anything*', I was able a year later to revisit the whole process, affirming more clearly some of the choices and still failing at others.

There were also questions that led to some of the decisions:

- about the user involvement (What would be meaningful for the user? What would an open system mean in the case of digital fabrication?);
- about contributions (What opportunities do I want to demonstrate? What are the artistic or design approaches that can seize these opportunities?);
- about editorial directions (Could the result be abstract or should it be meaningful objects? Should it be machines that I'm building or systems or something else?);
- about practicalities (How to understand personal data and geometry? How to deliver a feeling for the material and its behaviour? How to articulate interactive gestures, materials and fabrication techniques?);
- about methods and evaluation (How many experiments should I build? What can I deduce from experiments, what can I observe?),

Below are other examples of the decision-making process I went through in the different projects.

The choice of materials

With materials, the options to consider are pretty much endless and each bring its own set of questions, challenges, techniques, history, related work, etc. It can be a question of personal interest or it fits with the technique, with the overall meaning of the experience, or with the metaphors that are used. Are there materials that fit a particular project or metaphor? A particular data set? Paper pulp was chosen for the project *Pulp Fiction* in the class '*Expanded Mechanisms / Empirical Materialisms*' for various reasons: it can be made cheaply from recycling newspaper and magazines at home (again making do what's readily available), it's fairly under-explored as a material for fabrication, it has a rich history of aesthetic qualities. The paper pulp was later mixed with Rockite so it would dry faster and would create together very light brick units. I came back to paper in the class '*How to Make Almost Anything*', this time for its relation to folding structures and because of its behaviours when laser cut, especially if layered on top of a wood sheet that acts as ink when burned. In the '*Digital Manufacturing*' class, bronze was imposed as one of the materials we had to use, and I chose to interface it with wooden dowels because they are available from hardware stores and can easily be repurposed. Ceramics material is a personal favourite of mine and of course, it's one of the oldest materials used in human civilisation - it seems compelling to approach it within the realm of digital fabrication; it has properties and drying behaviours that are appropriate for metaphors of sedimentation, as the *Streamline* project shows. There was also the opportunity to use an existing clay 3D-printer that had been built at the GSD for a research project. Clay is very user-friendly and more sensual than ABS plastics. With the project *Twipology*, the milling technique was decided first and it was simply cheapest to start experimenting with styrofoam for the many necessary iterations. Styrofoam was still the cheapest solution when the project changed scale and an entire room surface needed to be covered. Regarding *Rabota*, the material was the main focus: it was the existing fabric of a home, and more particularly the bedroom floor.

The choice of data

In terms of body and personal data inputs, we are in front of an open field. Voice and sound are inputs that seem obvious, for their simplicity and playfulness - I used them for the final project in the class '*How to Make Almost Anything*'. For the 3 main projects: Twitter feeds were chosen in replacement of phone text messages, the initial choice for the easier implementation; sleep data was picked as it's a quantified self data easily available with a common tool like the Fitbit, it's rarely repurposed, and it felt relevant at the times when I was suffering from insomnia; the project Streamline led to consider a different set of data altogether, one that could be gathered from asking participants for their emotional states at different times of the day, over several days.

Initial case study: the multiple steps of a project

For the final project of the 'How to Make Almost Anything' class, I was finally able to design an entire interactive system - yet very constrained in terms of time, scale and technical abilities. As mentioned, I decided to explore sound as a data input. Sound is commonly used for interactive experiments, and in interactive fabrication as well. It's a material itself, one of intimacy and familiarity, that we use with ease and comfort. For the scope of the class, in regards to the larger scope of the research, I decided to have the final project be an object that is both functional and ornamental - a lamp shade. The overall idea was taking a metaphor of transformation from sound to light. I wanted to create a machine in the process, that would integrate the whole experience (from input to output), but it soon proved that it wouldn't be feasible within the time frame and structure of the class. As I was diving indeed into each week's assignment, my time was mostly used learning how to make the most basic aspects of it. I couldn't reach a higher level of complexity and therefore scaled back the general project.

The final experience implements the following process:

1. speak in a computer mic,
2. visualise it on Processing,
3. save a PDF of one sound moment,
4. save the file as an EPS for laser cutting,
5. laser cut on paper and wood,
6. mount on a lamp frame

The lamp had the benefits of holding the pattern in plain shape, of being structural, of allowing for an accumulation of layers, and representing an assembly construction³³.

Sharing the lessons learned: Applying observations

I conceived a J-term class at Harvard GSD in January 2015 called 'Quantified Self and Fabrication', for which I put forth the methods and observations I gathered prior³⁴. The description of the course was as follow:

"We produce increasing quantities of data in our daily activities, text messages, email, exercise data loggers, commute records, each could be opportunities for data-driven design and digital fabrication, a characteristic connection. We investigate in this course whether this set of data can have real effect on the physical reality of our lives. Have you ever thought of making a chair using a text message? How can your email exchanges shape the lamp in your bedroom?"

The 3-day course that will look at modes of creativity using data for fabrication and inform processes for collecting the data, manipulating it and structuring it.

Join a practical session discussing the relationship between the machine, material, data and design."

³³ A detailed account of the project and the multiple steps is described on the class website <http://fab.cba.mit.edu/classes/863.13/people/joelle/>

³⁴ It was conducted and co-organised with my collaborator Kevin Hinz.

The description was phrased with exaggerated examples on purpose, in order to trigger surprise and curiosity.

The structure of the class consisted the first day in the introduction of all participants and interests, a presentation on the topic and implications with precedents, and the types of data that could be used; tips on software tools available for processing the data; overview of materials in relation to machines or vice-versa. We then ask the students to form teams and identify the type of personal data they wanted to use. Many in-class discussions took place to generate ideas while afternoons were devoted to putting ideas to practice.

3 projects were elaborated by the 5 students of the class over 3 days. Team 1 used the recorded video of a commute walk and milled a maze board in wood, Team 2 used the motion of a hand and milled a sculpture of that motion in foam, Team 3 used photos of objects in drawer and their colour to sculpt a imaginary city-like ensemble.

An anonymous survey at the end expressed great enthusiasm for the class and confirmed that experts and designers could also be motivated by these methods: “The in-class discussions of our projects were perhaps the most exciting part of the class. I really appreciated Joelle and Kevin’s willingness to discuss and interest in exploring the possible implications and directions the projects implied and might’ve led to, even if those ideas were beyond the scope of the workshop. These conversations allowed us to think of new ideas around data collection, the connection to fabrication, and the broader implications of these kinds of practices, even if we would not be able to do some of the far-reaching projects we discussed.”

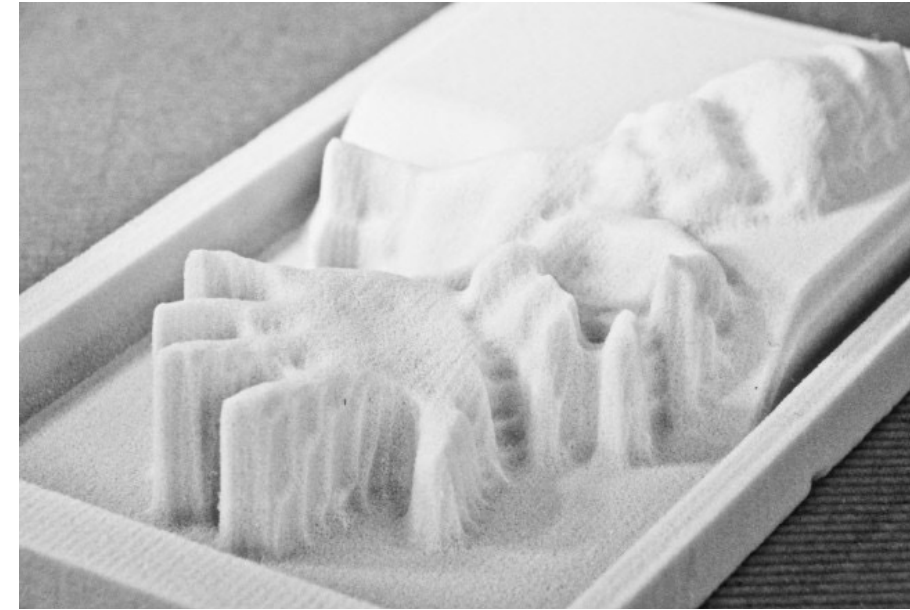


Fig 39. Saurabh Mhatre, ‘The Art of Motion’, 2015. Motion of a hand milled in foam. Photo by artist. Retrieved from <https://selffab.wordpress.com/project-1/>

4. IMPLICATIONS

Iterating on these experiments, sharing lessons, gathering feedback led to observing a number of implications for designing an interactive fabrication experience as described above.

Framework for an Interactive Fabrication Experience

How do we understand the relationship between data, people and fabrication? As indicated, the place of the body, the use of personal data and the proximity to machines are all elements at play in the fabrication process. Usually rather separated, this research proposes to articulate them together in a framework.

The conclusive framework contains *some or all* of these conditions:

- Use of personal data as parameters for machine control
- No instructions or minimal instructions
- Body as an interface for interaction with the process
- Proximity to fabrication machines and interfaces at home, in a public space (gallery, shop, street), in a non-professional environment, with tools already available such as the phone
- Use of fabrication latency as a strength and not a problem
- Use of machines that are created for specific experiments
- The outcome keeps evolving with time

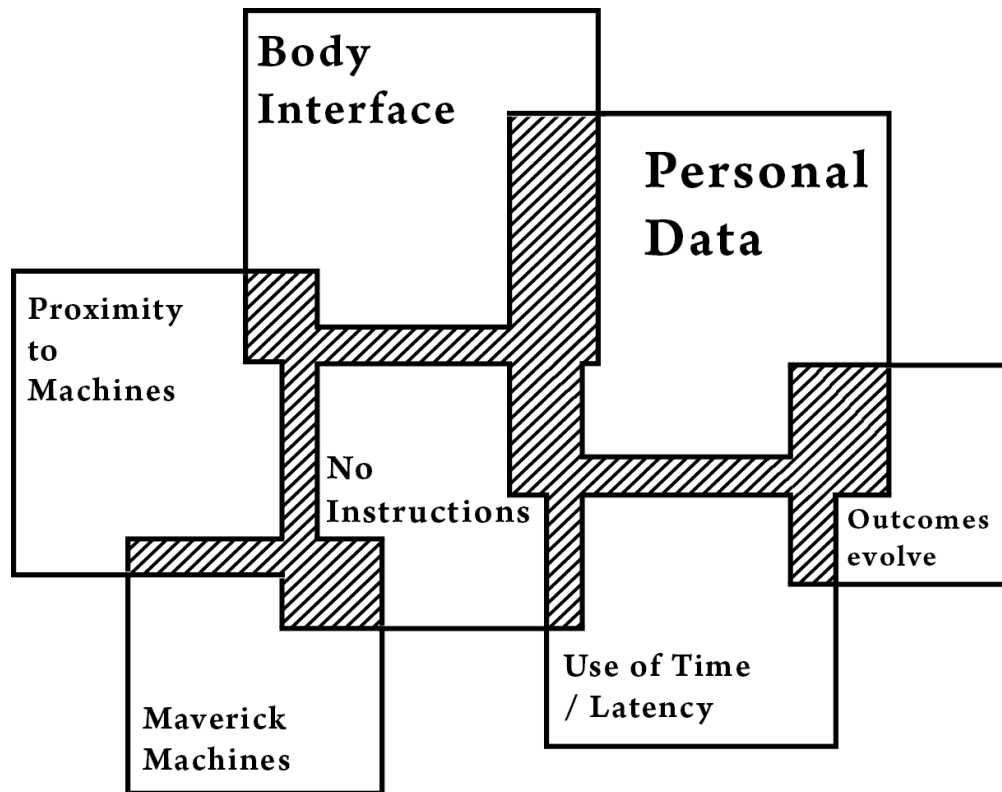


Fig 40. Framework for an Interactive Experience. Diagram Joëlle Bitton with Kevin Hinz and BJ Johnson.

Data and Geometry

This question of the correlation of the data to the geometry as brought up in a previous chapter became central. It relates as well to the purpose and workflow of digital fabrication. If there's no clear purpose, there's more agency left to the association between machines, materials and data that will lead the geometry.

One of the first observations that came about, was to question how the data should be interpreted into geometry. Could there be a method for that? The fabrication processes that we evoke trigger indeed unique questions of possibilities vs results. The relationship between data and geometry that is not based on equivalence but rather on aesthetic or user-experience decisions bring about the uncertainties of this research. Yet, methodologies can emerge that can be replicated and shared.

There are a few types of correlation that were noticed:

- The XYZ method
In *Twipology*, the data was on a XYZ basis, and therefore the geometry was defined for each of the direction with information from the text itself.
- The Metaphor of the data
In the case of *Rabota*, the data is based on cycles, repetitions, disruptions. So it made sense to use that to control the behaviour of the robot.
- The existing grammar
For *Lamp*, the pattern made use of the existing graphic representation of sound waves - the lamp shape gave it a volume. Other projects as seen above have made similar use of sound waves as they've been familiarly visualised. Mathematical equations are consistently a reference in that matter, referring to geometrical shapes that are founded on an existing language.

- The machine properties

There's the data correlation that makes use of the machine itself, the way it behaves with the material, the way it wants to 'go'. *Streamline* is an example of that, such is the project that software artist Lia conducted with her MakerBot.

- Purpose-driven

The project *Pulp Fiction* was purpose-driven for the most part, balloons were blown in different shapes according to a specific need. The project was also material-driven, to highlight the quality of the paper pulp.

Regardless of the types of correlation, there is the question of the legibility of data, cited earlier. Again, I would argue that it matters most in the case of information design, where data visualisation should support a clear comprehension of the issue-at-hand. Other than this specific case, it's a matter of the users expectations whether their participation is tantamount to that awareness. It's therefore the work of the artist and the designer, if the legibility should not be a factor, to accentuate that the experience is foremost one of contemplation, of wander or of appreciation for the shapes as they are.

Making sense of the experience

As an echo to that last question, another implication concerns the ways that the interaction is made sense of in relation to purpose and the produced outcome. Design in its common understanding posits a purpose. Similarly, fabrication invites a process of materialisation that is originated from a digital drawing that will serve as a guideline. Even though it's accepted and often welcome that errors, mistakes, incidents and changes will occur that will modify the original purpose, there is still a formed understanding of an end point.

In this research, I have questioned that end point, beyond traditions of considerations of outcomes that fill a need or a desire for an object that falls either in the functional or the ornamental categories. It is even possible that in some instances, the user produces an 'object' without even being aware of it. As the next chapter shows, the 'objects' that are produced in this research are thought to have a 'life' of their own beyond their fabrication that imparts a certain tangible inertia. Metaphors of decay, growth or metamorphosis have been mentioned as well as scenarios where the 'objects' keep being 'fabricated'. The 'objects' could thus continue to be transformed and to transform their users, or possibly additional users, as they get placed in different contexts. Fabrication does evoke a tangible, haptic, material manifestation of sorts. Inevitably, the objects that emerge from this process could be tangible captures of an instant, a version of the "Kodak moment"

*the geometry
of data*

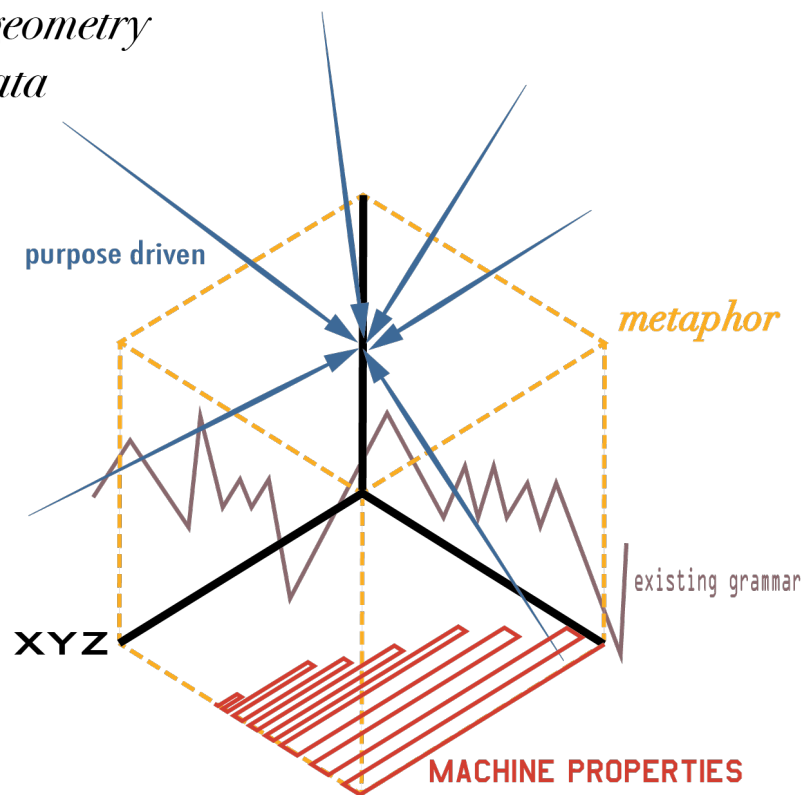


Fig 41. *The Geometry of Data*. Diagram by Joëlle Bitton, with Kevin Hinz and BJ Johnson.

that become objects of memory.

5. EMBODIED FABRICATION

Summarizing the comments laid out in the previous section, this research proposes that the input of personal data in digital fabrication enables users to physically intervene in their everyday life environment in unexpected, playful and speculative ways. I argue that a form of embodied fabrication emerges where processes can engage users beyond the design of a 3D file and beyond the immediate fabricated outcome.

Embodiment and Intimacy

In his work on ‘embodied interaction’, Paul Dourish (2001) showed that the convergence of tangible computing (Ishii and Ulmer, 1997) and social computing at the end of the Nineties affected the way users would interact with technology, as physicality and phenomenological perceptions were increasingly involved. In his words “users create and communicate meaning through their interaction with the system (and with each other, through the system)” (Dourish 2001).

In my research, I propose that interactive fabrication supports Dourish’s premise and adds to it by engaging the body of the user further into the process. As the machine changes scale to become smaller and portable or could adopt possibly a much larger scale, the body of the user can engage with a much greater proximity. The machine does not have to stay on a desktop either, it could be located in different parts of a house for instance (by the bed, in a closet, etc), it could be worn or held (which is already the case with the 3D-printed pen *Doodle*).

This newfound intimacy could let us explore possibilities of ‘embodied

fabrication’. Furthermore, digital fabrication as a social tool or social medium is increasingly being studied, notably for its ability to support collaborative fabrication at distance (Mota 2011, Ilan 2011). As we can use those tools to build relationships, they become agents of connectedness (Agamanolis 2003).

‘Programming the physical world’: transforming the fabric around us

With the expression “programming the physical world”, Neil Gershenfeld struck the imagination with science-fiction terminology (Gershenfeld 2013), something that only super-heroes can do when they bend the physical and material world around us, they twist it or expand it, by a movement of their hand or with a very deep thought, as seen in *The Matrix*, *X-Men* or *The Fantastic Four* (Kakalios 2005). Super-heroes walk through walls and are themselves machines of transformation (and fabrication and destruction). In the illustrations below, the character Silver Surfer is rebuilding his surfboard craft from his own body (he’s his own 3D-printer) and Jean Grey from *X-Men* mind-controls the molecules around her (see panels below).

This increased malleability of stuff endows the body of users with power, especially if the user-experience is set to remove steps and instructions and to add playfulness, intuition, immediacy and surprise. The idea of ‘programming the physical world’ reinforces the role of data and information as inputs into the process. The use of parametric design has already pervaded the material world with so much influence (Picon 2010, Jabi 2013, Dunn 2012). We are not limited in how we can adapt, map, instil data that we generate everyday for it to be materialised. In this research, the interactive experience of the user with the fabrication process is thus both driven and strengthened by the use of personal data.



Fig42. Silver Surfer Panel. Character created by Jack Kirby (1966). Marvel Comics.



Fig43. X-Men Panel featuring Jean Grey. Character created by Stan Lee and Jack Kirby (1963). Marvel Comics.

Forms of action

As I take the counterpoint of a formal fabrication process where a design is first drawn before being transformed into coordinates for fabrication, I put forth the possibilities for material interventions rather than thinking in terms of construction. The need for 3D software design that often is the primary obstacle for accessing digital fabrication is circumvented. This research explores processes that are not necessarily precise and performative: we could look at modes of erosion, abrasion, fermentation, interruption etc with material sources that may already exist, like the furniture and the walls in our home or the concrete on our streets. All are forms of action and intervention that are modulating what's at hand right now rather than building from the ground up. Recalling the open system notions described in the beginning of this chapter, the analogy is inclined towards 'seed planning' (or 'seed *planting*') rather than master planning, with botany beyond engineering as a model³⁵.

These ideas open up possibilities for individuals on their own or in collaboration to intervene and mark their physical environment. As they play and manipulate their environment with their own actions, they transform the space around them, show traces of everyday life, capture moments in time. It could be a form of "self-design" in the sense that Enzo Mari in his work *Autoprogettazione* advocated: an exercise in fabrication is an exercise in appreciation of the way things are made, and I would add the way things are in the material world (Mari 2014). It's a form of "self-projection" if we take the Italian word *progettazione*, design, for one of the meanings that it carries within: projection. Something akin to the *hypomnemata* that Foucault described as one of the techniques of 'care for the self'. I would argue then again that these processes create a form of literature, or *graphein* where we shift from the 'analog-to-digital' paradigm to the 'analog-to-digital-to-analog' paradigm.

35 Observations of "seed planting" are based on Edith Ackermann's remarks during the thesis defense.

Finally, this study is a literal interpretation of in-betweenness, as I'm proposing to materialise emotions, indelible moments of life and abstraction - both in the sense of what artists and designers have traditionally aimed for throughout history and in the sense of what this technology allows specifically in terms of immediacy and correlation. Examples abound in history of art, craft and design of representations of 'action concepts', traces of life as they happen, including concrete poetry, dance notations, Cageian scores and ready-mades. These are strange outcomes worthy of our gratitude.

MEASURE OF ABSTRACTION

Odd Materialism

1. MATERIALITY AT PLAY
2. PHYSICAL RIPPLES: TWIPOLOGY
3. THE DOMESTIC ENIGMA: *RABOTA*
4. MUTANT MATTER: *STREAMLINE*
5. OBJECTS OF A THIRD KIND

1. MATERIALITY AT PLAY

I have underlined in the dissertation's introduction the wonderful world of materiality and how it's too often disregarded as a by-product of a negative consumer culture. Materiality is so much more complex than that though. It's indeed who we are, in a literal sense. It's the process of transforming thoughts, ideas into visual, tangible artefacts, experiences that hold some of the emotions and power of human imagination. This study is as such an opportunity to notice better the material world of everyday or at least as George Perec referred to in his book *Espèces d'espace* to "question what has ceased to surprise us" (Perec 1974):

*"Ce qu'il s'agit d'interroger, c'est la brique, le béton, le verre, nos manières de table, nos ustensiles, nos outils, nos emplois du temps, nos rythmes. Interroger ce qui semble avoir cessé à jamais de nous étonner. Nous vivons, certes, nous respirons, certes; nous marchons, nous ouvrons des portes, nous descendons des escaliers, nous nous asseyons à une table pour manger, nous nous couchons dans un lit pour dormir. Comment ? Où ? Quand ? Pourquoi ?"*³⁶

36 "What we need to question is bricks, concrete, glass, our table manners, our utensils, our tools, the way we spend our time, our rhythms. To question that which seems to have ceased forever to astonish us. We live, true, we breathe, true; we walk, we open doors, we go down staircases, we sit at a table in order to eat, we lie down on a bed in order to sleep. How? Where? When? Why?" [trans. ed. John Sturrock, Penguin Books, 1997].

As this research is in the realm of fabrication and produces tangible outcomes, it should examine the materiality that it creates: what is it? What does it mean? What are the fabricated items that come out of the interaction with the machine?

An argument could be made that these outcomes are just by-products of the interaction, that the interaction or the experience or the system are "where the action is"³⁷ and are the main considerations of this research. This could be true in a certain angle, but one of the findings of this study was to acknowledge that the object at the end of the experience was both a marker in the timeframe of the experience and an interrogation to unravel. The produced materiality soon became the way to make sense of the experience and the tangible trace of a unique moment, giving the research and the proposal their meanings.

Taxonomy of Related Projects

In the previous chapters, I have presented several examples of a digital fabrication materiality that push the boundaries of the medium. The 2013-2014 exhibition *Out of Hand: Materializing the Postdigital* at the Museum of Art and Design (NYC) presented a number of these examples under six themes including "Modeling Nature", "Pattern as Structure" and "Processuality"³⁸. It was a great attempt at seizing some of the qualities of this emerging materiality. The *BrainWave Sofa* or the *Vases* from the design studio In-flexions that I presented earlier were featured in that exhibition. Other items featured in the exhibition were the EZCT's *Computation Chair* and Maya Lin's *Imaginary Iceberg*.

37 As Paul Dourish's book title on HCI explains.

38 Since then a few more exhibitions have showcase these "emerging materialities" as very recently as the Ars Electronica Centre festival in September 2016.



Fig 44. EZCT, 'Computational Chair (Best Test 1-400)', 2004, Elm, 35 3/8 in. high. Retrieved from *Out of Hand* catalog.



Fig 45. Maya Lin, 'Imaginary Iceberg', 2009. Plaster, 27 1/2 x 76 1/2 x 50 in. Retrieved from *Out of Hand* catalog.

This type of works are now more and more numerous. In the case of this research, I've selected for the related work mainly projects that have used interactive processes or generative processes based on a set of data, which is a much narrower scope than the *Out of Hand* exhibition. I established a taxonomy of projects that reflect on the trends I noted, even though some of these projects could belong to more than one category. Many projects pursue the legacy of data visualisation, where a dataset is represented visually, here in tangible manner, or the legacy of software art, where code creates forms. I make the case that the fabrication adds a dimension of complexity and presence, where before those items were restricted to computer screens or wall posters.

The following categories take into account the intentions of the artists and designers, their creative processes, the statements they make and the functions they are supposed to occupy.

Data Sculptures

The term 'sculpture' pertains to the notion that the object has no utilitarian function (at least in its primary premise). It's a work of art that emerges from a specific dataset. A sculpture is also a process of fabrication frozen in time. The project *PaperNote* (2013) conceived by students of the Copenhagen Institute of Interaction Design uses a sound source to realize a sculpture, with the technology of laser cutting. This sculptural approach is found in the work of artist Luke Jerram and its 3D-printed representation of a seismographic sample from the Tohoku earthquake in Japan (2011) that was shown earlier. Projects by artist Andreas Fischer *A week in the life* and *3 days in the life* (2008) view his urban movements and telephone communications with laser-cut shapes later assembled as a mural topographic sculpture. These pieces have inspired the project *L'empreinte des mouvements* (2012) by Catherine Ramus that retrace people's commute journeys over a month thanks to their geolocalisation data.



Fig 46. Andreas Fischer, 'A Week in the Life', 2008. Photo by artist.

Form chasers

In an article on generative system, Fran Castillo (2012) mentions the notion of “forms generated by code” or by software behaviours, citing the “forms follow data” paradigm previously defined by Manovich. Generative Design and Software Art have long been claiming a “craft of code”, using the inherent aesthetic properties of programming, codes and software to generate art. Some of these code artists have since integrated the tangible outputs of CNC-machines. The artist Lia has recently published a series of 3D prints called *Filament Sculptures* (2014) that experiment with the idea of filaments and the “movements of the printhead” of a MakerBot. The artist Marius Watz has an extensive catalog of generated tangible essays: *FormStudies* (2011) realised in a MakerBot residency and *ArcSurf* drawings (2012) realised with a laser cutter. Even though these processes are embedded in a software culture, these projects often get inspired by the medium itself, the machine and the materials and their affordances, possibly more than in other categories. The forms are therefore not necessarily

following just data, but also the whole ensemble of actors at play in a digital fabrication ecosystem.

This is why I include in this “form chasers” category the glitches, interruptions and remixes that fully embrace the operativity of the medium constraints and promises. Among many examples of such experimentations, there’s the *Approximately 800cm³ of PLA* project (2016), curated by Gabriel Vanegas, in which invited projects are 3D-printed each with a limited amount of material regardless of the original size of the project.

There are the 3D prints failures collected in a Flickr account, the ‘*Art of 3D print failure*’ for a newfound appreciation. And there is the work of Plummer Fernandez, the series *Digital Natives* (2012) where scanned everyday objects are distorted with algorithms.

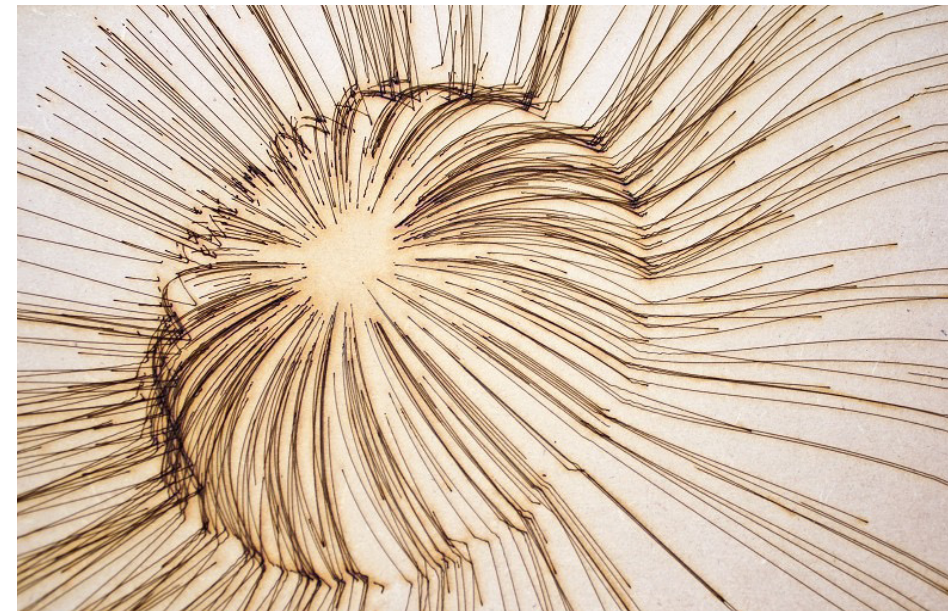


Fig 47. Marius Watz, 'ArcSurf,' 2012. Series of laser drawings on 6mm MDF. 20×30 cm, all uniques. Photo by artist. Retrieved from artist's website. <http://mariuswatz.com/2012/03/08/arcsurf-drawings/>



Fig 48. 3D printed Yoda fail. Flickr Collection 'the Art of 3D print failure'. Photo by Walter Gordy. Retrieved from <http://thecreatorsproject.vice.com/blog/3d-printed-glitch-art-when-3d-printing-fails>



Fig 49. M. Plummer Fernandez, Series 'Digital Natives', 2012. 3D Printed (plaster, ink, adhesive). Photo by artist. Retrieved from <http://www.plummerfernandez.com/Digital-Natives>

Fixtures As Structure

I'm transforming here one of the categories naming from the exhibition *Out of Hand* that was called "Pattern as Structure". Within that term, the section showcased computer-assisted art and design objects that were using patterns "not all visible to the naked eye". In a way, my taxonomy takes that starting point and details it further. In this category, "fixture as structure", I encompass all objects that have a familiar function, such as a piece of furniture, as the receptacle of a dataset that may or may not be related to that meaning.

One of the iconic examples in that section is the furniture piece *Brain Wave Sofa* by Lucas Maassen & Unfold (2010), modelled from 3 seconds of neural 'alpha' activity and milled. The furniture might be familiar but the geometry is still rather unsettling. This category includes items of jewellery, fashion, houseware, lamps, etc. Mitchell Whitelaw's *Measuring Cup* for instance "presents 150 years of Sydney temperature data".



Fig 50. Fig 47. Mitchell Whitelaw, 'Measuring Cup', 2010. 6cm high. Photo by artist. Retrieved from artist's website. <http://teemingvoid.blogspot.com.au/2010/06/measuring-cup.html>

Performers

The fabricated outcomes have a performing quality, they can be played like a record or reenacted in relationships or stage a scene. The project *Holodecks* (2013) by Lukasz Karluk maps a dataset onto a 3D-printed object than can be ‘read’ again later. It somehow enables the data that was used to create the object to remain useful beyond the print. In this case a piece of music 3D-printed into an object can be “played” in an iPhone app by reading it, in a similar process than with a QR-code. The CNC snow machine, the *Snowmaker*, can artificially deposit snow to create landscapes, like in the Swiss ski-station Zermatt. *Twipology* (2014), the project I created using Twitter feeds is staged as a garden landscape that people can use. In their work, *A Digital Music Box Ensemble*, the artists Takuma Takahashi and Shugo Hirao use responses to a questionnaire they established with personal quirky questions to generate a grid pattern then transformed into a punched paper for a music box.



Fig 51. Zermatt's ski slope designed with the “Snowmaker”, a cnc-machine depositing snow. Photo by Danny Lane. Retrieved from blog article “Where The Alps Are A 3D-Printed Landscape Made From Artificial Snow” <http://www.bldgblog.com/2014/01/where-the-alps-are-a-3d-printed-landscape-made-from-artificial-snow/>

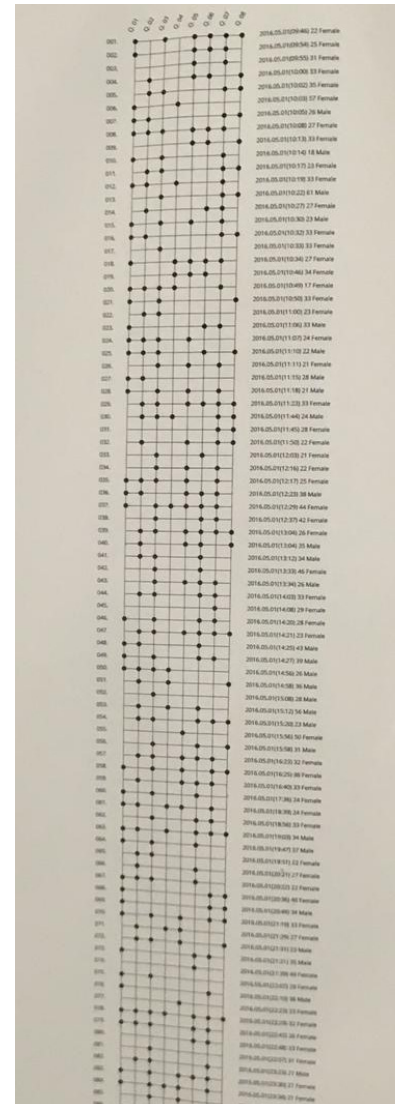


Fig 52. T. Takahashi & S. Hirao, ‘A Digital Music Box Ensemble’, 2015. 100 people were surveyed on 8 multiple choice questions including “Do you consider yourself lucky?”, “If you could travel with a Time Machine, What would you do?”, “Do you believe in ghosts?”. The ‘result’ creates a punched card for a music box.

Bodies as Interfaces

The research at the Computational Design Lab, Carnegie Mellon has been mentioned before, with a series of prototypes on the theme of ‘interactive fabrication’, including *Speaker* (2010), a platform that generates the wireframe representation of a sound wave recording, *Spatial Sketcher* (2010) that represents tangibly human sketches in the air, *Fabricate Yourself* (2011) that reproduces the human body once scanned and *Shaper* (2010), a 3D-printer like machine that is controlled with sketch-like gestures via a touch screen. The group has been mostly exploring ways of interacting in real time with a fabrication device (Willis *et al*, 2011). Other endeavours in that domain include research at the Hasso Plattner Institute in Potsdam on interfaces with a focus on ‘directness’ - for instance with a hand-held laser pointer guiding in real-time a laser cutter (Mueller *et al*, 2012). The *FreeD* is a “handheld digital milling device” developed at the MIT Media Lab (Zoran & Paradiso, 2012).

Projects that don’t necessarily use the term ‘interactive fabrication’ have emerged from design studios. Other than the *Vases#44* previously cited from the studio In-Flexions that use the voice of a participant to change the base structure of a vase (to be potentially 3D-printed), there is *Paysages Domestiques* by Romain Remigereau that enables participants to mimic “in the air” the shape of a vase with a system linking the Kinect Skeleton Tracker and Grasshopper/Firefly, with the object printed by a third-party service. More recently, Diego Pinochet has investigated a gesture grammar for a “cybernetic CNC cutting machine” (Pinochet, 2015). My projects *Streamline* (2016) has components of embodiment, where users are involved with their bodies and emotions in the fabrication of outcomes.

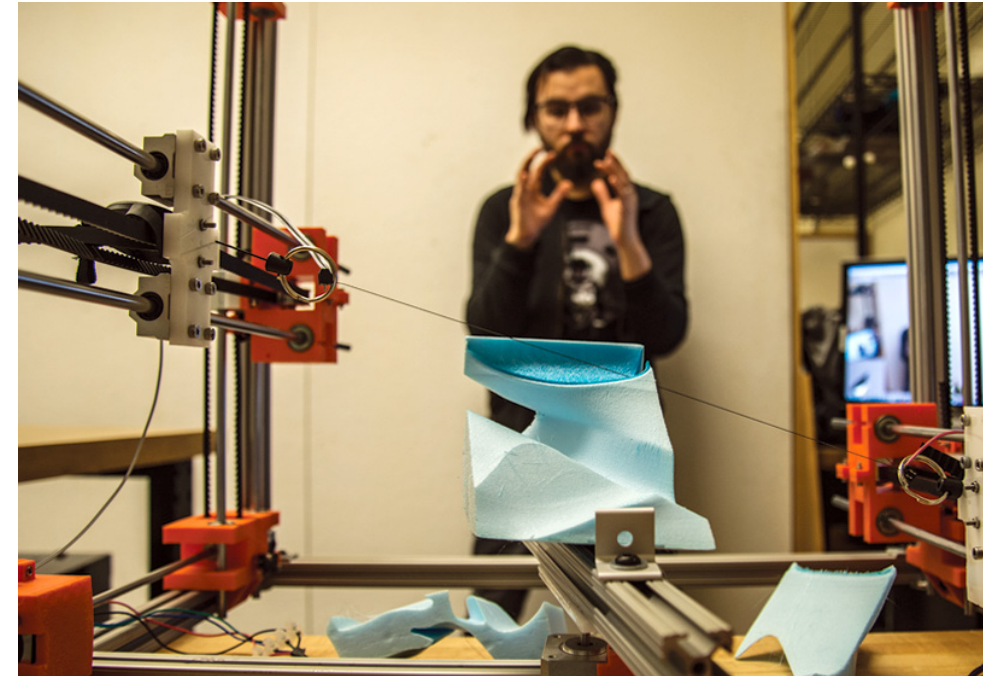


Fig 53. Diego Pinochet, ‘Making Gestures: A personal Design and Fabrication system’, 2015. Photo by author. Retrieved from <http://www.youfab.info/2015/winners/making-gestures-a-personal-design-and-fabrication-system>

Mavericks

Several of the outcomes described above are products of standardised machines or common processes that are explored or repurposed in a wide range of creative practices. There are also the outcomes fabricated with machines that were invented for unique and irregular purposes. I have mentioned previously some of the history of these ‘maverick machines’, an expression coined by Gordon Pask (Bird & Di Paolo 2008). The machine *WX* (2012) for instance controls the progression of water in an aquarium that

solidifies hot wax as it mounts. Other machines adapt to their environment and interact with the surrounding fabric, which I have called ‘situated machines’ like the *Solar Sinter* (2011) by Markus Kayser that transforms *in-situ* sand into glass and *Satelliten* (2015) that intervenes on existing maps and draws satellite trajectories. Similarly, my project *Rabota* (2015) is a machine that only operates in the existing fabric of a home.



Fig 54. J.L.G. del Castillo y Lopez, C. Ervin, and K. Palen, ‘WX’, 2012. Photo by authors.

Research Experimentations

Many of these projects were a source of reference and inspiration for the experimentations I conducted. In my case, there were a few elements at play that informed my choices. In regards to what was already existing, it was important to be distinct and go further or push other boundaries. For the sections ‘Data Sculptures’, ‘Fixture as Structure’ and ‘Form Chasers’, as brilliant and eloquent the projects are, the field even though young, has somewhat already been largely explored. I wanted to draw in different qualities, such as embodiment, real time, more direct connection with data, users implication and for that the projects from the latter sections ‘Performers’, ‘Embodied’ and ‘Mavericks’ were more fitting as references.

I’ve developed three prototypes to put the research into practice. Each project has enabled me to push the boundaries of interactive attributes for fabrication. With the project *Twipology*, I’m looking at the materialisation of collective social data, and the meaning of the generated shape. In the case of *Rabota*, I’m interested in the domesticity of digital fabrication using the home environment as a material to shape. Finally, with my last project, *Streamline*, I’m frontally addressing the notion of control and the performance of the material, with users controlling a machine in real time from anywhere.

The 3 projects have elements in common. They all refer to visual poetry, aspects of time captured, traces “born witness” of moments. They all use personal data, whether from quantified self tools or from applications, and tell something with that data. All the outcomes suggest objects of a third kind, an ‘odd materiality’. And each project addresses as well more specifically some of the questions and conditions that were laid out in the previous chapters.

The projects could be highlighted from different angles:

- data used (ie. Twitter feeds)
- machine / fabrication process used (ie. milling machine)
- material used (ie. bedroom floor)
- creative process (ie. compromises)
- metaphors/inspirations (ie. antique wood planer)
- user-experience (ie. controlling a machine with text messages)
- user scenarios (ie. a relationship at distance)
- outcomes (ie. a design probe)

These aspects have all been described, notably in the ‘Interactive Paradigm’ chapter as operative factors and as parameters that inform the creative choices. In this chapter, the focus is on framing the findings of the experiments in terms of outcomes. As such, the outcomes are the fabricated outcomes that constitute the platforms for conjectures. Therefore, in order to highlight the findings, I chose to put forth the materiality at play that encompass the objects themselves and the sense they make, the promise they hold or the desire they inspire. It’s also the tangible, visible artefacts that remain, with which the users continue to live and appreciate.

The point is made again about the material world: “Living is a process in which humans adapt to natural and man-made objects and environments. It is a reciprocal process of consciously or unconsciously forming and designing through living with material artefacts.” (Freitas 2008).

The three projects I have created thus put forth a specific materiality:

Physical Ripples: *Twipology*

The Domestic Enigma: *Rabota*

Mutant Matter: *Streamline*

2. PHYSICAL RIPPLES: TWIPOLOGY

Twipology is a styrofoam garden, the design of which is generated from Twitter conversations. Words and other elements of collected tweets are converted into XYZ geometries together creating a radical landscape. Loosely inspired by the constraints of a Japanese rock garden, where contours, reliefs and patterns hold metaphors for the world around, *Twipology* invites visitors to inhabit the space and reflect on the intensity of their delicate environment.



Fig 55. Joëlle Bitton, *Twipology*, 2014. Exhibited at fortyk gallery. Photo Jake Rudin.

The main challenge of the project resides in making sense of the geometries that were generated at first. One answer came from a visual perception of “ripples” that led in turn to its rock garden reference. And just as in a rock garden, *Twipology* does not grow - at least in a vertical sense (but it could grow horizontally). The idea of a social landscape that people could inhabit is a reflection on the origins of the data (in this case online social conversations): we assembled 1000 physical tweets together (each 3”x4”) in a 14’x18’ room.

Premise

Twipology was the first prototype that would fully integrate the lessons learned during the previous short exercises and would implement some of the research hypotheses: use of personal data for fabrication, use of collective data, direct and real time fabrication, machine portability or ‘intimate scale’, user proximity to the machine, public setting among others.

The project was conceived as an artwork and started primarily with the idea that users should interact with a CNC-machine with a fairly common and omnipresent interface: their mobile phone, and more specifically its text messaging function. In any set of circumstances, whether at home, in a public space, a gallery, at night, at day, in rural and urban areas, people carry their phones. All phones, basic or smart, can send and receive text messages. Therefore, an interactive system set in a gallery for instance that would require users to text could rely on them to do so instantly³⁹. The interface is already there. It allows as well many users to be participating at the same time. The other original wish was that a singular machine should be built for that purpose, for linking the ‘easiness’ of the interface, the strangeness of the ‘instruction’ (a text message) with a unique fabrication process, all in a public setting.

39 Many artworks have used that affordance in the past. A previous work of mine in collaboration with Raphaël Meyer proposed to night clubbers at the Elysée Montmartre, Paris during the Nuit Blanche (2007) to text messages to a phone number - the messages would then be represented with different graphic qualities and projected on several large screens above the crowd. Participants started to communicate with the rest of the crowd as the night went on.

Project sheet

- July 2014 - March 2015
- Collaborators: Nic Shackle and Paul Mesarcik at Thinkging, Kevin Hinz, José Luis del Castillo y Lopez
- Software: Twitter API, Processing, Rhino, Grasshopper, MasterCam
- Material: Styrofoam
- Data: Twitter feeds
- CNC-machine: CNC-Router
- Fabrication process: 1. collecting data, 2. transforming it into geometry, 3. routing it in styrofoam
- Aim: Using text data, easily accessible, to control machine in real time
- Main Operative condition: Twitter (the data)
- Secondary operative conditions: the geometry (correspondance between data and representation)
- Code variables/conditions: Twitter text properties: hashtags, length of words, number of words, use of photo, use of url, etc.
- Inspirations: No particular metaphor, the purpose was to start experimenting with an initial idea
- Level of Interactivity (scale 1-5): 2
- Progress: Twitter was easier to experiment with than text messages (for software reasons); using an existing machine was better as well to start the experimentation as soon as possible
- User-experience / Interactivity: Sending a tweet with hashtags that are given in advance
- User-scenario: Space that is created with Twitter data, used as a garden for people to contemplate
- Outcomes: visual poetry, ‘physical ripples of our lives’, the garden metaphor made sense of the shapes
- Shortcomings:
 - The initial project was to have participants send text messages in real-time, specifically for the project
 - There’s no clear connection made between the exhibition visitors and the Twitter users

From idea to compromises

From that idea, others aspects needed to be addressed: how would the text message be interpreted as an instruction by a CNC-machine? What type of fabrication should the machine operate? What would it produce?

At this point, the answers to these questions are based on intuitions and scenarios of use. I envisaged that the text message would be mostly used for its format (number of words, repetition of words, length of sentence, phone number used) and possibly in its content (text analysis). A form of fictional measuring instrument was imagined to be generated with these parameters with an ad-hoc CNC-milling machine, that would have the flexibility and lightness of a drawing tool (*see sketches below*).

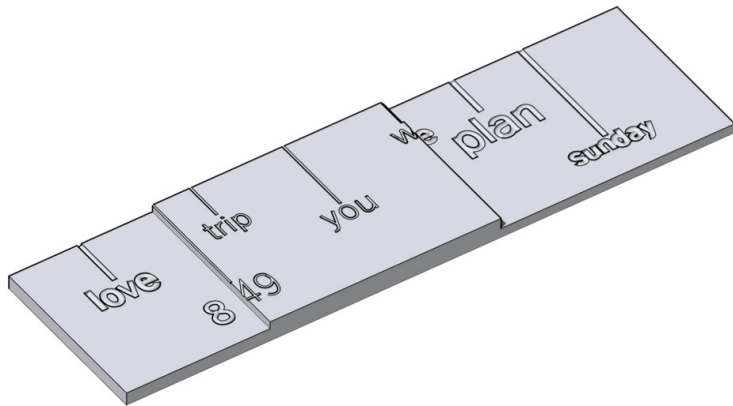


Fig 56. Joëlle Bitton, *Model of the ruler made with 'Informer'*, 2014.
Modelled in collaboration with Kevin Hinz.

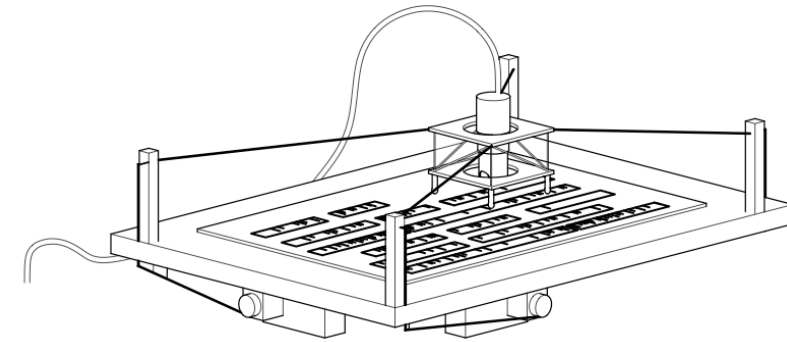


Fig 57. Joëlle Bitton, *Model for the CNC-milling machine 'Informer'*, 2014.
Modelled in collaboration with Kevin Hinz.

The model of a CNC-milling machine was chosen for several reasons. In the context of a public setting, it's presumed that a large number of objects would be produced with a quick turn around, which rules out the 3D-printer. The laser cutter was disregarded as well, as it needs heavy safety procedures and ventilation. Finally, I noticed that the possibilities of fabrication processes involving engraving, eroding and cutting are little explored compared to other innovative technologies, while it is a much more flexible process than deposition for instance.

When I started to discuss the idea above with possible collaborators for the project development, I was encouraged to break the project down into small steps for time, budget and technical constraints. Mainly, it came to put aside the ambition to make a specific machine and to focus only on collecting data and transforming it into a XYZ geometry that could be milled later on on an already existing CNC-router. The ruler representation was given up as well, as it was not fully satisfying at that point. The other

component that had to be dropped was the use of text messages, considering the many hurdles for setting up a server that receives and treats text messages. I was advised by the programmers⁴⁰ I collaborated with while on a stay in Cape Town, South Africa to use Twitter feeds, as the Twitter API allowed for flexible and rich data-mining. I accepted these compromises so I could achieve results in a rapid manner and because I considered that it would be a first iteration. Some elements of the original ambition were kept: personal data (Twitter feeds), a fairly ubiquitous medium (Twitter on laptop or phone), collection of data in real time, text as the “informing” data and the notion of a collective or public setting still possible. The Twitter API provided the opportunity to use or play with additional information: I only used the feeds featuring a specific hashtag term, which allowed to collect all feeds that were using the same term in real time. Hence, a diverse set of geometries could be showcased under the same hashtag. The hashtag used was set in the code as a variable, so that it could be changed whenever the program was running, allowing for adapting the collection of feeds with news topics or other reasons.

Twipology - version 1

With my collaborators, we agreed that the text would be transformed into a XYZ geometry for milling, with the X axis representing the number of words, the Z axis representing the length of each word, and the Y axis, an extrusion that used the Sentiment API, an algorithm that matched the word with its use on comments of movies on the IMDB.com website, therefore determining if the word was considered a ‘positive’ or ‘negative’ one. The program was created in Processing. Each time it runs and for as long as it runs, it collects the tweets using a determined hashtag. There’s a visualisation window that shows in real time as well each geometry that is generated (*see screenshots*). The title of the piece *Twipology* came about soon after I noticed the topological quality of the piece, and mixed it with the root of Twitter.

⁴⁰ Nic Shackle and Paul Mesarcik at Thinkging, a one-of-a-kind design studio in Cape Town that I was very grateful to work with.

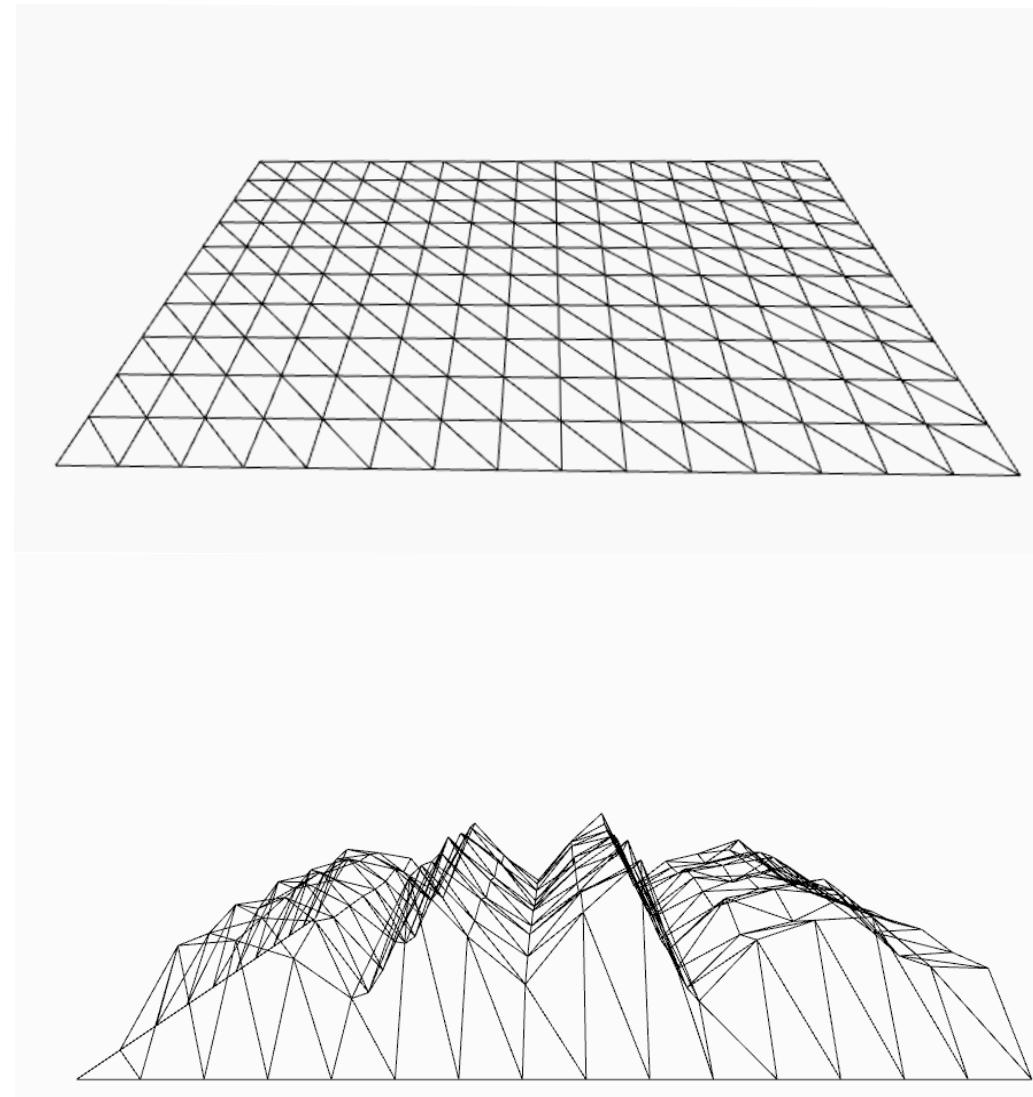


Fig 58. Screenshots of Twipology visualisations with the program written in Processing: base platform (above), tweet received (below).

An additional feature was added in the code: words would be randomly selected from each feed and turned into ASCII art (I proposed that feature in case it could play a part in the fabrication later on but ended up not using that possibility) (see pictures below).



Fig 59. Two examples of ASCII art generated from tweets with the Twipology app (2014).

Each tweet collected generates a CSV file (comma-separated values) with the X, Y, Z coordinates for each point of the mesh (see sample below). This CSV file is instrumental for the fabrication part.

sep=
0 0 208.89697
2 0 123.40114
4 0 106.76042
6 0 274.6861
8 0 141.48882
10 0 365.53595
12 0 486.50366

Fig 60. Sample of the CSV file showing the coordinates for the first section of the mesh of a tweet: X|Y|Z (there are as many sections as there are words in the tweet).

I picked several hashtags for rapidly testing the system for fabrication: #beatles, #casablanca, #cigarette, #control, #disco, #pink, #radical, #sugar, #surface, #system, #water, #whatever, #yesterday. As the program ran with these hashtags, I collected fifty or more tweets. Since it was collecting the

tweets that were received in real time from the moment the program was running, some hashtags were more popular than others: the frequency of receiving tweets that used the hashtag #depression or #system was much higher for instance than with #casablanca or #yesterday. For some of these, I had to wait several hours to collect the tweets. While other hashtags that were used to test the program at the very beginning like #iphone crashed the program, as there were too many tweets received per second⁴¹. From all the tweets I collected in that round, I randomly selected 24 tweets for fabrication.

The dimensions of a materialised tweet were decided loosely based on the dimensions of a medium size everyday object (book, tablet, notebook, plate, plant pot, etc), approximately 12cm x 16cm for the base - it's also a size small enough to start testing the fabrication rapidly. The Z size needed to be further constrained in proportion to the base. With the parameters of a CNC router and the milling tool, we had other constraints to take into account. We defined that the first tests would be limited to 7cm in height with a base constraint of 2.5cm to ensure some structural integrity in the sheet. The diagram below lays out the limitations. The overall optimal size of the materialised tweet based on the Z size constraint would therefore be 12cm x 16cm x 7cm, milled with a 1/4" tool.

In order to be understood as a file for CNC fabrication, the original CSV coordinates are read and remapped to the new constrained dimensions in the visual programmer Grasshopper, a plug-in of the CAD software Rhino. The points are relaid onto a grid and connected with lines: the new resulting

41 Hashtags on Twitter are usually used as items of collective conversation, therefore in conjunction with other hashtags or as a standalone iconic meaning that is understood by a community-at-large. It's probable that hashtags like #system will infer comments on technical problems ('systems down') or technology-related matters, #sugar would gather tweets about sugar addiction or diet issues, #cigarette shows people trying to quit, #depression brings people suffering from mental health together sharing their ordeals, #water showcases campaigns for fair water access, etc. Terms that are less representative and more open to interpretation may thus be less frequently used as a hashtag, and would gather less tweets. It's worth noting as well that when I selected these 12 hashtags, I did not always foresee that the meaning I had in mind would be rather different than its use on Twitter, appropriated by a social community. In that sense, the term #surface ended up being mostly used by people using the Microsoft tablet while I had in mind the architectural meaning.

mesh is then imported into a CAM software (MasterCam) where a toolpath is generated for commanding the milling router. Styrofoam was chosen as the material for prototyping the fabrication, for its costs and “malleability”. Another collaborator in this project Kevin Hinz oversaw that particular fabrication process. 24 single outputs were fabricated - we ended up calling a single output, a “twip”.

Frequency Limitations

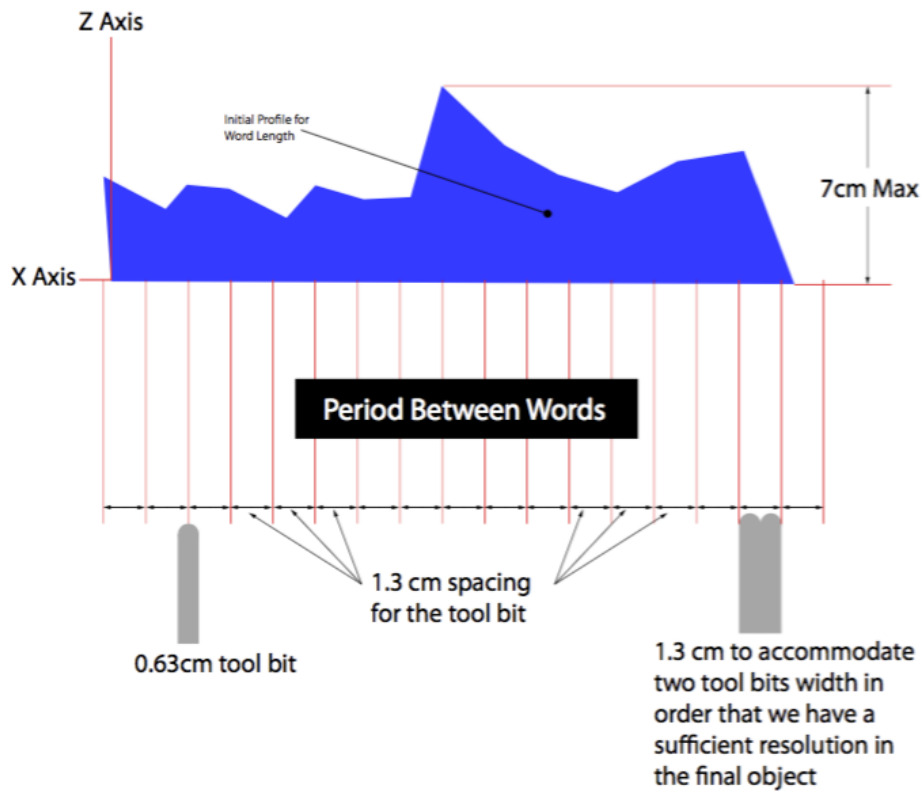


Fig 61. Limitations due to the toolbit size, milling in depth and across sections. Diagram by Kevin Hinz.

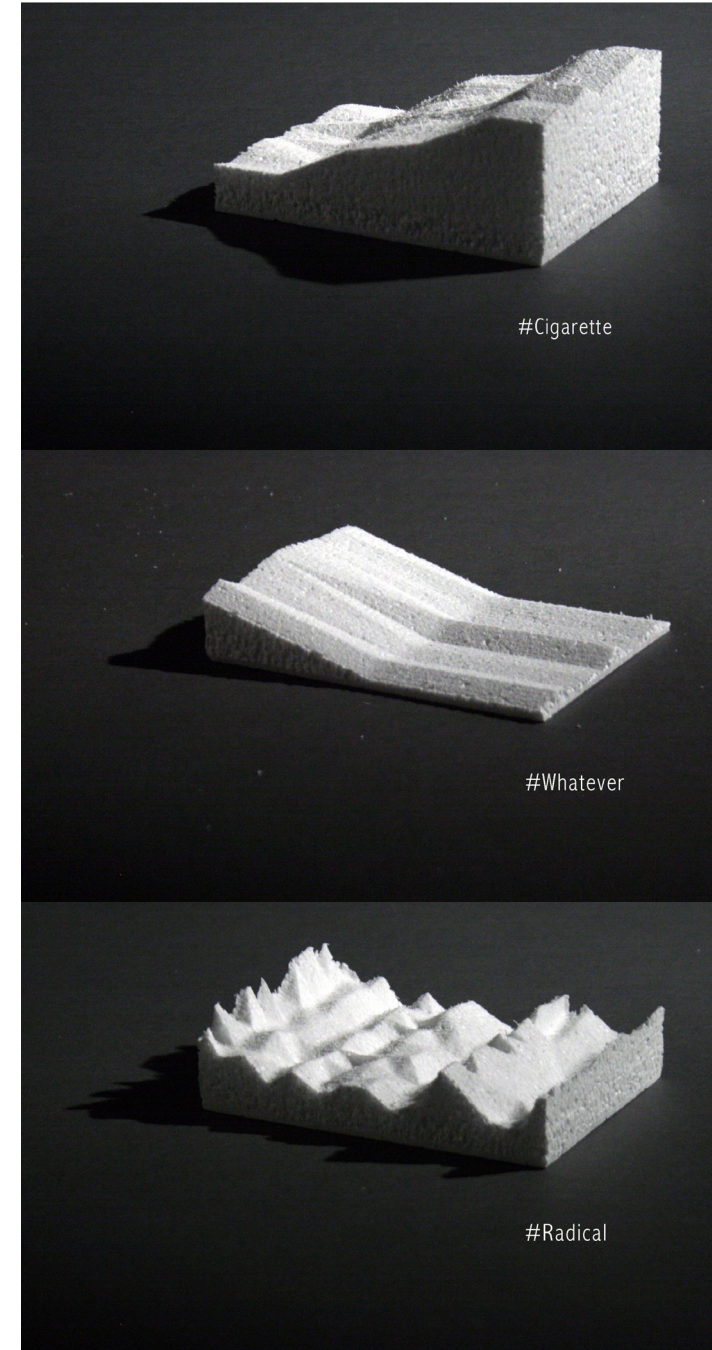


Fig 62. Twipology single outputs or “twips” milled in styrofoam (2014). Photos by Joëlle Bitton.

Twipology - version 2

The second version of Twipology came about when I tried to answer the question of the public sharing of such materialised items. If the original ambition of having users directly generating their own geometry with an access to the machine was put aside for this project, it still mattered that an audience that participated to the data could savour the result. Because of their fairly small size and their texture, I had always envisioned that the twips should be presented at floor level so visitors could see them from above or would have to stoop or sit down to look at the patterns in detail. I imagined the twips presented as an ensemble, a series, a growing collection from what I had gathered so far.

An opportunity to exhibit the work at the Harvard GSD *fortyk* gallery provided me with a context to think with. With an empty room available of 4 meters by 3 meters, I imagined the whole floor completely filled with twips instead of a few of them displayed individually. But what would that space mean? How could it be presented to an audience? It needed to tell a story of some kind, to be the metaphor of something, to be evocative.

Since I was basically composing a ground surface, I reviewed all sorts of ground features and textures: tiled floors, house floors, carpets, roads, sidewalks, swimming pools, crosswalks, giant chess games in public spaces, hopscotch lines traced in chalk, the game Twister, forest grounds, accumulations of dead leaves, moss covers, yoga mats, dance floors, snow landscapes, sea surfaces, farm fields and many others.

Since an accumulation of the materialised tweets would form an ensemble of patterns on the floor, I looked into artworks and displays for reference that use similar features:

- patterns of colour, contrasts, noise (James Turrell's light frames)
- grids, repetitions and rhythms (John Cage's diagrams and uses of I Ching, Kitasono Katue's poems)
- floors as playgrounds and as surfaces for perceptions (Robert Breer's *Floats*, the projection of the Eames' *Powers of Ten* on the floor at

Design Museum London (1998), the Jacques Tati exhibition at La Cinémathèque française (2008), my own installation *Abstract* (2007) where shadows were the interactive plays), etc.

Among these references, the work of Charles Gaines in particular (*see images below*) that can be appreciated at different distances inspired me to play on the points of view of visitors that could be gained when standing, lying down and sitting on top of the tweets at various points in the room.

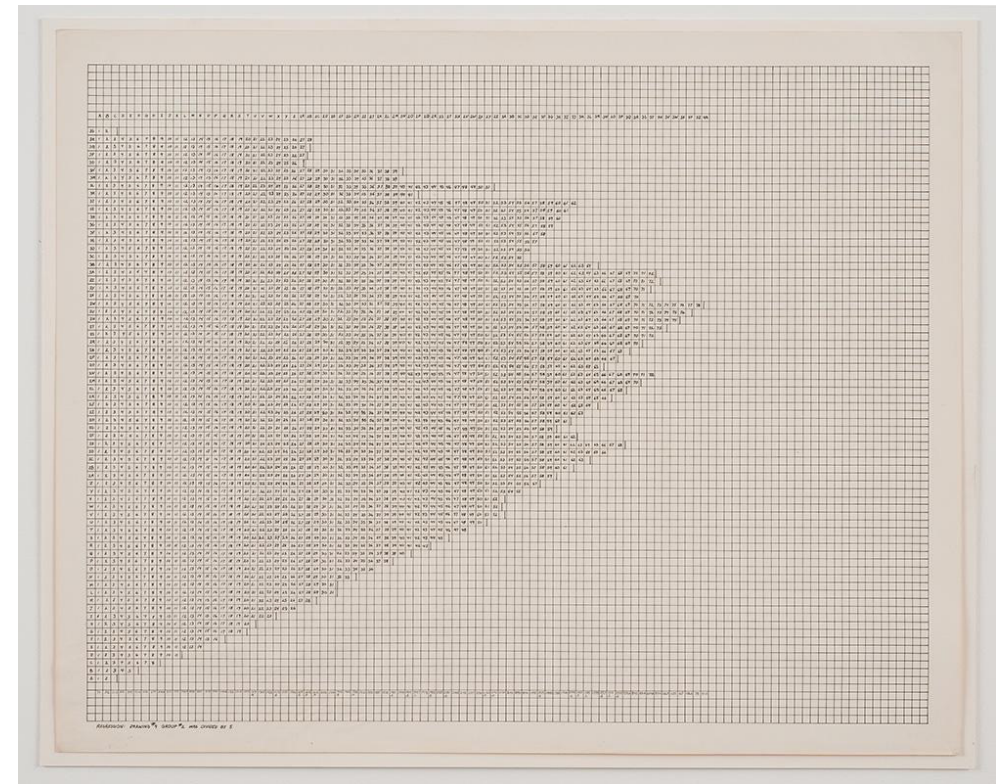


Fig 64. Charles Gaines, 'Regression: Drawing #5, Group #2', 1973-74. Mechanical ink and pen on paper, 23in × 29in, 24 3/4in × 30 3/4in (framed). Courtesy the artist and Susanne Vielmetter, Los Angeles Projects. Photo: Robert Wedemeyer. Photo and caption retrieved from <http://blog.calarts.edu/2014/07/14/charles-gaines-early-works-at-studio-museum-in-harlem/>

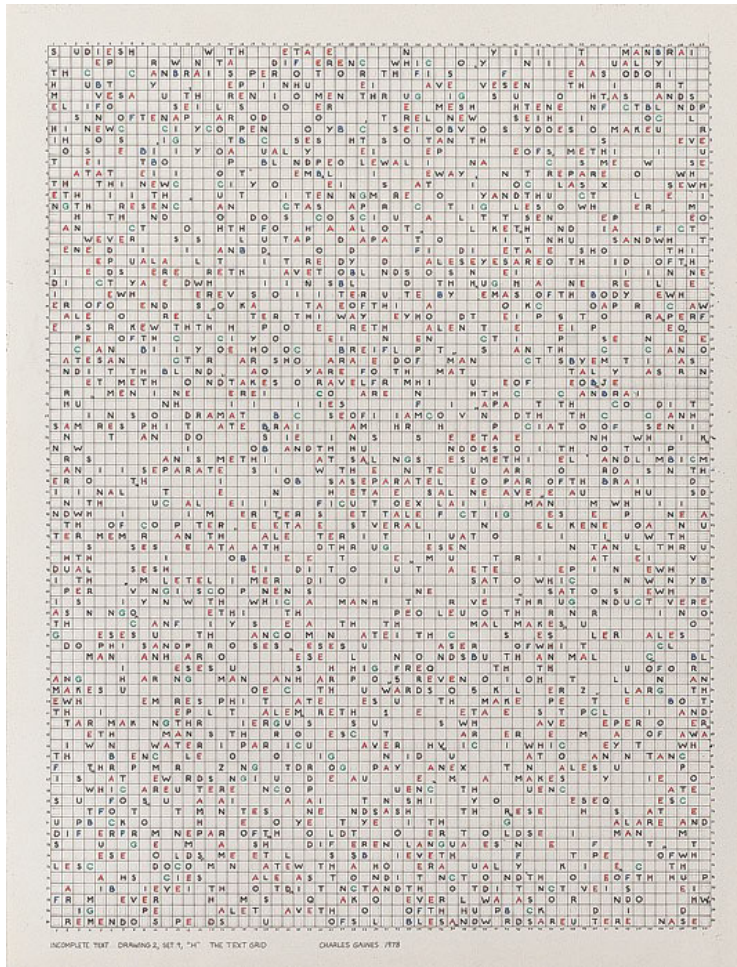
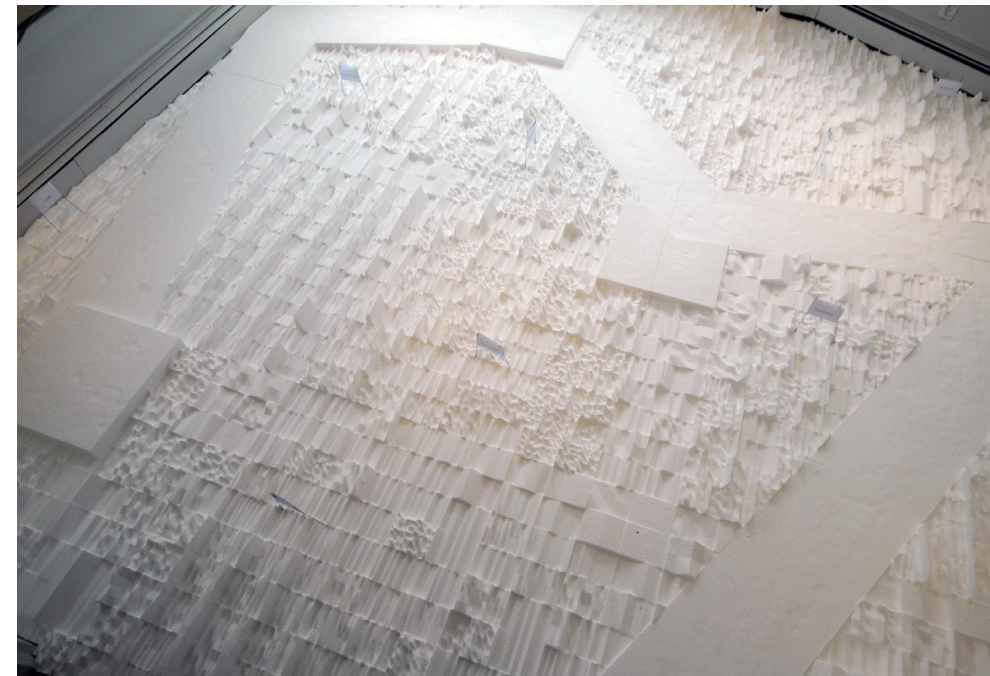


Fig 65. Charles Gaines, 'Incomplete Text, Drawing 2, Set 9, "H"', 1978. Mixed Media on Paper, 26 1/2 x 57 1/2 x 1 1/2 in (framed). Retrieved from <http://www.moca.org/collection/work/incomplete-text-set-9-h-green>

In the end, the notions together of grid, frame, point of view, distance, ground and texture all reminded me of my experience of Japanese rock gardens⁴². These gardens set specific constraints where contours, reliefs, ripple traces and patterns hold metaphors for the world around and where the visitors are lead to direct their gaze to certain compositions. With the materialised tweets that could be contemplated as an ensemble, in a segment, or individually, from a large distance or at close range, the metaphor of the garden soon imposed itself (*see images below*). With that, the ensemble of twips suddenly showed the physical ripples of a thousand lives.



42 I specifically studied and filmed Japanese gardens in various places of Kyoto and Tokyo when I created the artwork 'Abstract' (2007).

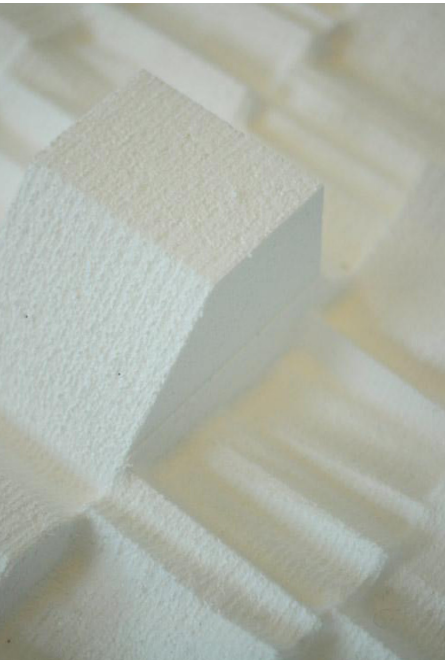
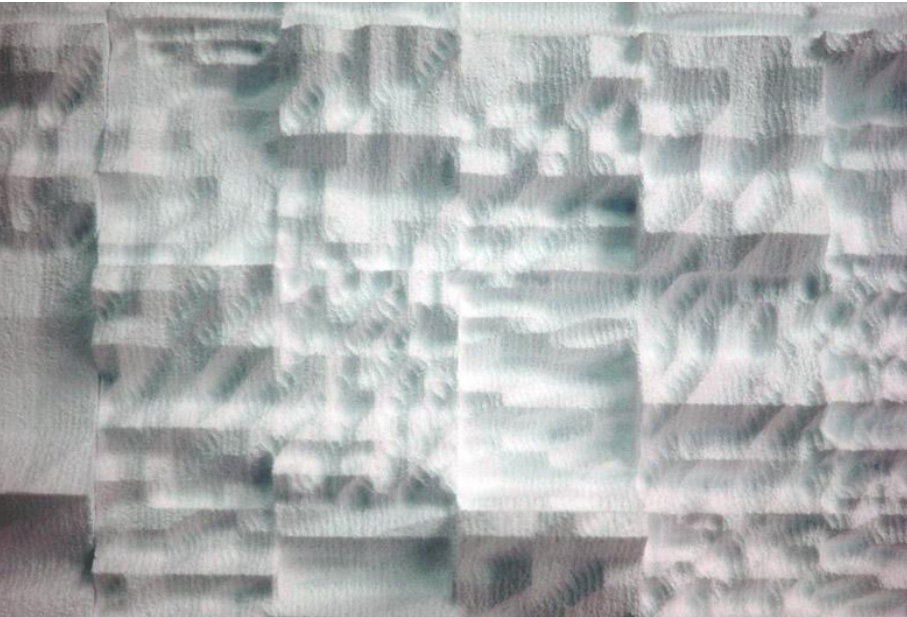


Fig 66. Three views of the Twipology installation at fortyk gallery exhibited in March 2015. Photos by Jake Rudin.

Several adjustments to the code and the fabrication process needed to be made for that second iteration of the project:

- With a starting reference of previous tests of 12cm x 16cm for a twip, and with a room of 4m x 3m, it was evaluated that 1000 or more tweets needed to be collected and fabricated.
- It was determined with these dimensions that six blocks of foam of 48in x 96in x 6in (the largest format available for the Onsrud machine used at GSD) had to be purchased for covering the entire room surface. The styrofoam material was chosen again for costs and time constraints. The material fit other qualities though: a brittleness, a texture and a playfulness that became characteristic of the piece.
- The maximum height of the foam we could order was 6 inches so the whole geometry was constrained to that size (although some peaks went still over that height and were simply cut off in the fabrication). The base dimension of each twip ended up being slightly smaller than the original one, but allowed for more variations with heights. We used 1200 twips in total.
- A new code was written by my collaborator Jose Garcia del Castillo y Lopez in the program Grasshopper so that the entire field could be generated in a JSON file (a format more compact and better adapted than CSV to manage high volumes of data). The next steps in Rhino/Grasshopper and in MasterCam were as previously described, except that the whole field was separated into six different files for the router, each one corresponding to one block of foam. Here again, my collaborator Kevin Hinz oversaw the fabrication process.
- 12 hashtags were again selected, 7 of them similar to the ones from the first version: #whatever, #system, #control, #radical, #surface, #cigarette, #pink, and five new ones: #raw, #passage, #abstract,

#kindergarten, #superficial⁴³.

- The room was divided into a grid of 12 zones (one for each hashtag) of 100 tweets each.
- New rules were set to test the organisation of the tweets together: the tweets with the highest peaks were assembled closer to each other in each partition. This 'assembly of peaks' were orientated differently in each partition to add rhythm, following the pattern of a typical clockwise orientation.
- I added a path where people could walk and three sitting areas as points of observation. I invited people to move about as they wished (they had to take off their shoes prior to entering the space). The walls of the room were also used at two moments of the walking path for displaying a selection of the tweets used in the installation so visitors could read them. Outside the house, steps were installed by one of the window to provide an additional point of view into the space. Each hashtag zone was marked for the public by its name written on a small wire pole.
- Instead of gathering the Twitter feeds in real time from the moment the program was launched, the new code worked in a way that it collected the last 100 tweets made with the defined hashtag.
- In order to adapt the user interaction to that change, I issued a call for participation to various public lists (in my social network, GSD students, media art lists, etc) for using these hashtags on Twitter in anticipation of the piece. The participation was relatively low, possibly because it was not advertised properly. In between the moment that the code was ready and strict time constraints for using the Harvard GSD router further narrowed the window of efficiency to involve the

43 The five new ones bear the names of some of my previous artworks. They were chosen for this piece because the words I used in the past to name my works are words that I keep working with and that keep looming in my creative process. It seemed fitting therefore that they would become factors in a piece using words as hashtag icons. Again the tweets using those words didn't always fit the meaning I had in mind: #raw in particular was almost exclusively used by the wrestling television program Raw and the World Wrestling Entertainment championship. They used a spam bot (automated program that keep sending the same information) - so all tweets gathered for the hashtag 'raw' were almost the same one repeated 100 times. This is reflected in the materialised pattern, resulting in one of the most significant observations made from the development of the project.

- public. The bulk of the tweets collected were therefore again mostly from anonymous individuals that had tweeted the selected hashtags in the last month or so.
- The fabrication process was extensive: 7 days straight and 8-10 hours per day were needed to mill the 6 blocks of foam with all the intricate details of each twip.

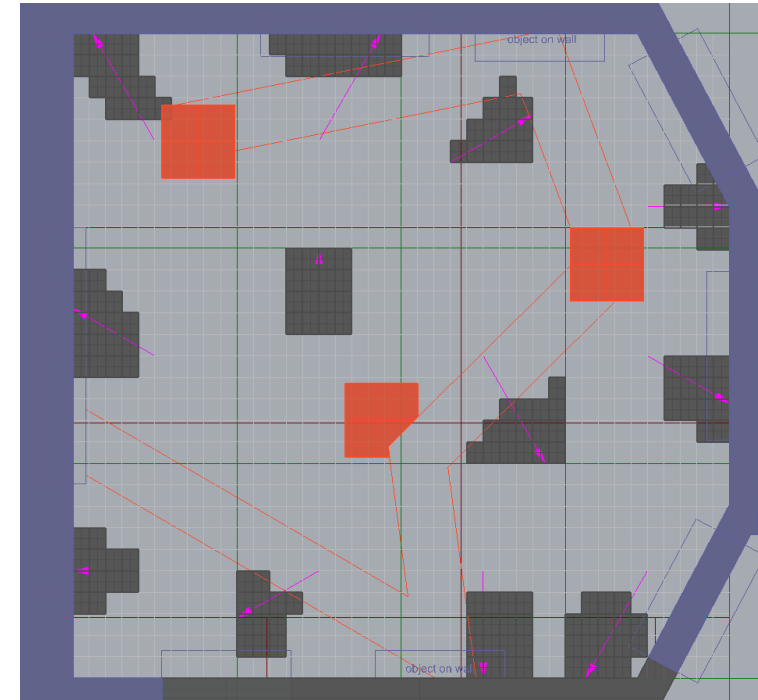


Fig 67. The model represents the Twipology plan for the 'fortyk' gallery back room. The dark green macro grid marks the 12 partitions per 12 hashtags, the light grey micro grid represents 100 twips per partition, the dark grey assemblies of twips marks the high peaks, and their positions show a clockwise orientation (with pink arrows underlining it), the dark red grid marks the division for fabrication in six blocks, the orange lines show the walking path for visitors and the orange squares show the sitting points.

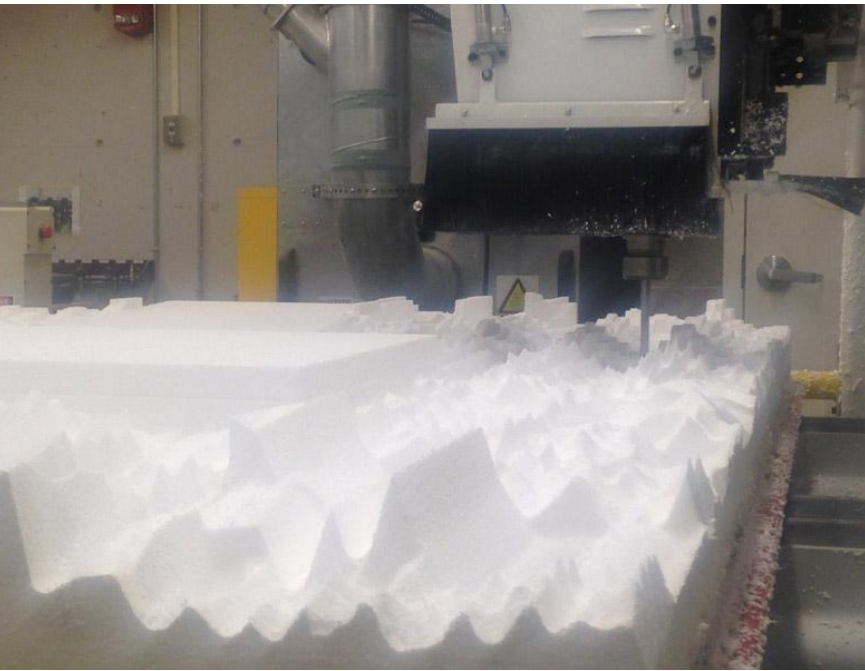


Fig 68. The Onsrud router milling one of the Twipology block of foam.
Photo Joëlle Bitton.

User study

The exhibition took place over 7 days and drew in many visitors (approximately 50 for a special evening party). I observed various social behaviours in the space over three visits, from people sitting and conversing, to people laying down or drawn in contemplation, spending more than 30 minutes in the space to a few minutes (*see pictures below*).





Fig 69. Visitors at the fortyk gallery exhibition of Twipology, March 23-31, 2015. Photos by Kevin Hinz and Jake Rudin.

To get a better sense of visitors' experience, and its lasting effect, I proposed an online survey about a month later after the exhibition ended and sent it out to the GSD student mailing-list and to visitors I knew came to the space. It had 11 respondents. I consider here what could seem a very low number of respondents a great return on an email request, in the context of a low-profile exhibition, a month after the exhibition happened; respondents had to have visited the exhibition and be willing to spend 10 minutes on a survey, especially during exams time at Harvard (an incentive was given of a prize raffle for two chances of getting a gift certificate of a \$30 value each).

Stats

Respondents were 4 female, 4 male, 1 undisclosed and 2 persons didn't answer the question. 7 persons gave their age, situated between 28 and 60, with the median at 32. Most heard about the exhibition from word-of-mouth. A majority of respondents is interested in fabrication processes, with 6 persons considering themselves novices, 2 amateurs, 0 expert and 3 "others" ("1st time experimenter", "experienced apprentice" and "no experience"). 6 visitors visited the exhibition once, and 4 visitors more than once (between 2 and "3-4"). A majority spent between 15-30 minutes in the space or more ("an hour"). The rest of the respondents spent between 5 and 15 minutes in the space.

The garden experience

Among the questions asked, I inquired about how the visitors experienced the space. Most responses showed that visitors embraced the idea of walking, sitting, conversing and contemplating⁴⁴:

*"i felt comfortable and cosy, perfect
place to sit and think, or not think at all"*

"It created the right atmosphere for an

44

Quoted responses are edited for spelling mistakes and typos

informal conversation. It triggered thoughts. It acted as a boundary object and at the same time as a peaceful context”

“I walked to the center and sat down. I felt like a giant..”

Engagement

Another question was related to the visitor’s expectations - if the exhibition met them or not: 8 persons indicated “yes”, 2 had “no opinions”, one of which was because he didn’t know what to expect going in and was “*definitely delighted by the outcome*” and 1 answered “no” because the exhibition “*excelled*” his expectations. Further comments to that question revealed what aspects engaged the visitors in particular:

“because i felt as in a garden, a white garden of peace. which is somehow strange as twitter is somehow noisy... (...) i think that if I visited it with lots of people the experience would have been different”

“I was happily surprised by the contemplative nature of the space due of the textured surface”

“I thought it was quite cool how the artist made a space for the viewer to exist among the installation, not just on its periphery”

“It was fun to lay down amidst the forms and get up close and personal to it”

“I was probably imagining another parametric garden design and what I found was a very poetic and, I dare say, zen approach to interpreting virtual conversations”

The data in the garden

I asked visitors if they were connecting the artwork to the Twitter feeds. The question was probably too open to get a homogeneous set of responses - it was understood in different ways, I found the remarks inconclusive although I gathered from the answers and the general reactions that it was acceptable not to be concerned with the question of the legibility of the data.

“There are labels around the artwork and from the name twipology”

“I got an in-depth explanation by the artist so I didn’t have to connect”

“The connection is clear”

“The direct translation of the data was not evident, nor was it important I think... It is more interesting that the relationship was abstract”

Personal data for fabrication

Another question related their experience of the piece to envisaging other ways to use personal data for fabrication. Most answers embraced the idea but without being specific or sure to what it would entail: the respondents

were not clear about the ways they could put it into practice:

“i would love to see how the information i handle each day could be represented in a 3D form. i think that seeing this could show me a new perspective on what type of data i’m creating and exchanging with people”

“I am always open to exploration but I would need a knowledgeable guide”

“The subtle manipulation of surface texture, a ‘wobble’ so to speak, in what would otherwise be a smooth toolpath (introduced into the tooling) could be an interesting nuance; a direct representation of something personal into what is otherwise impersonal”

“Not sure of its application beyond art installation, which was cool”

“Just like one’s dna is (almost) unique, one’s data could be unique. If this data is fed into the fabrication process as one of the inputs, perhaps it could result in some cool visualizations”

“I see in this garden a poetic and aesthetic way of letting the individual and the collective retain readability [in data visualisation]”.

Open question

I proposed an open question to gather various perceptions: what the visitors “liked the most and the least”. Most comments only featured what was liked the most (only one comment answered to both, the most and the least). Many comments related to liking the material aspect, the texture and the “visual effect” and the general immersion:

“to get my shoes off, to walk and sit down and talk. I also liked that it was on view in an intimate place”

“the varying ripple highs and frequencies”

“the styrofoam”

“I like the textured surface the most :)”

“Most: that one could penetrate the garden (as opposed to just look at it like an object). Least: (slightly contradictory with the previous comment) the pathway to access the garden (felt a bit brutal)”

Throughout the survey answers, there were no negative or dismissive comments. One person (in response to her experience of the space) commented on a perceived inconsistency that the “*The minimal white look tends to create a bare feeling which seemed out of context with the intent of the design brief*”. The absence of strong negative comments can be attributed to the fact that people who take the time to answer such survey have a general positive experience (or a really terrible one).

On tangible moments affected by the passage of time

Throughout the observations made on this project, I recalled a quote by Adolf Loos where he compared the reality of materiality to photography:

“precisely what I want is for people in my rooms to feel the material around them. I want it to have its effect on them I want them to be aware of the enclosing room, to feel the material, the wood, to see it, touch it, to perceive it sensually, to sit comfortably and feel the contact between the chair and a large area of their peripheral sense of touch, and say: this is sitting as it should be” (Andrews 2010 citing Loos 1924 “On Thrift”).

Twipology was intended that way, to let users embrace the materiality of abstraction at its most minimal expression.

And such with tangible items existing in our material world, the garden is affected by time, dust and traces of visitors. One possibility would be to let that ‘moment in time’ slowly fade away or to attend to it, preserve it or let it grow further as the conversation continues on Twitter. The foam material used in this iteration may not be conducive to care, it’s tacitly accepted than foam is for temporary use and too brittle to sustain long term use. So growth would constitute yet another experience where users could be

engaged with another material than foam, possibly a vegetal living organism to reinforce the metaphor of the garden itself. This idea led to a proposal for a public space installation that I formulated with colleagues at GSD as a variation of *Twipology*⁴⁵. The project is named *Texture* as a play on the source of information (“text”) and the texture of the garden material that visitors interact with. In this case, the Twitter feeds that are collected are generating a the geometry of a cardboard honeycomb. The honeycomb acts as decomposable mould that is packed with soil and planted for a garden to grow within it (*see proposal below*).



Fig 70. J.Bitton, J.L.G. del Castillo y Lopez, J. Grinham, K.Hinz. 2016. “Texture”, proposal for a public space installation. Render by J. Grinham.

3. THE DOMESTIC ENIGMA: RABOTA

Rabota is an autonomous CNC “carving” machine on wheels, uniquely controlled and driven by sleep data. The machine measures approximately 12”x7”x8”. The material that the machine transforms is the existing fabric of the home, more specifically the bedroom floor. *Rabota* is conceived as a subtractive erosion machine that operates at night while the owner is asleep with her waking up to an altered landscape. The floor was chosen particularly for its metaphor of solidity (we rely on it to stand), a support that we’re weakening to uncover the depth of layers beneath us. Similarly, the sleep is an under-explored moment of semi-consciousness, the world of dreams that perpetually escapes materiality. *Rabota* becomes the strange companion in a familiar environment, a sort of a dysfunctional wood planer that cuts through the floor as it processes the data of our sleeping lives.



Fig 71. Joëlle Bitton, ‘Rabota’, 2015. Photo by Jake Rudin.

Project sheet

- October 2014 - September 2016
- Collaborators: Ianis Lallemand, Akshay Goyal, Kevin Hinz, David Nuñez, Muazzam Khan Noorpuri
- Software: Python, Fitbit API
- Hardware: Dynamixel Motors, Raspberry PI, Dremel
- Material: Floor
- Data: Fitbit sleep patterns
- CNC machine: Itself, ‘router on wheel’
- Fabrication process: data sent as collected, operates robot that carves as it moves
- Aim: Domestic fabric as the ‘material’, making a machine that is mobile and intimate, that offers a CNC-fabrication experience at home
- Main Operative condition: Home (the material)
- Secondary operative conditions: the body, sleep, quantified self (data), time (the fabrication process), etc.
- Level of Interactivity (scale 1-5): 4
- Code variables/conditions: 3 states, behaviours adapted
- Inspirations: Wood planner, sedimentation, layers
- Progress: Adaptation to constraints, Raspberry PI sets its own learning curve, collaborations were not optimal (short commitments, time problems, etc).
- User-experience / Interactivity: User sleeps and data is received by the robot, that is controlled by it
- User-scenario: While the user sleeps, at home
- Outcomes: Companionship, traces of unconscious moments
- Shortcomings:
 - Real time is an issue with the Fitbit data (it cannot be sent until the full session is shut)
 - The data from the Fitbit is very poor (based on accelerometers)

Premise

I started to conceive this project very early in the research as part of a showcase *in three*. As mentioned before, I thought that this study would require at least three projects to tackle different aspects. The three projects were very loosely defined at the beginning. The idea was always to enact forms of interactive fabrication: linking personal data with a machine and a material. But the articulation between the three essays and their scopes would be better specified with every grant application, with every prototype in classes and with advancing the thesis questions in general. The dimension of time started to be a more pronounced factor to address in its different perceptions: real time, over time, and elapsed time. The question of the material was also becoming more driven, so that it would be an agent for enhancing the ‘physicality’ of the experience and for pushing the engagement of the user to an extreme. As such I was leaning towards using existing materials at home (the kitchen counter, the coffee table, the wall, the floor, etc..) as materials for “fabrication” along with more radical alterations of them: erosions, abrasions, endless accumulations, viscous compilations, in one’s home or in someone else’s. At the same time that these ideas matured, the development of *Twipology* led to put aside the ambition of making an ad-hoc machine and of implementing a series of functions. It was clear that they would then become the priorities of the second project. All the objectives that could not be reached in *Twipology* would be reinvestigated here: casual interface, direct and real time fabrication, ‘intimate scale’ of the machine and user proximity to the machine.

One of my early ideas was to use the typical day-to-day movement of a user in her home to actuate a machine in real time that would make her traces manifest. The material would be a block of wood (piece of furniture or other) in the user’s home: “the machine proceeds to mark an element of wood in the home with an abrasive tool as if it is eroded. It could be an element already existing (the counter of a kitchen, a living-room table) or a block inserted in the space. This experience could be tested over a week”⁴⁶.

46 Excerpt from my thesis prospectus (May 2014 version).

In terms of personal data, other than movement, I was drawn to using consumer tools that would collect data as a life log, everyday, at all hours, in an accumulation of measures. Quantified self tools were ideal vectors of data selves that could be repurposed for CNC fabrication: step counts, calorie counts, heartbeats, sleep patterns. Similar to the mobile phone cited earlier for its ubiquity, the quantified self tool like the Fitbit was soon becoming the interface that the user would carry around without even being aware of its presence.

Discussing Ideas

As I was defining the second project more in details, I met Ianis Lallemand, a fellow artist and researcher, also exploring digitality and materiality and enrolled in a PhD at EnsadLab Paris in the group Reflective Interactions with which I had collaboration ties. We decided to start a collaboration at distance to develop that machine that would abrade a piece of wood over time. In my early conversations with Ianis, one of the initial metaphors that guided the creative process was that of a wood planer, and its repetitive action that reveals layers after layers, a sort of palimpsest of erosion (*see image below*). The planner also generates and accumulates dust, wood shaves, particles that become part of the landscape.

We agreed that the machine should roam at home, an environment that is not traditionally fitted for digital fabrication processes. Reviewing various options of home ‘surfaces’ as listed above, we opted for the floor. The floor had many alluring qualities: it’s the support that we rely on everyday, literally our foundations. Our inner self was directly linked to our interior home. We could make the floor collapse with our disturbed mind. Or it’s the collapsing of the floor that would be our own demise, a form of instability with no return. Or it would be a way to reveal hidden layers of a floor, foundations, structures, construction materials, paint layers, traces of previous occupants, Or it could be that we would just be connected to our neighbours in new ways, in a building that could allow to see through the floor/the ceiling and we would finally understand where a previously unidentified sound was



Fig 72. Wood planer. Photo uncredited. Retrieved from the website of a sharpening service company located in France <http://www.becker-affutages.fr/outils/affutage-outils-a-bois/11/2/rabot-a-bois.html>

coming from⁴⁷. The machine was understood as a long-term companion since it would transform the floor over time.

Many questions were still unanswered: would the machine operate autonomously, randomly? Could it be displaced while in operation? Would it try to avoid us? Would it be moving only when we were not present in the home (like the toys from *Toy Story*)? Things would then change at home furtively that we would barely notice when coming back home, a vague awareness like in the movie *Dark City* that something shifted while we were asleep. The strange was taking its place within the familiar. Artworks of Gordon Matta Clark, Sarah Oppenheimer, Arcangelo Sassolino and Roxy Paine (with his erosion machine in particular) were in that sense essential references.

For the data that would control the machine, I soon proposed to use the

⁴⁷ Another floor transformation reference was the empty drained pools during the 1976's California drought that accommodated the new shapes, axles and polyurethane wheels of skateboards.

Fitbit tool that I had long wanted to repurpose, and in particular the sleep information. I was at the time suffering from insomnia and I started to use a Fitbit One for tracking my sleep. The period of sleep is itself mysterious, complex and indiscernible. So many phases happen: we toss and turn, we're still or restless, in deep or light sleep, or altogether lying and looking at the ceiling for sleep to happen. The state of semi-consciousness was fitting well a machine operating in our "absent presence". And evidently, the metaphor of inner self/interior home was ideally enacted by the moment of sleep.

Further discussions led to define the machine as autonomous, fairly light in appearance but well grounded, driven by sleeping data, modulated by the depth level of the sleep and free to roam on the entire bedroom floor. The "cutting" tool itself was not yet defined but it wouldn't be motorized individually - the abrasive action would happen in the movement of the machine, like a wood planer. It emerged that the machine should be a sort of CNC-router on wheel, its working name was *Floor Machine*.

Testing Ideas

As described in the *Twipology* account, the initial idea is rapidly confronted to constraints, most often related to time, costs, technical issues and other impracticalities. Once a concept is imagined, the process consists in making it real, which means a lot of compromises with the original idea. As a way to probably cope with the disappointments but also as an artist that enjoys mistakes, accidents and surprises, I consider compromises as a condition for the emergence of art, especially in the realm of interactive and digital art (yet again, I'm not sure I have a choice in the matter). And so like with the first project, *Floor Machine* compromised in many instances.

We started to develop the actual design method to conceive and build the machine. In terms of technology, we couldn't find any similar project or reference of a mobile fabrication CNC-machine. We did see eventually a school project from California College of the Arts, the *Swarmscapers* that aggregate and bind sawdust at a small scale, as a demonstration of future

building machines on extraterrestrial planet surfaces⁴⁸. That machine is rather complex to operate and is not fully autonomous - the machinery was not adapted to our intention so it couldn't be used as a technical reference. We had to build our own system. Akshay Goyal, MDes student at GSD joined our collaboration to help with structure and engineering solutions.

In terms of tooling, Kevin Hinz that I consulted on the matter suggested that a cable-free Dremel-like tool could be used as a the "cutting" device - it was the most practical solution in terms of application of force as it has its



Fig 73. Dremel and various tools attachments tested on wood and cardboard. Photos by Akshay Goyal.

48 <https://3dprint.com/32903/swarmscapers-robots/>

own motor and doesn't need added mechanical pressure. From there, we started making tests of Dremel carvings on surfaces like cardboard and wood to see the results.

We opted for using the wireless Dremel sold in stores. The architecture around the Dremel would be that of a moving robot-like kit: wheels, motors, a driving board and a design assembling the parts. The ensemble would have to be fairly small, light, be able to move forward/backward and turn 360 degrees. The project benefited from the support of the group Reflective Interactions at EnsadLab for procuring the components of the robot. They were chosen and ordered based on previous work done in that lab - a feat that saved us time and facilitated our choices but that would also tie us to a technology and a system before we even started to look into specific needs.

The list of components used was as follow:

- Dynamixel Motors AX-18A⁴⁹
- The Raspberry Pi 2 Model B
- A board that interfaces the Pi (or other PC) with the motors for control: USB2AX⁵⁰
- A board that powers the motors: the Robotis SMPS2Dynamixel Adapter⁵¹
- Li-Po batteries (11.1v - 1000mAh - 10c)

Akshay suggested to use only two wheels each attached to a motor receiving particular commands. And a third motor attached to the Dremel so it could be held up or down. The first assembly design consists of two levels - the bottom one holding the wheels and motors and the top one with the Pi and the battery. The Dremel would be attached at the end. The first tests were made with the platforms laser cut in acrylic (*see images below*).

49 http://support.robotis.com/en/product/dynamixel/ax_series/ax-18f.htm

50 <http://www.generationrobots.com/fr/401584-usb2ax-pour-servomoteurs-dynamixel.html>

51 <http://www.trossenrobotics.com/store/p/5886-SMPS2Dynamixel-Adapter.aspx>

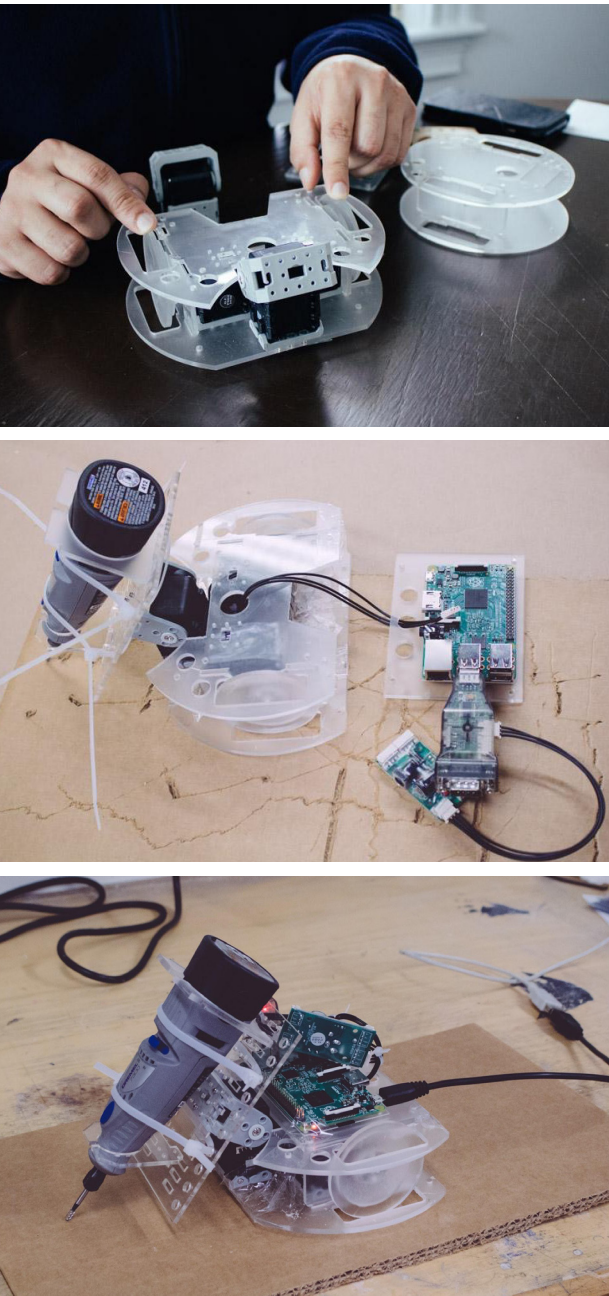


Fig 74. Assembly of the first version of 'Floor Machine' in the Harvard GSD project room (April 2015). Photos by Ianis Lallemand.

Additional procured material:

- A voltage modulator for the Pi (converting 11.1v to 5v)⁵²
- An (almost) endless series of cables, adapters, etc
- Custom-made weights to counterbalance the weight and torque of the Dremel (we used simple rectangular moulds to pour Roc-kite along with metal items like bolts and screws).
- Custom made wheels laser cut in acrylic

Machine Control

Once the assembly was done, we needed to test its behavior and drive. From that point, it's worth noting that the tests of CNC control followed a parallel path with the optimisation of the technical parts and of the design assembly over several months (March to September 2015). The first step for control is to access the Raspberry Pi to program it. Just like any computer, in order to access its interface, a screen, a keyboard, a mouse and power are needed - an infrastructure which can be easily overlooked.

If the system needs to connect to the Internet or to an Intranet as it runs (to download installers for instance or to operate with incoming data), it will need either an Ethernet connection or a WIFI dongle - the Pi Model 2 doesn't come with its own wireless. Again this was completely overlooked when we started the mount. The Ethernet connection itself got rather complicated: in our office space, there's no Ethernet plugs anymore. (And if there are firewalls or other security issues, special permissions from the IT system admin may need to be obtained so the device is authorized on the network). Succeeding in connecting the Pi to the Internet via Ethernet was just one step. Since we intended the machine to be mobile and autonomous, we couldn't keep it connected via an Ethernet cable beyond the first tests. The WIFI situation with the Pi Model 2 is surprisingly nerve-racking and setting it up proved to be a massive time consumer⁵³. We procured a Wifi dongle⁵⁴

52 <http://schmartboard.com/schmartboard-5-volt-populated-single-voltage-regulated-power-module-710-0003-05/>

53 The model 3 that has been issued recently has since been including a Wireless LAN protocol.

54 <https://www.amazon.com/Edimax-EW-7811Un-150Mbps-Raspberry-Supports/dp/B003MTTJOY>

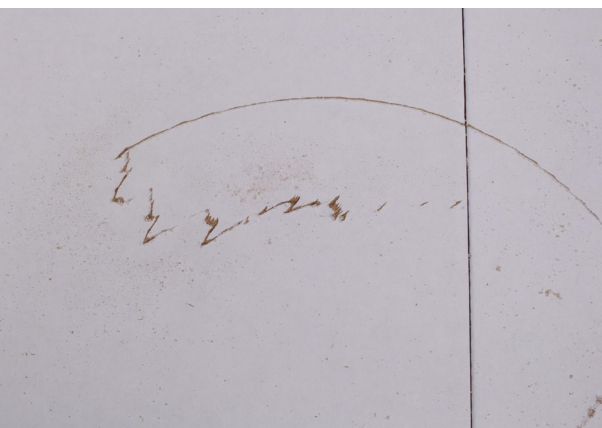
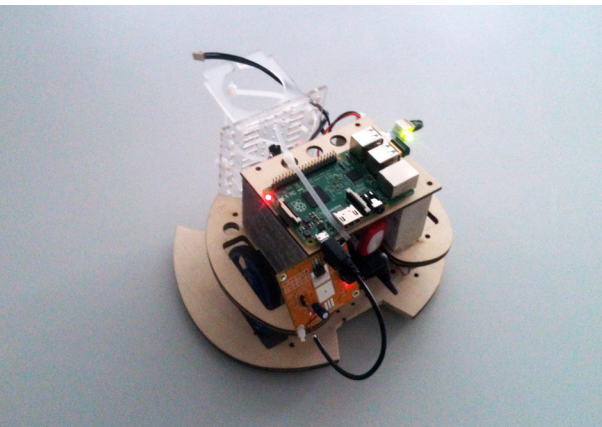
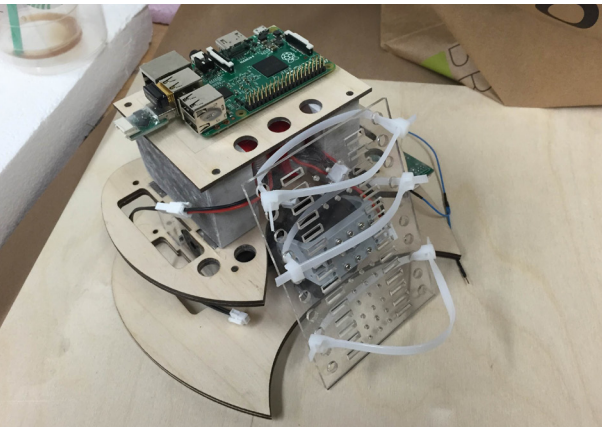


Fig 75. Second iteration of 'Floor Machine' and traces of the machine (June 2015).

and proceeded to set up a wireless connection. (There are various instructions for WIFI set up for Raspberry Pi that can be found online, but none are very straightforward⁵⁵).

In the initial tests, in order to control the movements of the robot, we first used a Midi interface, the TouchOSC app⁵⁶ on iPad (we didn't want to add complexity with the Fitbit data yet) that could simply command the machine to move in a direction or another. Ianis wrote the code for that and published it on the *github* platform⁵⁷.

In parallel, the increased autonomy of the machine led to a new overall design assembly with optimisation of placements and spaces - a third level was added to make room for the weights, still keeping a fairly compact design. The mounts were laser cut in wood instead of acrylic.

Sleeping data controlling the machine

The machine is meant to be controlled and driven by sleeping data. For this, we're using the Fitbit One as it's an item commonly used for tracking sleep and visualising the sleep patterns on a web interface⁵⁸. The company Fitbit has an API⁵⁹ that allows for third-party app developments that operate with mining the Fitbit data. Somehow though, the official Fitbit API doesn't provide detailed sleep occurrences that are essential for controlling the robot with all the variations of the sleep at night. Fortunately, the jFitbit is an unofficial Java client that provides sleep levels of a person on a 1-minute interval⁶⁰. The data is gathered in a text file - as shown in this excerpt.

55 The instructions we ended up using the most are featured in the following link: <https://www.raspberrypi.org/forums/viewtopic.php?f=31&t=7471>. It should not be necessary anymore to deal with this issue with the new Pi Model 3.

56 <http://hexler.net/software/touchosc>

57 <https://github.com/ianisl/floor-machine-ipad-musicio-dynamixel-osc-server/blob/master/app.py>

58 <https://www.fitbit.com/one>

59 <https://dev.fitbit.com/>

60 <https://github.com/claygregory/jfitbit>

2014-11-07 01:35,2
 2014-11-07 01:36,2
 2014-11-07 01:37,2
 2014-11-07 01:38,2
 2014-11-07 01:39,2
 2014-11-07 01:40,2
 2014-11-07 01:41,2
 2014-11-07 01:42,1
 2014-11-07 01:43,1
 2014-11-07 01:44,1
 2014-11-07 01:45,1
 2014-11-07 01:46,1
 2014-11-07 01:47,1
 2014-11-07 01:48,1
 2014-11-07 01:49,1
 2014-11-07 01:50,1
 2014-11-07 01:51,1

The data presents the date, the time at 1-minute intervals and the sleep “status” of the user (with the numbers 1, 2 or 3). We realised that there are actually only 3 types of sleep that are reported in the Fitbit app: ‘asleep’ (1), ‘restless’ (2) or ‘awake’ (3) - which is somewhat a misrepresentation of what we expect when we are sold that a device can “track” our sleep. Essentially most quantified self devices on the consumer market base many of their tracking features on the very basic technology of accelerometers that can tell if the body part onto which it’s attached is moving or not (likely a hand or wrist most of the time). So the accelerometer could deduce that a person is static or moving in bed but the Fitbit is only *inferring* that this information is equivalent to the quality of sleep itself. In any case, we worked with that data to control the robot: an important creative component is to correlate the data to behaviours of the machine. As a starting point, the machine stops when the person is awake (again in reference to the idea that the machine only operates when it’s not ‘seen’), the machine runs in a fairly smooth way when the person is asleep and the machine starts to behave erratically

when the person is restless. Additional variations in the behaviours were added over time, based on the data, such as the length of time that a person is in each state, the succession of states, the short interruptions, etc. These improvements were implemented by programmer David Nuñez who collaborated on the project and updated Ianis’ initial code. The updated code is shared on the *github* platform⁶¹.

Another more important drawback with using the Fitbit is that the data cannot be sent and received in real time (while the person sleeps). The data is compiled *only* when the person presses a button on the device to signal that the sleep duration is over (ie when the person wakes up). So at best the data that we could use was that of the previous night, that the robot would reenact. Again with this project in that iteration, I had to let go of a real-time interaction between the user and the fabrication process.

Another difficulty is to attribute a time element to the sleep time occurrence: if the machine matches the sleeping time at 1-minute intervals, there’s hardly any perception of movement at all. So again, this is a question of compromises and adaption.

For the benefit of a demo and of prototyping, we opted that a minute of sleep would be understood as a few seconds of sleep. The robot would then not reenact just one previous night but several of them in a one-hour session.

Still in parallel of the software process, the assembly of parts led to further changes of the design as the machine became more efficient. A rectangular shape was better fitting the design, as more space was needed and a third platform was just not practical. The oval/round shape was disregarded as it looked less appealing in a larger size, and too close to items like the Roomba cleaner. The platforms were again laser cut in wood, in a blend of cherry and walnut. The assembly is press-fit and all the parts are mounted in a way that they could easily be moved, displaced and replaced - as such, there is no use of glue at all.

61 <https://github.com/davidnunez/floor-machine-ipad-musicio-dynamixel-osc-server>

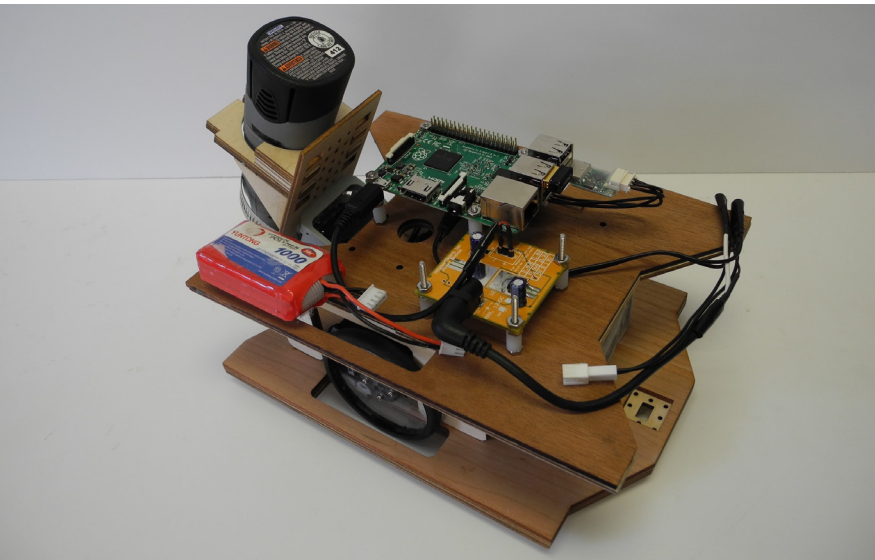


Fig 76. Third iteration of the design assembly (August 2015). Photo by Kevin Hinz.

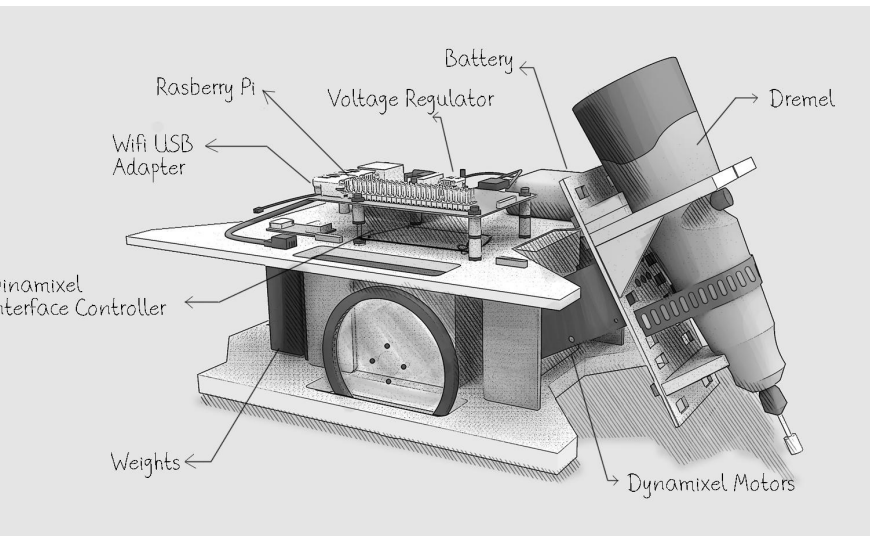


Fig 77. Sketch of the machine with the different parts (March 2016). Drawing by Gabriel Soufer.

The Shell

A shell, an envelope for the machine, is not always necessary yet it often helps to shelter the components and does provide an overall sense of the piece. We first tested a vacuum-formed transparent plastic shell (around an oval honeycomb structure) but it was hardly conclusive.

Once the assembly had been perfected and led to a change of the overall geometry into a rectangular shape, a shell was designed partly following the lines of the mount. The shape is thus asymmetric, awkward, vaguely familiar: it tells of a foreign object that is not a threatening entity and not really a companion. In this iteration, the shell is opaque and completely white to reinforce that strange familiarity. The reference of Robert Breer's *Floats* had already been present from the beginnings of the project concept phase, notably in the idea of a machine that would look both 'light' and 'grounded'. It was again here an inspiration. The shell was first tested in laser-cut paper, then cut in white aluminium, with the help of my collaborator Kevin Hinz.

In order to have an easy access to the part or to imagine other shells as replacements of this iteration, the aluminium shell is not screwed or glued to the assembly, it's held by the tension of 4 wood dowel pins attached on the four corners of the lower platform. This way, it can be easily taken off and put back on.

Exhibition

With this iteration, the machine was exhibited at the *Data Body as Artifact* exhibition, at the Fukuoka City Museum⁶² from September 29th to October 4th 2015, as an event of the ISMAR'15 conference. The piece was set among other pieces that commented on the body as data, or on data as affecting the body (with among other Lozano Hemmer's *Level of Confidence*, Sterlarc's *Diagrams, Data & Bodies* and Dewey-Hagborg's *Invisible & DNA Spoofing*). The curation of the group exhibition gave *Floor Machine* its angle in that

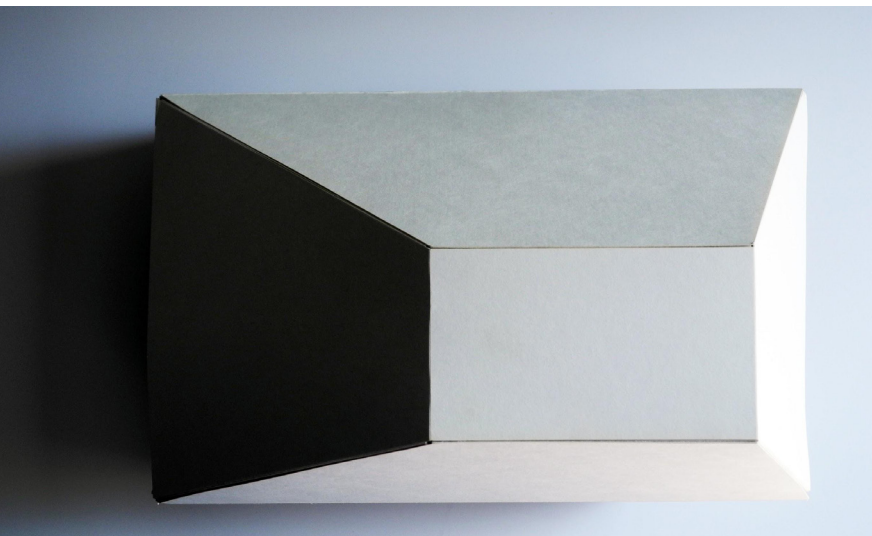


Fig 78. *Shell laser-cut in paper, side view and top view. Photos by Joëlle Bitton (August 2015).*

particular context, a machine that very much implemented the idea of embodied fabrication.

The exhibition setting and context could not allow people to sleep and interact directly with the machine⁶³ but it was a great opportunity for an audience to discover such possibilities and for us to test the machine in a public context. I didn't survey the visitors in this case, as it was not an appropriate context and the language constituted a non-negligible barrier. Yet, I could collect a few direct observations, where the audience was engaged by the movements of the machine and contemplated it for few minutes at a time.

Further improvements were made in preparation for the exhibition, notably an easy access to the Pi via an intranet set up, using a wonderful USB wireless nano router⁶⁴. A 2m x 3m MDF wood platform with a border of 2cm high was built for the exhibition for the machine to run all week and create layers of dust. MDF proved to be the best materials out of all the ones tested previously: smooth enough for the machine to run without interruptions and with enough material quality to generate visible patterns.

A public setting of a week long exhibition with several hours of public access is a critical condition for testing an interactive device. A couple of shortcomings were observed:

- the 1000mAh Li-Po battery powering the Pi and the motors was enough for a duration of about 50 minutes before it needed to be replaced. The Dremel had its own battery that ran for a similar amount of time. For a continuous exhibition lasting a whole day, it would thus require the batteries to be regularly charged and exchanged every hour.

63 The sleep data used for the exhibition was a set collected prior by four different users for this purpose (including me). It was therefore "replayed" over few times in different order.

64 <http://www.tp-link.com/en/products/details/TL-WR702N.html>

- the machine didn't recognize obstacles (sensors not yet implemented)
 - it had therefore to be manually turned around when it would get "stuck" at the border of the platform.

On a not so surprising note, the sound that the machine was making was actually pleasant and not annoying (as a remark that was often made as to whether this machine would not wake a person up during its nighttime operation). The machine quickly proved to have a personality of its own and in that sense was a success.

Rabota and further improvements

After that exhibition, the machine was renamed 'Rabota' as it was taking its own course in terms of design and metaphor - my initial collaborator Ianis followed another direction, the design of the shell in particular revealed differences in our approaches and methods. As a project grows, it matters that it's open enough to adopt divergences. In that sense Floor Machine led to two new projects⁶⁵ and could foster further identities as it replicates.

"*Rabota*" is the Russian word for 'work' (Latin transcription of *работа*), it's also the same root for 'robot' and shares the same etymology with the French "robot", going back to the early wood planer inspiration. "Rabot" in French means to flatten the plane of a surface.

Based on observations made at the exhibition and other settings, improvements were conducted to make the machine even more autonomous:

- added battery autonomy, going from the original 1000mAh to 8000 mAh⁶⁶
- Dremel hacked to plug it into the machine battery so it doesn't need its own source and can run continuously

65 Ianis went on to design a different envelope and named his machine 'Sentinel'.

66 http://www.hobbyking.com/hobbyking/store/_20845_ZIPPY_Flightmax_8000mAh_3S1P_30C_Lipo_Pack_US_Warehouse_.html

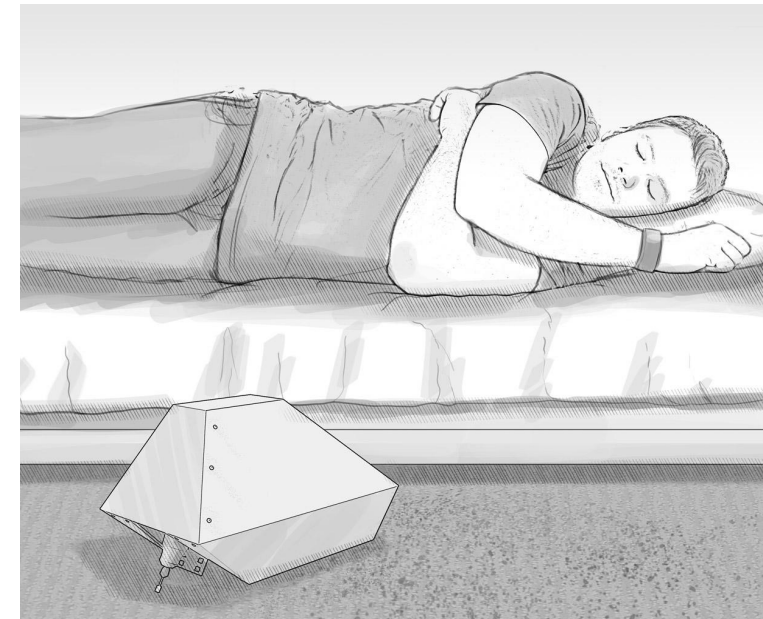


Fig 79. *Rabota at home. Drawing by Gabriel Soufer.*

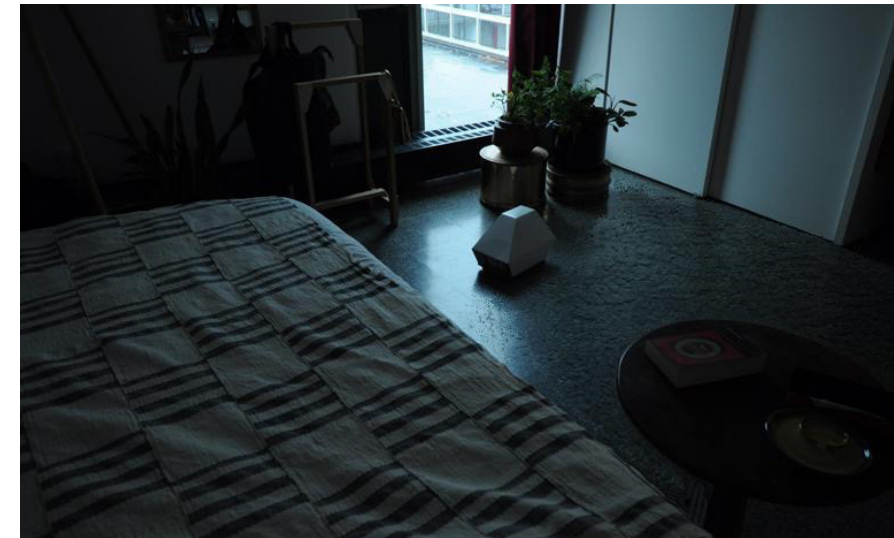


Fig 80. *Rabota at home. It's early morning, the user woke up and left for work. The machine has stopped for the day. Photo by Jake Rudin.*

- Dremel taken off its original shell so it can be better inserted in the machine
- modification of the assembly to accommodate new or larger parts (notably the battery)
- added proximity sensors for obstacle (ultrasonic type sensors)
- added light indicators for various states of the machine
- design of new behaviours of the robot
- design of a new shell that leaves the machine parts partially visible.

The search for more battery power was very insightful and generated its own set of lessons into Li-Po batteries⁶⁷. There are actually not many Li-Po batteries on the market that are both powerful and 11.1v (usually above 6A-8A, the voltage is rather 14v for quadcopters, drones, etc.. which is not suitable for the Dynamixel motors that are used). Some people have hacked a Macbook laptop battery for instance⁶⁸. Fortunately, before I followed yet another complex road, a friend pointed to the battery I eventually purchased (see reference above). *Rabota* is now set to run for almost 8 hours autonomously.

One future iteration of the project would have to include a more accurate sleeping dataset obtained with professional medical tracking tools and that could be sent to the robot in real time. An exhibition or installation in a setting that would allow users to experiment the robot for a day or longer would be necessary to observe the possible range of interactions and implications.

Domesticity and strangeness

Introducing such piece at home could seem contradictory to the notion of what a home should be, a sanctuary. In his article *Architektur* published in 1910, Loos makes a distinction between art and the house because he opposes with good reasons the uneasiness that an art piece can provoke and

67 This online reference was very helpful to cover the topic of Li-Po batteries: <http://www.rchelicopterfun.com/rc-lipo-batteries.html>

68 <https://www.ez-robot.com/Community/Forum/posts.aspx?threadId=3909>



Fig 81. Latest iterations of Rabota - September 2016. Photos by Kevin Hinz.

the need for comfort: “The work of art is brought into the world without there being a need for it. The house satisfies a requirement. The work of art is responsible to none; the house is responsible to everyone. The work of art wants to draw people out of their state of comfort.” (Andrews 2010 citing *Loos*).

One could argue though that the home could be at times a place of anxiety. Heidegger defines it as the uncanny: an *angst* of being-in but not included in the world (the home) (Schwenger 2006). Some call for actually defamiliarising comfortable items so they can become more inspiring (Bell *et al* 2005) and for “making the familiar strange” for learning (Philpott 2013); others call for making the strange familiar to accept the uncanny (Hui 2014) and for appreciating the melancholy of things, the “perception always falling short of full possession” (Schwenger 2006). The exhibition catalogue *Strangely Familiar* (Blauvelt 2002) finds a middle ground with speculative design as a guideline.

Similarly, *Rabota* navigates between the two, the familiar and the unfamiliar, in an undecided way.

4. MUTANT MATTER: STREAMLINE

Streamline is intended as a smartphone app that allow users to send data directly to a 3D printer (extruder), in real time, and on the move, based on a collection of daily moods. It’s bypassing the need for 3D drawing skills typically required before starting a project, a common obstacle to mainstream fabrication. This is the premise for involving users with fabrication processes in a direct and affective manner. Taking inspiration from ways that quantified self apps collect data from users daily, the *Streamline* app prompts users to state their moods at a particular moment of the day. This stream of moods is interpreted into 3-Dimensional XYZ geometry and sent directly as gCode commands to a 3D printer for fabrication. The fabrication can happen over a day, a week or even longer, thus using latency as a chance encounter to expand the complexity of results. Furthermore, the experience designates distance and connectedness as possible attributes, as two users or more can interact, one controlling another’s printer from different locations.

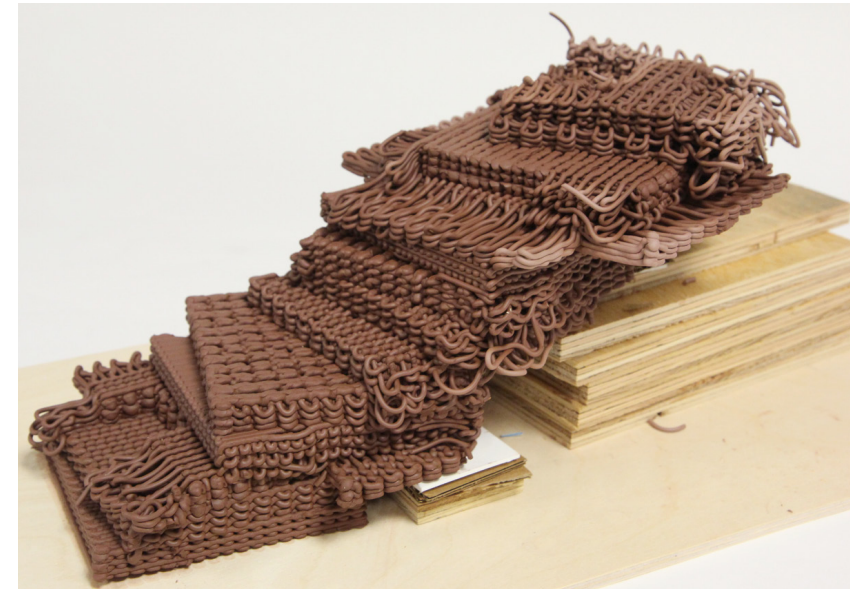


Fig 82. Joëlle Bitton, *A Streamline print over few days*, 2016.

Project sheet

- February - November 2016
- Collaborators: Kevin Hinz, Vincent Roudaut
- Software: OpenFrameWorks
- Material: Clay
- Data: Selected inputs from user (moods)
- CNC machine: Delta 3D printer or other extruders
- Fabrication process: User sends input, machine keeps printing over time
- Aim: Use of clay, continuous fabrication, performance of materials impacts outcome, time as creative factor
- Main Operative condition: Time (the fabrication process)
- Secondary operative conditions: clay (the material), mobility, distance, etc.
- Level of Interactivity: (scale 1-5): 4
- Code variables/conditions: 8 emotions, patterns, layers, parameters
- Inspirations: Interactive fabrication, direct fabrication, embodiment, accumulation, sedimentation, geology
- Progress: Adaptation to constraints, limitations of ambitions, feeding the material to the machine
- User-experience / Interactivity: User sends input 3 times a day, which are then controlling the machine with specific patterns/behavior
- User-scenario: While the user is going with her day, either sending info to herself, or to a friend at distance
- Outcomes: performative materiality, chaos on layering

Premise

In a similar way than with the two precedent experimentations, *Streamline* is ideated from different concerns: driven by research needs to test out specific conditions, a set of intuitions, limitations encountered in previous work that can be revisited and new objectives that come along the way. In that sense, the three projects were all vague ideas at the beginning of the research and their concepts kept evolving as each project got made and realised. The project is in constant tension, even at the stage of the idea, and it's always in the back of my mind, even when developing other works. *Streamline* was intended to tackle in particular the notion of time, even more so than with *Rabota*, in that it would use it where it's traditionally thought as a frustration to eliminate. Another notion that this project was set to explore is distance, and its role mediated by technologies in relationships and connectedness, a recurring theme in my work⁶⁹, that this time could be staged in a fabrication process. Other features to include were again real time fabrication that had to be dropped in the developments of the first two projects along with a more direct and evident relation between the user actions and the fabrication machine.

I also 'brought back' the idea of using a mobile phone for commanding the machine, the 'casual' and widespread interface I wanted to first use in *Twipology*. The mobile phone is, as mentioned before, ready-at-hand. It's *carried around* everywhere the person goes, and even when the person is not moving, the phone is never too far to reach. Thus when it's not being actively used, the phone is still a presence that manifests itself regularly, especially when it's a smartphone : alarms, timer, notifications, prompts of all kinds, from a wide variety of apps. And ascending gradually in our daily life, the intelligent assistant that promises to soon answer all of our questions and offer true companionship is, if not the real deal yet, at least always one voice

69 I explored that topic in particular when I was a research fellow in the 'Human Connectedness' group at Media Lab Europe, Dublin from 2002-2005.

command away to give us the time of day or the weather report⁷⁰.

The rich interface of the mobile phone / smartphone with already integrated user-experiences provides therefore opportunities to test features for interactive fabrication: notably with the phone qualities of mobility, of constant access, of daily use and of its growing role as a guide/guardian in the life of the user.

User scenario

With these elements, I chose the parameters for the interactive experience. Taking inspiration from ways that quantified self and logging apps collect data from users in a daily fashion, the *Streamline* app prompts users to state their moods few times per day (for instance once in the morning, afternoon, and evening). This stream of moods is interpreted into layers of XY geometry, converted in gCode lines and actuating a 3D printer. The data is thus used as a structure for the fabrication of an object by accumulation of successive layers with a type of deposition process over days, or weeks even. The user would decide on her own when an iteration of deposition was over: possibly after a day, or after a month. The numerous iterations would create a series of artefacts. The material envisioned for the fabrication was clay, a sensory-rich material, fitting the idea of accumulation and sedimentation, apt for being collected in a series of artefacts and potentially more relatable to a wide audience.

The name '*Streamline*' was given to the project for this idea of continuous flow. In addition, it's referring to a workflow, an assembly line, a geometry, and the design era that bear the name.

⁷⁰ Siri (Apple), Google Now and Cortana (Microsoft) are the apps integrated in their respective devices (with the last two available cross-platforms). Several assistant apps developed by other companies are also available. They all offer similar services with various degrees of efficiency. Amazon Echo and its Alexa phone app are praised as the "smartest" assistant that connects to an expanding range of devices and services for home, work and entertainment, and draws the contour of the always-available-friend/guide/guru status the assistant is taking or should be taking. Some announce it as the solution to the loneliness of the human condition, others as the spying Trojan horse that we bring into our homes. But after all, the one who 'watches' could both mean for protection and for surveillance. There's a fine line between attentiveness and control.

The machine intended for this project would be a typical additive XYZ extruder: it fit the aspects of "continuous" fabrication based on the log of the user's moods, an accumulation of data. The progress could be easily visualised in a week-long or more performance. The app is intended to be available and distributed - so with a additive printer in mind for this project, users with access to a MakerBot or other similar machines could start using it. And lastly, not having to build a machine for this project would allow to focus on the software development and on the material behaviours.

The home location was again fitting the experience, as a background companion that would occasionally be activated. I also considered the connectedness potential of the system: the machine that is actuated could be that of a friend instead of one's own. For instance, two users in a relation could generate artefacts at each other's place.

For the purpose of tests, since I wanted to run the experiments with clay, I used a clay extruder system that was already available at Harvard GSD that my collaborator Kevin Hinz had built for his research. A custom-built Delta 3D printer and a robot arm were alternatively used with the clay extruder system during those tests.

Related Work

There are hardly any consumer mobile app interfaces (or web interfaces) existing that operate directly with CNC-machines. I found one tied to a proprietary brand (the Buccaneer 3D-printer) and another one duplicating an existing online service (Cubify). For the most part, they propose a service of customisation of existing shapes, colours or sizes, by far the most common strategy to get non-experts familiar with new technologies. Customisation can be fun to a certain extent, but the learning and creative process in that context is limited. As always, my purpose is to enable appropriation, repurposing and adaptation. As such, audio and video social apps like Dubsmash, Vine and Snapchat are more open-ended in ways that users get creative and are better references in this study.

Moreover, additive 3D printers on the market are not equipped with wireless connection - they cannot receive incoming data from the Internet. For those that are open-source and therefore 'hackable' so that I could add a wireless connection myself, I face another issue that the board controlling the printer - most likely an Arduino board with a RepRap board extension (RAMPS) - will not be able to be modified for accessing a wireless protocol. This could be one of the reasons why there were so few projects connecting printers with real time data.

A few more relevant direct references appeared in the recent months:

- the *FarmBot*⁷¹, an open-source CNC farming machine that deposits seeds in the ground, waters them, destroys weeds and monitors the soil moisture, among other functions. The machine can be directly operated by its user via a Web App Interface: for instance, placing seeds according to the desired vegetable garden and scheduling irrigation at distance. The machine also receives external data such as the local weather info and can adapt tasks according to it. Typically, this machine scales industrial processes (like the 'Snowmaker') to a fairly accessible system than can be reproduced, controlled in real-time and with synchronisations. The inventors have described their software/hardware architecture in thorough details and have shared the code on github as well. As the development of *Streamline* progressed it was useful to have that reference for comparison - even though the *FarmBot* operates with a much more complex infrastructure. Yet, the hardware communication set-up between user/app/machine is fairly similar to what was conceived with *Streamline*.

71 <https://farmbot.io/>



Fig 83. The *FarmBot* CNC farming machine launched their pre-order campaign in July 2016 to great success. Photo retrieved from the company's website.

- the *iBoardbot*⁷², a much different type of CNC machine than the one above, is a small drawing whiteboard to which a marker is attached and that can be operated via the Internet: users can thus "write" messages or "draw" on their own boards or on their friends' board at distance via a Web App. The app operates as well with the IFTTT web service that correlates automatically conditions to actions over a range of online uses: the board can for instance display the subject line of an incoming email. The IFTTT service allows users to create their own correlations⁷³. The project was proposed on Kickstarter by a robot design company. The machine and code are here again open source.

72 <https://www.kickstarter.com/projects/879074320/iboardbot-the-internet-controlled-whiteboard-robot/description>

73 IFTTT stands for "If then, then that" and is widely used to correlate an immense range of devices and services in an automated way (as simply as logging one's locations systematically onto a Google doc for instance or sending an email to family when leaving work, etc...)

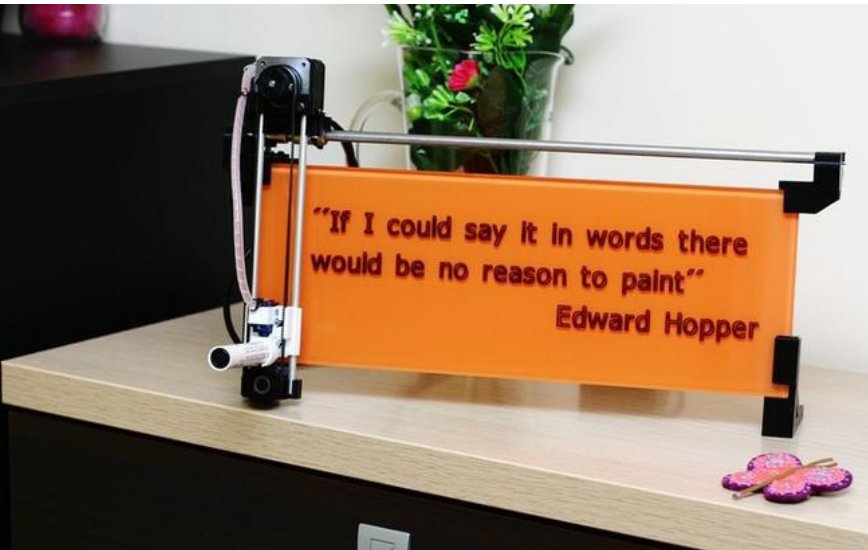


Fig 84. The iBoardbot launched its Kickstarter campaign successfully in February 2016. Photo retrieved from the company's website.

- The *ofxEpilog*⁷⁴ is an openFrameworks add-on for sending vector files to an Epilog laser cutter via an Ethernet connection. The creators propose with this system to control certain parameters in real-time: the power, speed, and frequency of the laser. These conditions can be correlated to all types of data input, generating wide variations in the cutting of the original document. The research project was conducted at the YCAM Interlab (Japan) in 2014 and presented in March 2016 at the ICDF conference (Ando et al 2016). The code of the project is again available on github.

74 <http://www.iamas.ac.jp/16701>

Iterations

These examples above were not available when I started conceiving the project. There were various both conceptual and technical aspects to tackle. Each aspect was investigated and advanced in parallel:

The data collection/prompt system

This is a fairly simple aspect of the project: a typical mobile app⁷⁵ would be developed and set up to push a notification to the user three times a day or more (for instance, 9AM, 3PM, 10PM or decided by the user). A user interface would propose 8 possible moods and the user could just check one of them. That way the interaction would not be very disruptive. It would just take a second. The 8 moods were defined temporarily as: happy, angry, tired, melancholic, hopeful, serene, depressed, excited.

The translation of the data into geometries and into gCode

The point here was to establish the most direct correlation possible between the data and the gCode to command the printer in real-time. That meant that the data would need to be interpreted as toolpaths, as 'streamlines'. A toolpath could then easily be assigned as command lines. Again for the purpose of testing, I made approximative associations. A base geometry had also to be decided in order to layout and orientate the toolpaths, as well as rules for the accumulation and possible variations in the rules. The diagrams below showcase the initial decisions as a way to frame the early tests.

75 The choice of the mobile platform didn't matter at that stage.

toolpath modifications

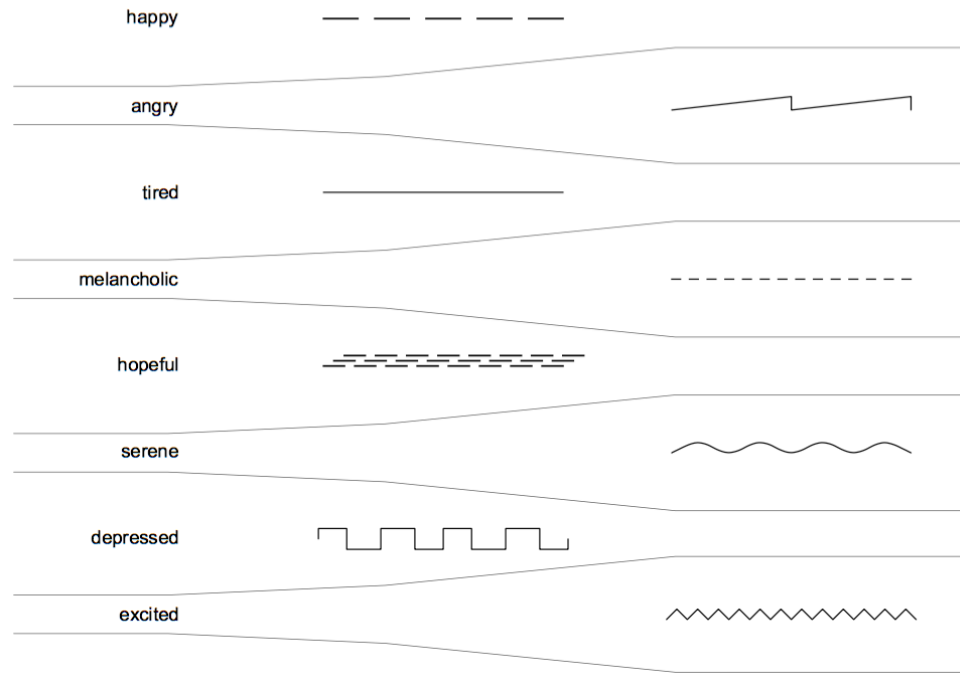


Fig85. Moods assigned to toolpaths. Diagram Joëlle Bitton & Kevin Hinz.

toolpath 2D step-over

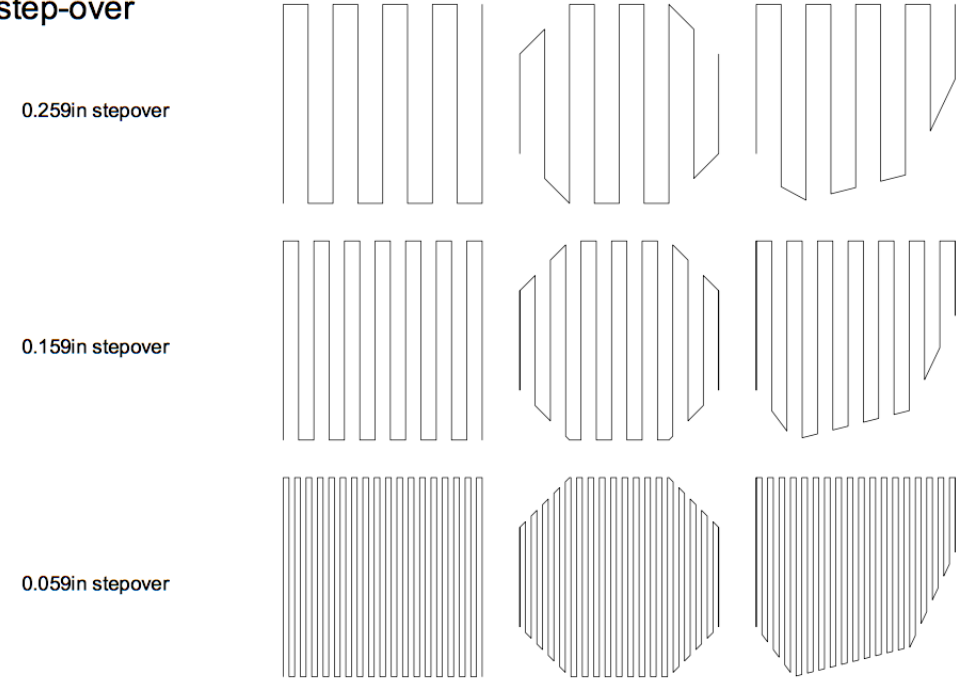


Fig86. Step-over as a possible variation depending on user factors: single mood repetition, wide range of moods, only highs and lows, length of time, etc. Diagram Joëlle Bitton & Kevin Hinz.

design contributors

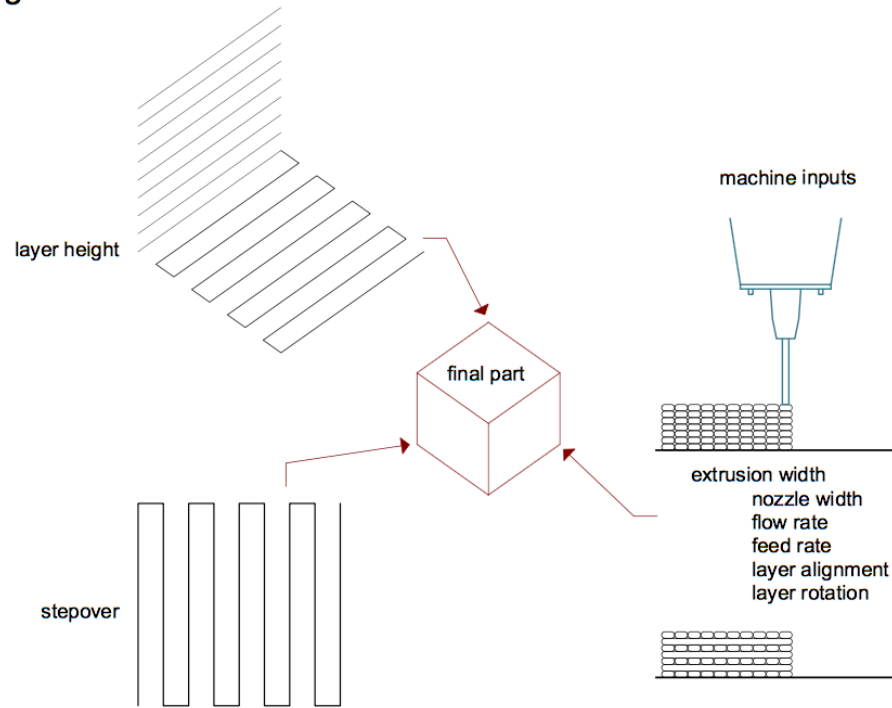


Fig 87. Other possible variations for the outcome of final part. Diagram
Joëlle Bitton & Kevin Hinz.

the transmission of the gCode to the printer

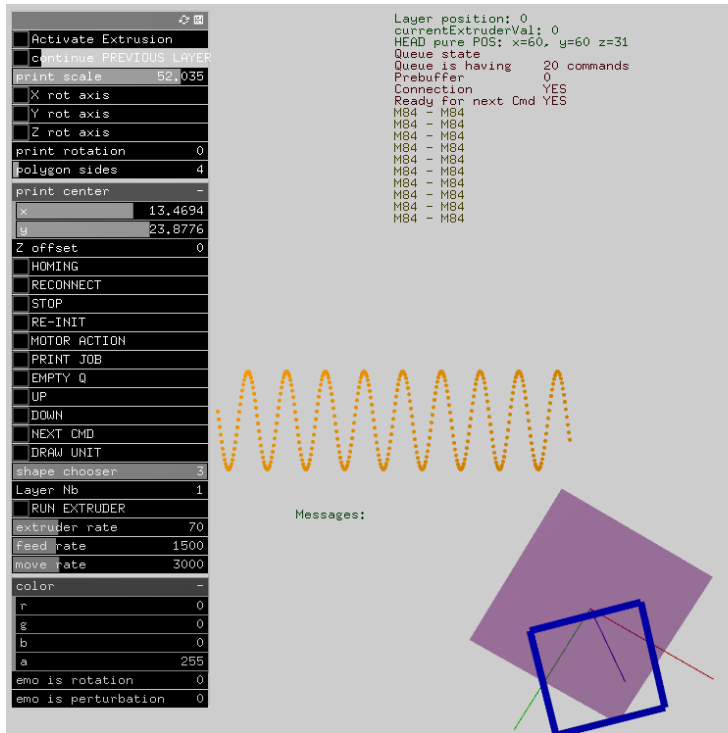
The infrastructure of the system was determined as such:

The data collected from the app would be sent to an online repository on a server (a 'cloud') on in a JSON file and then from there sent to a computer like a Raspberry Pi or a computer stick. That computer would then send the commands to the Arduino/Ramps board assembly that operates the printer.

As a 'cloud' server, I could use an already existing service coupled with an app but they cannot be trusted to last or to respect privacy issues. As well, I'm already using my own server. The drawback would be that if the app is launched publicly and is very successful, the costs of the traffic on my server with incoming and outgoing data couldn't be managed. Users would have to contribute to the costs somehow.

For the development of the project, the mobile app was not the priority. It mattered first to send data as gCode to a printer and tests its behavior with material. I collaborated on this phase with Vincent Roudaut, a programmer I had worked with on various occasions. Over few long days, an interface on OpenFrameWorks was developed that would run on MacOSX and could instruct the Delta 3D printer connected over Ethernet to follow commands in real time, it was almost becoming a drawing tool, as the computer mouse was used to control the extruder. Additional parameters such as flow rate, feed rate, rotation angle could be changed in real time as well by modifying values on the interface. This was a very conclusive test (*see images below*).

MEASURE OF ABSTRACTION



ODD MATERIALISM

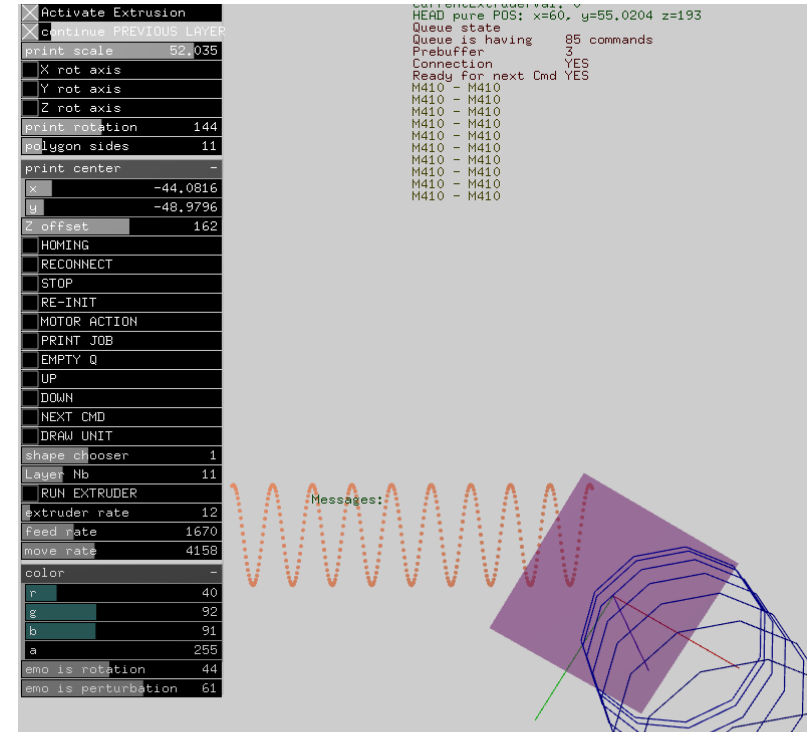


Fig88. Screenshots of program controlling printer (with parameters such rotation, extruder rate, scale, etc)

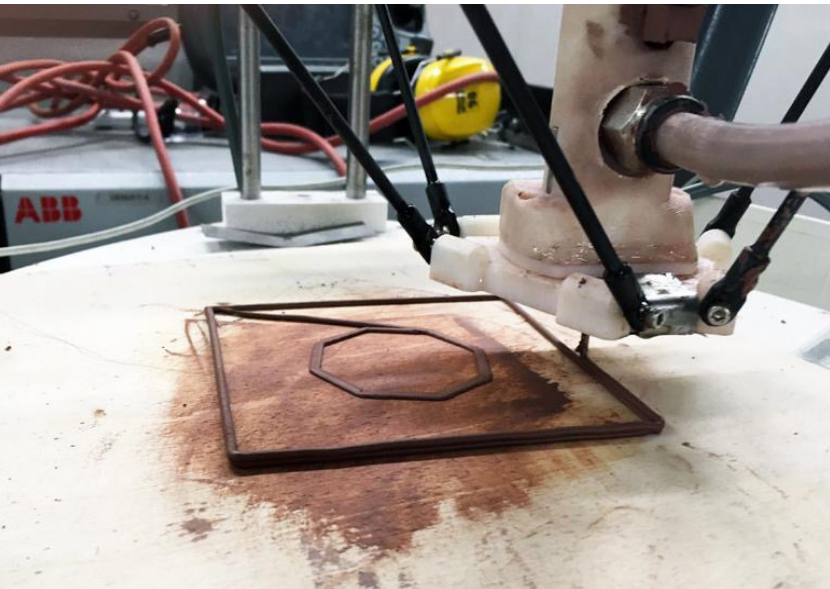
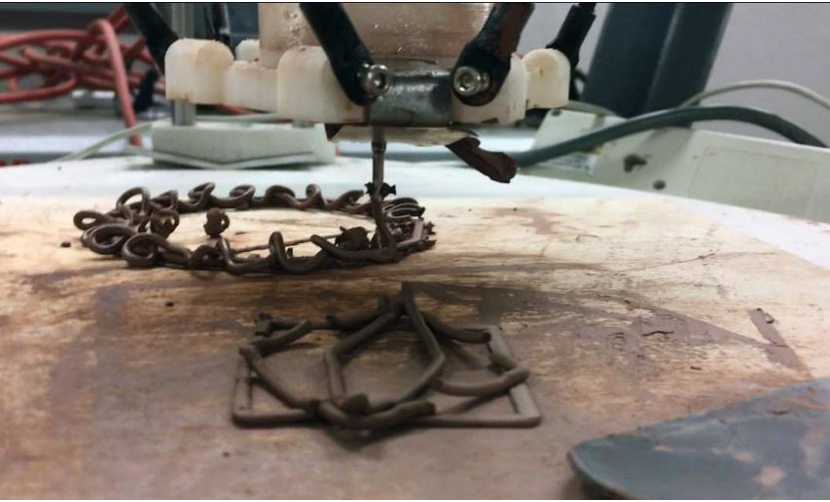


Fig 89. "Drawing" with a clay extruder in real-time. Photos Kevin Hinz.

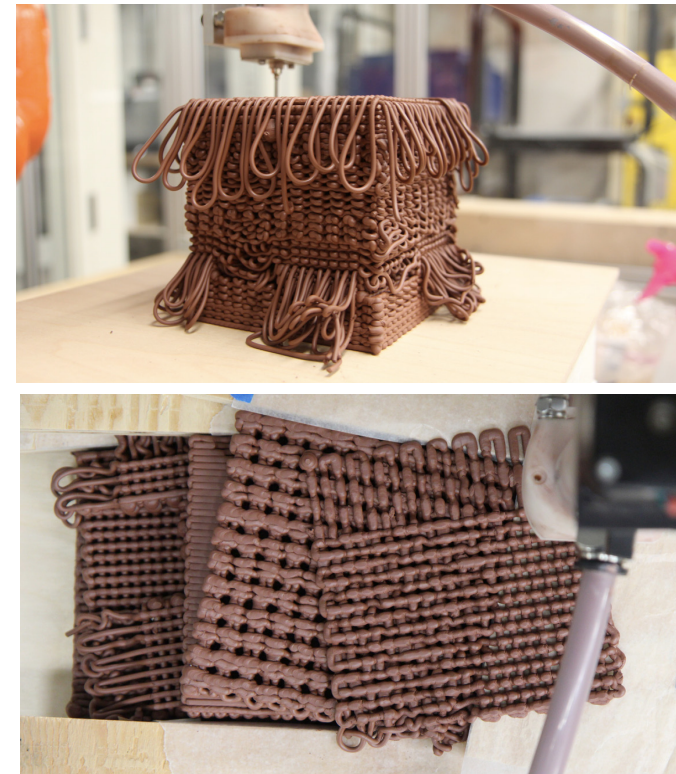
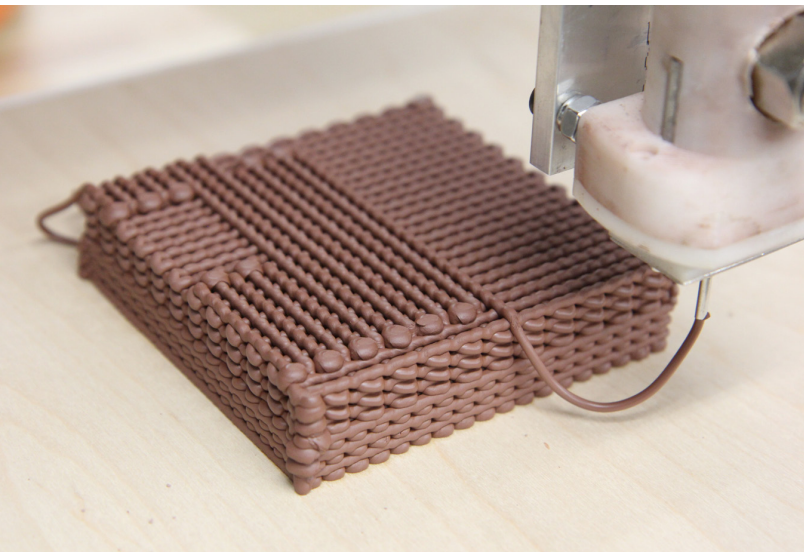
The next iteration specified further possible variations and rules according to the user's behaviour that would generate the object:

- With the constraints of the Delta 3D printer, the dimension of the object boundary was a cube of 141.42mm^3 . We tested a larger boundary using the same clay extruder with a robot arm.
- Each input of data (a user's mood) would generate 4 to 6 revolutions (layers) of the same toolpath across the base of the existing boundary (a square).
- Each group of 6 layers could have or not a different rotation from the previous one.
- The toolpath of reference for a mood could be disrupted in places (interrupted or shortened).
- The toolpath could be extended in places beyond the object boundary (up to 200mm).
- The toolpath could create a more or less dense surface.

Several combinations of these variations were further experimented with for prints to get a sense of the possible outcomes and of the possible surprises (*see pictures*).



Fig 90. Accumulation of patterns with a clay extruder (here attached to a robot arm) creating Streamline objects. Photos by Kevin Hinz.



Capture of abstraction

With *Streamline*, there is a direct attempt to materialise ideas and concepts. Such is time for instance. With the idea of “continuous fabrication” or “unfinished fabrication”, there’s a sense that time can be apprehended.

With the materialisation of moods, the project is in a dangerous territory, that of prescription. It’s again the question of applying a geometry to data, yet this time, with inferring that things as complex as emotions and moods can be reduced or simplified to labels and graphic rules. The proposal stated above of combinations and associations between geometry and emotions is of course an open one and a temporary one, that can be iterated in different directions, in order to avoid clichés. That said, this issue has long been debated and continues to be so among designers and architects - not necessarily of a direct representation of emotions but of a correlation between forms of design and the emotions it can create (*see image below*). My stance is to refrain from prescribing any sort of responses.

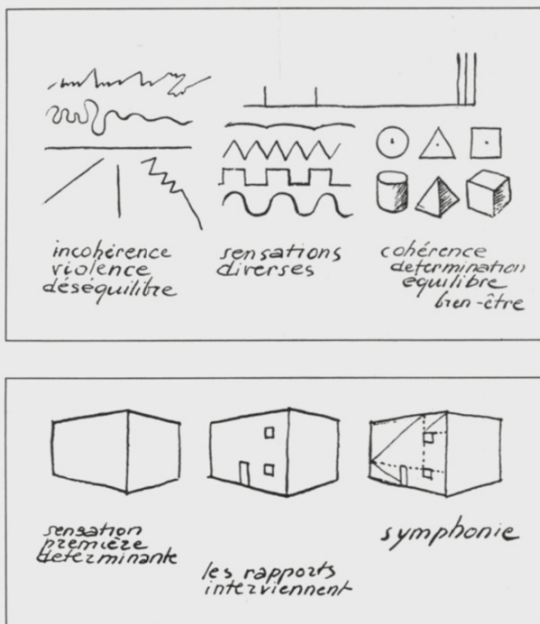


Fig91. Le Corbusier, diagram published in his article “Architecture d’époque machiniste» in *Journal de Psychologie normale et pathologique* (1926). Forms have emotional effects (or vice versa?).

Forms of Connectedness

Streamline is also a proposal of experiencing fabrication with other people, friends, relatives at distance, allowing them to impact a person’s interior, domestic environment, “communicating one bit at a time” (Kaye *et al* 2005). It’s possibly a form of background presence or awareness, such as it’s been described by Dourish (1992) and Patel & Agamanolis (2003), where a system is actuated in the ‘background’ signifying a person’s presence without it being disruptive. As Huang summarised it, “background awareness is a delicate form of connection between close partners, such as a connotative sense of presence or a subtle perception of each other’s moods and emotional deeds. Awareness of daily cycle, routines, or presence is especially important in relationships among family members, close friends, and coworkers. This awareness supports people to convey reassurance and a sense of context for communication, and also forms a bond built between people by background synchronization of their rhythms.” (Huang 2006).

Streamline could propose individuals in a relationship to communicate in such an indirect mode of delays and irregular rhythms, further suggesting intimacy at distance, and even a form of sensuality (Bitton 2006). In the context of this research, it was not possible to conduct such user study, but the proposal is laid out in a graphic novel story that I scripted in collaboration with a graphic designer, as to imagine a near-future reality of an interaction between friends (*see storyboard below*).

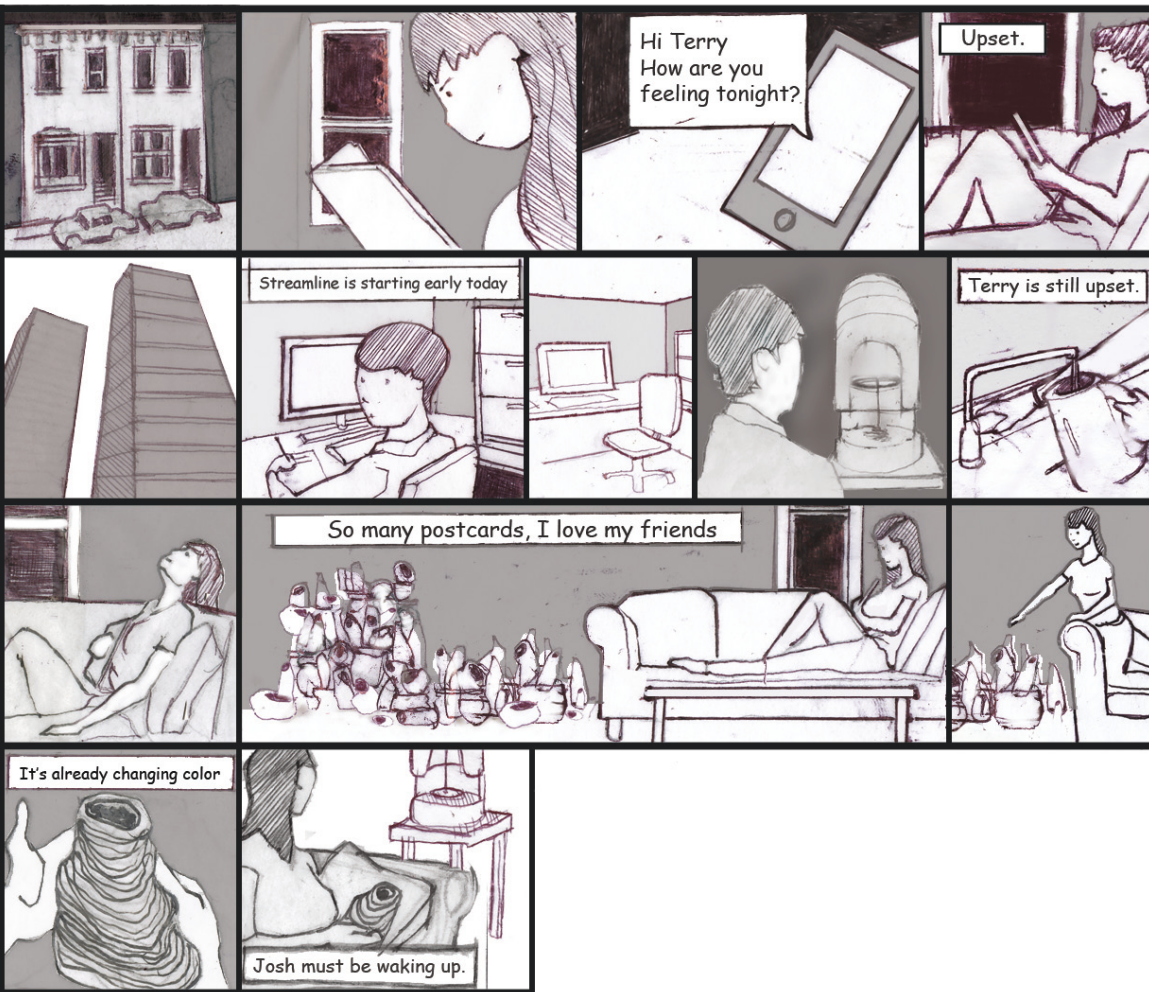


Fig92. Joëlle Bitton and BJ Johnson. *A Streamline Story*. 2016.

5. OBJECTS OF THE THIRD KIND

Each experiment I conducted shows distinct possibilities of interactive fabrication. They are not final answers nor strict guidelines. As it's not a study in data visualisation. And the legibility of the data is not a concern, as there's no functional purpose driving the design of the outcome, legitimately there could be expectations of meaning: What is then produced in the end? why should these artefacts be made? I would argue that it's in the pursuit of an odd materiality for its own sake that there's a liberating endeavour.

I presented 3 materialities: the ripples of life, the domestic ruin, and the mutant. These projects constitute speculative and unexpected interventions in everyday life environments. They can also allude to emerging forms of storytelling with interactive parameters constructing this narrative affordance. Personal data is at the centre of the experiences, that informs the physical world around, and in some cases engages the body further in the process. The possibilities of embodied fabrication are expanding as fabrication processes adapt to human size, mainstream contexts, intuitive interfaces and infinite combinations of data logs.

The materialised outcomes enable us to question the end point of fabrication that often falls in either functional or ornamental categories, with the built artefacts considered inert. As I have eluded above, I envisage a materiality that is very much embedded with affected attributes. I've mentioned various metaphors of mutation for instance that can be invoked for 'objects' that keep on being 'fabricated' beyond the machining part.

Towards the unknown

Since the objects in this study are not defined by their functions, their forms, their uses, their meanings or even their symbols - they're fabricated "beyond the shape" (Ion & Baudisch 2016) - could it be that it's the action within their emergence that informs them (and with the ambiguities that

the term ‘action’ invites, since again the awareness, the purpose, the plans of making are very loose)? As in some of these experiences, users generate things without even realising it, sometimes forgetting about it, it could be that their *being* and their *acting* are the primary materials, with outcomes only reflective of that.

It posits that machines can even better than respond to that human stance, as they themselves are powers of action, they are ideal dance partners. Tooling terms such as “subtractive”, “additive”, “extruding” thus transcend their immediate meanings.

It’s clear in that case that digital fabrication affects our relationship with physicality and we may not know yet all the consequences and implications to come. We’re heading towards an unknown, literally: “In May 2011, new media artist James Bridle announced a Tumblr blog (...) “The New Aesthetic.” According to Bridle, the blog features “material which points towards new ways of seeing the world,” which the current examples of 3D printing and laser cutting are no doubt a part. Bridle’s examples are described as “something designed for network culture to take up: for him, the products are ‘unknown,’” (Forlano citing *Berry et al 2012:17*.) That network culture is strongly associated with searches, explorations, adventures (‘surf’, ‘browse’, ‘navigator’, ‘pirates’, ‘hackers’, etc), it’s a flux of approximations where precision is not a priority.

Fabrication in that world could be then akin to what Bolt describes as “material thinking”, a radical mode of fabrication: “In this dynamism, the outcome cannot be known in advance” (Bolt 2007). She pursues further: “I would like to argue that contemporary artists often become so pre-occupied with intentionality, meaning and making an artwork, they tend to reduce their materials and tools to a means to an end. (...) I have proposed that creative practice can be conceived of as a performance in which linkages are constantly being made and remade” (Bolt 2007).

Possibly, it’s not just in that network culture that this is an opportunity. John Cage had advocated in many ways for a form of “practicable anarchy” as

a way of organising society (Cage 1976:53), reflected in his art process using chance, chaos and indetermination for letting a piece emerge.

Fundamentally, notation is a serviceable device

for coping with imponderables.

Precision is never of the essence in creative work. Subliminal man (the real creative boss)

gets along famously with **material** of such **low definition, that any**

self-respecting computer would have to reject it as unprogrammable.

Roberto Gerhard. ¶ ***Creative work defines itself. Therefore***

confront the work.

Fig 93. John Cage, *Notations*, 1969. Excerpt by Roberto Gerhard quote on notations. (p.240).

Yet, in this research, as laid out in the previous chapter, we're not completely in the realm of total randomness, arbitrary and accidents. It would be dishonest to pretend this. Interactivity sets conditions for things and for events to happen, but it's otherwise constrained by specific conditions. Though, with interactive fabrication, materials may indeed have more agency than with typical precise fabrication processes that look to "imposing forms on [them]" (Flusser 1999).

Materialisation of Abstraction

The elusive materiality may have to do with *what* is represented: concepts? thoughts? emotions? ramblings?

The more abstract is the thought in a way, the more the materialisation is playful and mysterious. What would it mean for instance to give consistence to emptiness, void? Can the ineffable be materialised? Artists Elad Horn and Emily Kappes presented at Harvard GSD their '*Inevitable Errors*', an exhibition of shapes formed with balloons and plaster.

Could it be that it's *nothing* that is being represented, leading to a *no-thing*?



Fig94. Elad Horn and Emily Kappes, *Inevitable Errors*, 2015. Exhibited at fortyk gallery. Photo retrieved from fortyk gallery website.

It's probably here that the artist and the designer have the most excitement (at least in my case): in that exercise of giving a shape grammar to concepts - the exercise of the diagram being probably the closest analogy. The *Rabota* machine could be seen as tracing the unconsciousness, letting a cognitive thought appear that has escaped the consciousness. In that sense, it has undertones of works of Borges and Kafka (maybe with less fear to it). The idea of distance is another rather inspiring and inventive concept to play with, especially if it's about *filling the gap* in a distant conversation.

After all, Flusser did mention that design is about "giving material shape to concepts" (Freitas 2008 citing *Flusser*). In a way, it's possible that this research is a literal interpretation of this, albeit without looking for structural or optimal functions. Materialising the immaterial could be the literal and absolute junction between theory and practice.

The status of the object

Beyond the identity of the object, it's important to address its status, as a possible shortcoming of the research lays precisely here: how can we relate to these objects? how can they speak to our senses?

Usually we think about objects in relation to our attachment to them, to the values and symbols we assign to them. As theorized by Sherry Turkle (2007), everyday objects, whether inert, mechanical or electronic, are carriers of emotion and evocation of "markers" of memory and values. The relationship to the object hence tells the narrative of the attachment of an individual to others, the narrative of her relationship to the world, or of the representation that she makes of it (Bollas 1979). Objects are indeed mediation tools, said to be revealing culture - the ways that we live with them and that we use them are studied by ethnographers who uncover how people behave through objects. They can look at them as one would look at archival texts. "The use of objects in our daily routines, the adaptation of artefacts to our preferences and all of our material consumption carries meaning and reveals something about us. The household appliances and furniture

we choose, the clothes we prefer to wear, our reactions to technological devices like cell phones or electronic mail are all revealing social, cultural relationships” (Freitas 2008 *about Dant*).

This is why objects are excellent props and probes in speculative design and human-computer interaction studies (Gaver 1999, Wright & McCarthy 2010) - because they tell so much of our everyday life practice and because we have stakes in them. “The functional relationships users have with things (...) are only one part of the picture. In his analysis of economic developments leading up to modernity, Fernand Braudel (...) conceptualised material life not only in its geographical and historical complexity but also with an emphasis on the ordinary life of people, their local customs, behaviour and innovations in material life” (Freitas 2008).

Yet, would this type of considerations be valid for the objects made in this study? For Markus Kayser, who created the *Solar Sinter* machine, he considers this work as the “design of a promise”, of a potential: “the promise is very real”⁷⁶.

Another possibility is that the objects make sense and gain status over time, as they become more numerous, as they constitute a series, instead of the standalone posture. They can then be compared to one another, show patterns, evolutions, behaviours. They can be part of assemblies and combinations in a cognitive process: “Lévi-Strauss [...] described *bricolage* as a way of combining and recombining a closed set of materials to come up with new ideas. Materials things for Lévi-Strauss, were goods to think with and, following the pun in French, they were good to think with as well” (Turkle 2007).

So in the end, again, maybe it just matters to play. To simply enjoy playing with material, like we did as children with play-dough. To not care so much what is made but more about the senses brought about by materials and sounds and toolings, letting the material perform and following its track.

76 Cited from a conversation with the artist, October 2013.

We’re always in tension with a material when we create - in pottery, for instance, the material is said to often have its own agency (Malafouris 2008). The illustrator Saul Steinberg describing himself as „a writer who draws“ stated that a „drawing is a conversation on paper” (Schjeldahl 2012 *citing Bair*), as if the paper and the pen were in it together. The composer Alvin Lucier who uses brainwave amplifiers as a source of sound, holds the speaker as a performer. His process is to “not compose”, meaning not interfere with the natural panning of the sound moving across the room (Lucier 2014). This underlines that materials are performers in their own right, “always in a state of becoming”. Feminist physicist Karen Barad uses the physics term of “diffraction” as an understanding of the performativity of the matter, and like Cage, as an invitation to apply it to our social organisation (Barad 2014).

After play, another option comes art. Possibly, it’s just the emergence of art that is happening and that would be that: “In this shift from the individual artist to the relations between the individual body, the social body and the material conditions of making (say a painting), the actors can include paint, the canvas, type of support, the weather, the wind and gravity as well as discursive knowledges” (Bolt 2007). But we couldn’t satisfy ourselves of the label “art” as to dismiss anything that is not *the rest*, could we?

The thing with things

The thing with things is that they are *very* malleable in terms of status, according to an infinite list of conditions (trends, value, culture, ownership history, journey, etc...). Moreover, it seems that oftentimes, the *idea* of things is more attractive than the things themselves. A book like Walter Benjamin’s *Arcades Project* for instance is so much more evocative, appealing, desiring in its *idea* and *imagery* than as a book to read. Photographies or exhibition displays of objects are in that sense sublime ways to capture their “aura” or suggestive force that by far occult their primary roles. See for instance my projects “*Futur Antérieur*” (2013), 56 close-up shots of precision instruments from the Harvard Lush Collection and “*White Square Of*” (2012), the display of 50 3D-printed objects as a concrete poem (*see picture below*).



Fig 95. Joëlle Bitton, 'Futur Antérieur', 2013. One of the 56 close-up shots of Rawson Electrical Instrument Co. precision instruments, Harvard Lush Collection (Collection of Historical Scientific Instruments, Department of the History of Science, Harvard University). Exhibited in the exhibition "Short Circuit: Exploring a New Acquisition at the CHSI", Harvard Science Center, Summer-Fall 2013.

It would be slightly out of the scope of this study to discuss at length notions of values and commodification of the items that are made in an interactive fabrication process. It's nonetheless a topic that is determinant in order to encircle their place in someone's life. If the object is simply a pretext for making and interacting with digital fabrication, then indeed the focus is shifted onto practices and activities. The object would "embody one's activity" (Thomas 1991). As brought up in the second chapter, making is often associated nowadays with positive reinforcers, but it can also be an illusion of freedom - 'DIY', 'bricolage', 'homemade' are just as much associated with scarcity and survival. Who wants to keep using a bed made of repurposed wooden pallets once they can acquire something more reliable and solid,

professional-looking? So, the line is fine between considering these objects as junk or as treasures. And thus this embodied and interactive fabrication context constitutes a fair proposal for an emerging materialism, that act as an alternative to the capitalist view, a materialism that could both show appreciation for all things in the world and include its own restraint, a rejoice for the alien, useless, freak and senseless. In that sense, it bears a cautious kindred to George Bataille's revolt strategy, a self-defined scatology that conjure the 'informe' - rot, waste, spit, body secretions - as liberators (Bois & Krauss 1996).

This perspective acts as an alternative to thing theories that on one end of the spectrum dismiss things as frivolous and as hindrances to spiritual ascendancy and on the other end of that spectrum consider things as 'equal' to humans and yet would still end up judging them.

Bill Brown remarked in his article on the "American uncanny" (2006) that things were getting "alive" in the titles of recent essays: "*The Tears of Things*, *Things That Talk*, *Ideas in Things*, *The Secret Life of Things*", following the lead of Appadurai's "*The Social Life of Things*" (1986), one of the seminal studies that had established that things had a cultural history of their own. Since Brown's article, more titles have appeared: "*Stuff Matters*", "*The Uncommon Life of Common Objects*", "*The Sympathy of Things*", etc. In parallel of that trend, posthumanist and transhumanist theorists invite us to accept the end of the human-centric area, where things are upgraded to the status of equal beings⁷⁷. (Not to confuse this newfound life of things with animism - the danger of exoticism would be too high).

But as Brown is himself aware in his article *Thing Theory* (2001), and as mentioned in previous chapters with references to Christian materiality, Futurism, Confucianism or ready-mades, the life of things is really *not that new* of an observation. Heidegger, among others, proposed his *thingness* theory of a certain sentience, itself referring to Meister Eckart's early-14th

⁷⁷ With the stance that things are equal to humans, there's always the lurking threat of considering in turn humans as things, and thus treating them as disposable commodities. But regardless of opinions on posthumanism, human groups have not waited for that theory to enslave other groups.

century perception of the mystical being of things. Other schools of thoughts have recently established discourses that seemingly move in that direction (object-oriented ontology, vitalism, actor-network theory, speculative realism, etc) yet they still fail to capture the actual substance of things. When Latour mentions that yes, things do talk but they'll remain silent *unless we*, humans, "make them talk", he's completely missing the point (Cole 2013 citing *Latour in Resembling the Social 2005:79*).

It's the same difference that I draw between the Internet-of-Things and this present study: on one hand, objects are given a prescriptive add-on, and on the other they're *already* talking. As Andrew Cole notes in his critique of object-oriented ontologies: "While they all work hard *not* to project the human into the heart of things, in their attempt to respect the indifference of objects in themselves, they do so anyway (...) [they] hear the call of things and speak *to* and *for* them, despite the new rule that we cannot think of objects as *being-for-us*" (Cole 2013). Among other incongruities worth noting in theoretical discourses on things, is a sort of hierarchy that puts 'things' above 'objects'. For Ingold, things are more open and more welcoming of life than objects that are them definitely inert (Ingold 2006), which I find a contraction in itself - if things could be animated then why wouldn't objects?

I actually argue that all terms like 'things', 'artefacts', 'objects', 'stuff', 'items' are interchangeable - the material world is too vast, too diverse and too nuanced to be encompassed by one term anyway⁷⁸.

Another very curious and stereotypical hierarchy has also established between everyday objects and art objects by some theorists: art objects, for instance, are too snob for material culture theorist Daniel Miller to be considered in his studies about common uses: "the very pretensions that surround the concept of art itself render such objects as relatively alien and difficult to absorb within the mundane social relations in which people are normally enmeshed. (...) The art object inevitably speaks to the rhetoric of art itself (...) which allows a few people to feel they understand and appreciate such works while making those same works largely oppressive and alienating

78 I could make a possible distinction in terms of size and scale, where I would perceive that objects are held while things include larger and more vague items. But I haven't found that an important distinction needed to be marked between these terms, as least in this study.

to the rest of us" (Miller 1998). Miller's perspective is reminiscent of the conclusions that Csikszentmihalyi made on a study of appreciation of art by "*normal people*"⁷⁹ where he noted that everyday items and homemade objects were more impactful: "The average person meets the recognized art object with the respect due to something awesome and expensive, but usually the experience leaves no permanent trace in consciousness" (Csikszentmihalyi 1991). Without dwelling on the rather condescending views that the appreciation of art escapes "mundane" and "average" people, these discourses are easily damaging the production of knowledge and actually reinforce the class system that these researchers denounce, precisely that art is not for everyone⁸⁰. Needless to say, I don't assess a hierarchy between types of objects nor do I presume the ways people can interact with them or can get attached to them.

The recent exhibition *Persona*⁸¹ has shown very eloquently that all sorts of things have been considered sentient and impactful throughout societies, cultures, religions, arts, crafts and designs for centuries, with the 20th century further letting loose of remnants of a distinction between animate and inanimate. Symbolism and late 19th century poetry notably have let ways for Dadaists and others to embrace the ready-made lives.

Living with ingenuous friends

When looking at the place and sense of things, I opt for the stance of artist Odilon Redon: "Friend of botanist Armand Clavaud, captivated with Darwin, Lamarck, Cuvier and Pasteur, and with medieval bestiaries, Redon was convinced that the chain of beings was infinite and the chances that form them was innumerable"⁸². The marvellous is already existing, everywhere,

79 The term "normal" is in quote in the journal article

80 I'm personally glad that such view never stopped me from being moved by art and practicing it.

81 At Musée des Arts Premiers, Paris

82 Summarised and translated by me from the *Persona* exhibition cartel for La Tentation de Saint-Antoine

simultaneously at every existing corner. It's the superpositions, the tensions and the contradictions within that that let things emerge.

As they do, some of them become life companions. It can happen when human dispositions are attributed to non-human entities (in a similar way actually that these dispositions can be attributed to other human beings) (Epley *et al* 2007). Anthropomorphism as such is motivated by understanding and encompassing our environment and by engaging in social relations (notably in childhood). Other times, objects become companions as they're designed for empathy, inclusiveness and conviviality (or at least thoughtfully), topics that have permeated design discourses with Illitch, Papanek, Munari, and before them Morris, Semper and Ruskin. Objects are therefore promises of companionship, repeated over and over again, with the realisation every now and then that they're not actually people.

Computers, mechanisms, and artificial intelligence have only added to the confusion. They didn't create it. They only take the promise slightly closer to the secret dream that's been there all along: having real, devoted companions, benevolent and unconditional. We're looking for friends, for love, for companionship in all the items that surround us. An issue of the French children publication *Le Journal de Mickey* introduced the Maxx Steele robot produced by the company Ideal in 1984 as a real ideal friend. Of course, the disappointment is commensurate to the expectation and the desire.

Making mutating objects

So in the end, what is being fabricated here is a compromise - this could seem like a negative outcome since the term is often used that way but it's not. The promise is still there vaguely, and it's not a lie. It's telling like Redon that possible play combinations are endless.

Objects can thus be parts that need to be articulated. They can be thought as unique or as units of a series. In chain stores where items are standardised, it's the combination of parts by people that makes the style,



Fig 96. Cover of 'Le Journal de Mickey', 20 October 1985. The Robot Maxx is "real".

a sum of its parts. The life cycle of the object can be seen as "the social 'performance' of materials and objects". It keeps therefore being put into shape. They can be made to be put together at home later like with the Ikea kits⁸³. The assembly is for Barthes for instance a proof of life. He brands most toys for instance as a way for children to imitate the adult world, and to learn to be obedient citizens. Barthes makes an exception for building sets that enable the child to "[create] life, not property: objects now act by themselves, they are no longer an inert and complicated material in the palm of his hand" (Barthes 1970:64).

In his '*Manifeste du Corréalisme*', Kiesler describes the evolutionary properties of objects: "he saw the house as a composition of spaces "as elastic

83

Comment made by designer Christopher Guberan in a conversation, Fall 2014.

as the vital functions” (Springstubb 2015). For Kiesler, “the elements of construction—whether for a city, a chair, or a house—should be a “nucleus of possibilities” developed and transformed in relation to its environment. The final form of the design should emerge organically, just as the “multiple, specialized functions of organs are already contained in the amorphous embryo of the human body.” (Springstubb 2015 *citing Kiesler*).

The objects made with interactive fabrication processes are thought to be partially unfinished, they keep living, they keep having a life of their own - they can keep eroding, growing, decaying. Objects end up not always what they were made to be but what they have become. They have a journey. They mutate. (Thomas 1991).

Born witness

Finally, these objects are objects of a third kind, “born witness” (Csikszentmihalyi & Rochberg 1981) of a moment of interaction with the material world; in this sense distant cousins of our Kodak instant photos that put a once exclusive technology in the hands of the many.

As the history of popular photography shows us, we can only be enthusiastic and eager for the creative uses and the subversive misuses that will emerge, that we can’t anticipate yet but that can only arise once users get to play with the tools - given that the tools are open and accessible enough⁸⁴.

With this research, I intend to contribute to the disruption of assumed workflows with artistic and experimental tactics.

⁸⁴ Kodak is also a story of a monopoly and as such has been over prescriptive when they could have let it go



Fig 97. Kodak Print Ad for the Instamatic camera. 1967.

MEASURE OF ABSTRACTION

Conclusion: Love and the Machine

This conclusion proposes a final reflection on this research and the topics at hand.

In a study that attempts to correlate discourses on the digital and the material, machines, fabrication, interactivity and personal data, there are difficulties to find the proper articulations.

During my investigations, I had to acquire and expand a very diverse set of knowledge in engineering, material properties, architecture, computer science, physics, maths, electronics, history of technology, craft theory, and many more that constantly opened new horizons. An important adjustment consisted in staying on track. Thinking about these topics in terms of art, design and HCI helped me keep a focus in that sense. Yet, as the research went on, it became clear that activities related to fabrication and technology implicate ontology and questions of existence itself and that it mattered to propose my take on these as well.

I set out to propose a process of fabrication that seamlessly could flow from one's mind to one's machine. Yet the ultimate goal is not to make that process instantaneous as in the *Star Trek* Replicator or the magic wand of fairy tales. Because then the machine would fade and disappear, it

would mean that it's no longer influencing the creative process. In his 2015 graphic novel *The Sculptor*, Scott McCloud imagined a character that was empowered to mold the physical world directly with his hands. He goes on to intervene in New York City freed from any technical constraints. But possibly because of that, the sculptor is losing himself in a voracious omnipotent frenzy (see panel below). So it matters to still maintain boundaries and distinctions between the self, the machine and the artefact: it's indeed in the choreography and the conversation between them that things happen.

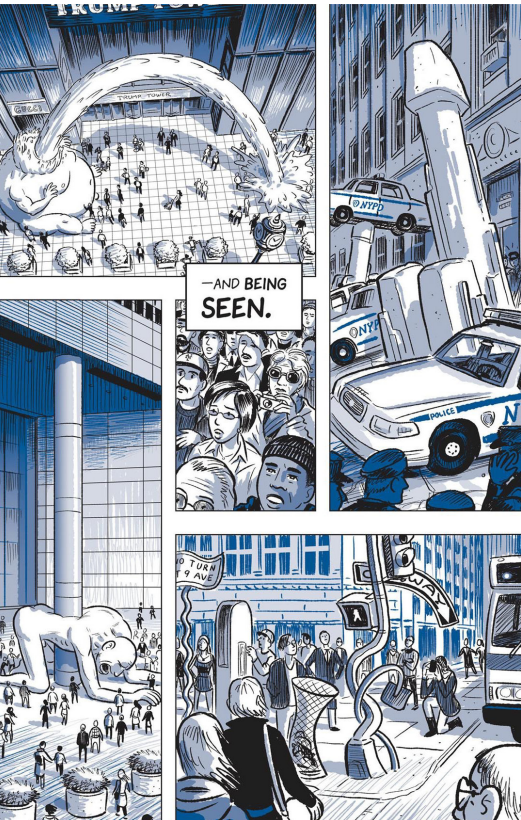


Fig 99. Scott McCloud, Panel from *The Sculptor*, 2015, published at First Second Books. In New-York City, the people wake up to discover the night work of David Smith who can with his bare hands reshape the entire physical landscape.

In that sense, I argue that accepting the mediation of the machine, is also a way to accept the other as its own entity rather than wanting to absorb it. This is in essence what I intended to demonstrate and hopefully achieved: a form of human-machine companionship that would capture the materiality of intimacy. Within that, I make light of an 'undisciplinary' research method and guidelines; I propose a form of inscription, *datagraphy* and the geometries this can take; I gather a taxonomy of related work; observing these works and my own experiments, I suggest types of interfaces for interaction with fabrication and a framework for interactive fabrication experiences; with a research set both in theory and practice, I tackle design and technical challenges and propose innovations while I contribute to ontological discourses that question the rapport of digital and material, of information and matter and of machine and singularity.

I could wonder though if I have failed or succeeded in endeavours where a public at large is concerned? The art works, the lessons learned and the lessons shared throughout the dissertation have enabled this work to have a great potential for contribution. But what would be the size of the audience? It would be difficult to anticipate for instance if the more elusive stance of oddity I suggest for daily life could be adopted. Have John Cage or Bruno Munari succeeded or failed in that sense? They both wanted their work and discourses to support forms of everyday life revolution and emancipations. But without mentioning their immense and long-lasting influence in the world of art and design, politic representatives for instance have hardly embraced their proposals of chance anarchy or quirkiness for governmental policy.

As William Morris put it: “we lack, so to say, audiences rather than preachers” (Morris, 1888).

This is never more true than with technology and with discourses as the ones I cited earlier that hope for a global emancipation from corporations with 3D-printers for instance. We should thus always acknowledge a threat of failure that lurks in the background as, as much as knowledge is shared online, a complete autonomy with software and hardware almost always

requires a high expertise in programming, in design and in electronics that ends up being exclusive (exclusion as a pitfall of initiatives promoting DIY has also been described by Nicole Dawkins in her work on DIY in Detroit, 2011: 280). Solutions for inclusiveness need to be developed but the inclusiveness is profoundly linked with the culture in which the technologies emerge, and are proposed and received - solutions often end up with over simplified and prescribed interfaces.

A wide survey I conducted with more than 100 respondents from different places in the world (mostly USA, France and the UK) has somewhat confirmed Morris' view where my work is concerned: technology is by far and large still considered as a tool that needs to be reliable and obedient, the laptop and the phone are most of the users' favourite machines and technology is still generally considered a threat for the future. So much for my 'poetic' view of disruptions and errors that I hope to propose.

In terms of concrete impact, my thesis is not driven by solving a problem. In general, I refrain from postures that consider that it's possible and even recommend to "design for impact" (Bell *et al* 2005). Again, I don't think that design and impact are compatible (or should be). Otherwise, it's a form of advertising, pushed into users lives and doesn't take into consideration multiple implications.

In the end, I gathered that my pursuit of oddness in design and fabrication is a suggestion for adopting tactics in life that bypass all forms of selection that generate hierarchy and exclusion. It's a position for embracing oddness in daily life, and in particular, the otherness, without conditions: the freak, the queer, the nomad, the immigrant, the refugee.

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