Negotiating Agency: Computation and Digital Fabrication as Design Media

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy.

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Master in Architecture

School of Architecture and Design

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NEGOTIATING AGENCY

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Corneel Cannaerts

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ABSTRACT

My research investigates agency of computation and digital fabrication and its influence on the making and materiality in architecture and design.

Recent developments in the computation and digital fabrication have made these technologies increasingly accessible to architects and designers in practice and academia, taking it from a rare novelty to a ubiquitous part of design practice. This has opened up a field of design exploration and brought material-making and materiality to the centre of attention in computational design, affording designers control over production processes at unseen scales and resolutions.

The discourse in this field tends to stress the positivist impact of these technologies – better integrated workflows, higher precision, uninterrupted flow from design intent to material artefacts – describing them as transparent and neutral. The practice of working with computation and digital fabrication in design differs from these idealised processes: materials can misbehave, computer code inherits a world-view and assumptions based on engineering and geometry, machines have limits and depend on specific material supply chains. My research investigates the extent to which this difference reveals the agencies of materials, computation and fabrication, and tests the extent to which this can lead to new creative opportunities.

I have conducted my research through my creative practice and scoped it in a designerly, practical, artistic, and scholarly context - my work consists of a series of design experiments, design studio-led investigative projects and workshops. Developing the research coincided with establishing MMlab, a research lab predicated on hands-on experimentation, fabrication and making. The research was further developed through literature and project review, collaborations and discussions with a community of practice at conferences and the practice research symposia.

My exegesis groups the research in three explorations, each consisting of a framework, a number of case studies and a reflection. The first, **Design and Making** explores the role of making during the design process and materializing as a way of exploring rather than concretizing design ideas. The second, **Code and Matter**, explores how materiality and fabrication are encoded in computational design models. The third, **Allographic Machines**, explores designing in negotiation with specific fabrication machines. A number of inquiries were developed through these three explorations: the negotiation between design intent and the creative significance of the unexpected as well as the expected outcomes of design processes; the negotiation between the agency of the designer and the agency evident in materiality, computation and fabrication, the allographic qualities of external agencies in design.

The contribution that my research makes to new knowledge can be located within the specificity of the explorations: firstly, making explicit the agencies uncovered through the explorations; secondly, recognizing these agencies to be negotiable; and thirdly, developing design projects through negotiating these agencies. Fourthly, next to these specific contributions, a more general modus operandi has been developed for negotiating external agencies as a designer: an agile, prototypical approach to evaluating rapidly changing technologies in design.

INTRODUCTION

INTRODUCTION

This PhD explores the extent to which computation and digital fabrication technology influence the engagement of architects and designers with materiality and making during the design process. My central proposition is that while computation and digital fabrication allow for materiality to be designed, and processes of making to be controlled, with a precision and at resolutions unseen before, these technologies are not neutral or transparent. The specifics of the digital fabrication machines used, the code that runs them, the materials they work with, and the process of making, will have an influence on the materiality of the fabricated artefact.

In a design process mediated by digital technology, material properties, computer programming and digital fabrication machines all have agency[1]. Agency, in most general terms defined as the capacity to act or exert power, has often been ascribed only to humans[2]. In my PhD I have extended the notion of agency to include the influence of non-human elements in my design process, specifically matter, code and machines[3]. Instead of seeing this influence as unwanted, or even problematic, I argue that the design process can benefit from negotiating with these external agencies leading to innovative design outcomes.

This proposition is investigated through a series of practice based explorations, comprising of a series of projects, design experiments, design studio-led investigative projects and workshops, developed in the context of my creative practice, and within the academic context of Sint-Lucas, Faculty of Architecture KU Leuven. Developing the research coincided with cofounding and establishing MMlab. The research was further developed through literature and project review, collaborations and discussions with a community of practice at conferences and the Practice Research Symposia, in collaboration with SIAL and RMIT.

This research is developed in the medium of design and conducted through projects. Direct engagement with the work is crucial for this research, whether it is hand making a material prototype or

[1] Miriam Webster Dictionary defines Agency as: *The capacity, condition, or state of acting or of exerting power; action or activity; operation.* See http://www.merriam-webster.com/dictionary/agency, (consulted on 20/12/2014).

[2] For an in-depth discussion on human agency, see the article on *action* in Stanford Encyclopedia of Philosophy http://plato.stanford.edu/entries/action (consulted on 05/01/2015).

[3] My understanding of agency has been developed by undertaking this research and is aligned with Andrew Pickerings notion of non-human agency, see Pickering, Andrew,. *The Mangle of Practice: Time, Agency, and Science* (1995) and Knappert and Malafouris argument for material agency, see Knappett, Carl, and Malafouris, Lambros (eds.), *Material Agency: Towards a Non-Anthropocentric Approach* (2008). The concluding chapter contains a more in-depth discussion on this understanding, see pp. 230-232.

installation, hacking together and using and abusing code, or building, modifying and operating machines. This written exegesis contains the framing of and reflection on the work, but it is only part of the PhD; its words and images need to be complemented with the intangible code and files and tangible artefacts that make up the work.

BACKGROUND AND MOTIVATION

Is digital destined for banality? Certainly. Its literal form, the technology, is already beginning to be taken for granted, and its connotation will become tomorrow's commercial and cultural compost for new ideas. Like air and drinking water, being digital will be noticed only by its absence, not its presence. Face it - the Digital Revolution is over.[4]

During the last two decades digital technologies have had an increasing influence on the practice of architecture and design. This is most evident in the tools and media used for designing, but also extends into the fabrication and production of architecture, the context in which we build, how architecture is lived in and experienced and how architectural culture is spread and consumed.

The motivation for starting this PhD can be situated within the post-digital condition sketched above, as my practice has been established while this condition has been unfolding. After graduating in 2004, and working for a few years as an intern in several architectural offices, I had a growing frustration with the distance between the design and the actual making of architecture, and the amount of time and energy spent on representing already formulated ideas in different formats. While computers were used throughout all phases of the design process, there was no time - and no interest, at the offices where I worked as intern - in using computation to improve this process of going from design to making, let alone explore its potential for design.

My frustration contrasted with the experiences of working outside of architecture in related fields of visual arts, digital media, graphic design and electronic music. Gradually my practice transformed from a more regular architectural practice into working as a freelancer and collaborator in visual and performing arts and building artefacts and installations, focusing on computational design and digital fabrication. These experiences allowed me to engage more directly with material and fabrication, speeding up the cycle designing and making, and are important for my understanding of architecture as an expanded field.

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[4] Nicholas Negroponte, *Beyond Digital*, wired Issue 6.12 | Dec 1998

CONTEXT AND MODES OF RESEARCH

When I was offered a teaching and research position at the Mixed Media unit of Sint-Lucas in 2007, I saw this as an opportunity to bring these experiences and concerns into architectural design and architectural education. The context and communities of practice in which this research is developed have influenced the modes of research:

The body of work reflected on in the PhD coincided with starting up MMlab in 2009, a research lab predicated on hands-on experimentation, fabrication and making. The MMlab comprises of a number of fabrication machines and it functions as a self-initiated context for design experimentation and as a learning environment, central to this environment, is the direct engagement with material, machines, and code. The MMlab functions as a means of communicating the research with the internal community of colleagues and students within the school - through elective courses, design studios and workshops - and establish relationships with external partners in practice, academia and industry - through organising lectures, events and external workshops.

Participating and presenting the work at the Practice Research Symposium, as organised by RMIT, has been an enriching and humbling experience. The feedback from the panel and insights gained from informal discussions with peers and supervisors have helped steering the projects. Research papers describing my work have been presented at international conferences focussing on architecture and computational design - Ecaade, Smart Geometry, Design Modelling Symposium. Through these exchanges with the MMlab a number of international collaborations have been established - most notably with Ecole Nationale Supérieure d'Architecture de Versailles, Paris, CITA: Centre for Information Technology and Architecture at The Royal Danish Academy of Fine Arts, School of Architecture, Copenhagen and SIAL: Spatial Information Architecture Lab at RMIT, Melbourne.

Informal networks have played an important role establishing, discussing and sharing the work: in 2011 I cofounded Processing Ghent, a community that brings together people using computation as part of their creative practice: artist, musicians, designers, architects… This community is part of a global network called Processing Cities that consists of similar initiatives around the world. Within this his network I have lectured and given workshops on using computation as a design medium for digital fabrication. The international network of fablabs has also been instrumental in starting up the lab, although the MMlab has a different research agenda. We have close relationships with this network, most notably, timelab in Ghent and iMal in Brussels. Through these networks my work has been exhibited nationally (Ghent, Brussels) and internationally (London, Paris).

STRUCTURE OF THE EXEGESIS

After the ***introducing chapter*** my exegesis is structured in three parts or explorations. These explorations are organised thematically, and focus on a subset of interests and questions within the work, but they are also hierarchical and partly chronological, the interests and questions become increasingly specific and focussed, and the work builds on the previous explorations. Each exploration consists of a critical framework and a number of cases that reflect on a particular interest within the work. The cases do not necessarily overlap with projects, some cases will describe one main project but also refer to previous work and works by peers, while others group a number of projects. The three levels of the structure - exploration, case and project - reflect the highly diverse nature, scope, duration of the body of work that makes up this PhD. The structure allows me to sample and map the cloud of projects, workshop, installations, artefacts, images and design experiments. Rather than providing a complete overview of thirty plus projects, it allows me to highlight particular moments and instances in the work, and recurring interests, and overlap between the projects.

The first exploration, ***Design and Making***, starts from the distance between design and making that motivated my research, as outlined above. It explores what it means to make as a designer during a design process, making as way of exploring and triggering, rather than mere materialising of design ideas. The cases operate within the space opened up between a set of seemingly contrasting notions: design and making, material and digital, working within a medium and unmediated construction.

The second exploration, ***Code and Matter***, dives deeper in the digital world, by going beyond the interfaces of standard software, and engaging directly with coding as a design medium. Rather than looking at the world of code in isolation, this chapter explores what coding can bring to the practice of architecture and design; more specifically the chapter looks at code in relation to matter. On the one hand, it looks at how matter, its properties and behaviours can be encoded and simulated in the digital world; on the other hand it looks into code as matter, the stuff that makes up the digital world.

The third exploration, ***Allographic Machines***, describes and discusses a set of case studies aimed at designing for digital fabrication, as a set of technologies and machines that operate between the digital and the material world, as a design medium with its specific qualities and challenges. Rather than a process that describes only external form and extensive properties of an artefact, it explores digital fabrication for its intensive material qualities, and as a process that unfolds in time and leaves its traces in the fabricated artefact.

A number of enquiries were developed through these three explorations: the negotiation between design intent and the creative significance of the unexpected as well as the expected outcomes of design processes; the negotiation between the designer and the affordances and resistances[5] evident in materiality, computation and fabrication; the allographic qualities of external agencies in design. My understanding of agency has developed though conducting these explorations and inquiries, and in the ***concluding chapter,*** I will discuss the implications of this understanding for my design practice, summarise the argument of the PhD, and discuss the contribution made by my research and identify possible further research.

[5] Throughout the exegesis next to *agency* I will use the notion of *affordance and resistance*, as that is how I understand matter, code and machines to exert agency. In the concluding chapter these notions are defined and my understanding of their relevance for design practice discussed. See pp. 231-232.

EXPLORATION I
DESIGN AND MAKING

"Most architects do not make buildings – they make information for buildings. They turn ideas into drawings, models, texts and data, where many results inform the production of buildings and others do not. Among the host of critical and diverse traits required in architectural production, the making of buildings demands an expertise that is familiar with the tactile and the physical. It is a body of knowledge and experience that goes beyond the production of information; it is an area that is sporadically documented and, despite the often extraordinary outcome, it involves a level of skill that many designers cannot claim to fully possess or practise".[1]

INTRODUCTION

In architectural practice, designing and making are activities happening at a distance from each other, both in time and location. The separation between designing and making can be traced back to the emergence of architecture as a profession and the emancipation from an applied to a liberal art in Renaissance. This coincided with the establishment of drawing as a dominant medium for design – a principal means of communication and an important legal document.[2] Tracing the history of architecture as a profession, its modes of representation and the connections with other participants in the building industry reveals different ways in which architects and designers have dealt with this divorce. Generally speaking, our mode of engaging with making has remained at a distance, mostly operating through the drawing. However, a number of idiosyncratic practitioners can be found in architectural history who provide an alternative to this distance, and who have explicitly dealt with questions of making and materialisation.[3]

The divide between design and making was further deepened by projective geometry, standardisation and industrialisation and was substantiated by protection of the profession in legal terms. On the surface, the contemporary connections between designing and making in architecture look straightforward enough; designers and architects produce information in the form of drawings, models, text etc. Contractors take that information and make it into built artefacts. However, as the opening quote by Bob Sheil outlines, the connections between practices of designing and making are more intertwined; such a simplified scheme and a strict separation between makers of information and makers of artefacts is problematic in at least three areas.

Firstly, the act of designing cannot be reduced to the making of information, let alone limited to just making information aimed at building. In order to capture ideas, designing requires a medium, and this medium will have an influence on the formation of design ideas. One could even argue that design ideas only exist if they are captured in a medium, or, as Stephen Groak argues, that "...*drawing*

1 Bob Sheil, introduction to *Design Through Making* (July/August 2005), p. 6.

2 This history of architectural representation is widely published, the most comprehensively in Alberto Perez-Gomez and Louise Pelletier, *Architectural Representation and the Perspective Hinge* (2000) and Dalibor Vesely, *Architecture in the Age of Divided Representation: The Question of Creativity in the Shadow of Production* (2004).

3 From Philibert Delorme's stereotomy, Gaudí's sculptural stone architectures and his later use of ruled surfaces, to the collaboration of Pierre Chareau, Bernard Blijvoet and Louis Dalbet on Maison de Verre, or Jean Prouvé's experiments with prefab construction.

is a form of thinking, not merely a record and presentation of a thought already completed".[4] It is my assumption that the specific properties and the materiality of the medium as well as the skill and insights of the designer all contribute to formulating design ideas. Another way of stating the same argument is that designing always includes a degree of making, which is more than just capturing formulated ideas, more than just information.[5] Next to drawing, model making is of particular interest here, as it most clearly demonstrates engaging with matter and making as active parts of the design process.

Secondly, designers and architects cannot claim to possess all the knowledge necessary for making a built artefact; the information provided by designers and architects is necessarily incomplete and does not completely determine the built artefact. Consequently, the act of making requires interpretation, specification and decision making that will influence the design outcome – in other words, the act of making contains a degree of designing. One of the reasons why the information provided by architects and designers is incomplete is that part of the knowledge needed for making is tacit[6] and partially escapes being formulated as information. Another reason resides in the unruly materials used for making, which will partially escape control of the architect, notwithstanding attempts at control through standardisation, tendering documents and use of material samples.[7]

Thirdly, the act of translating information between designing and making is not one-directional[8] nor neutral as it does not leave the information unaltered. In his influential essay *Translations from Drawing to Building*, Robin Evans starts from the observation of the divorce outlined above. Architects do not work with the object of their thought directly, but rather always do so through some intervening medium, mostly the drawing. Evans goes on to criticise both extreme positions taken in this debate: either locating the work of the architect solely in the building or locating the work solely in the drawing: "*The two options, one emphasizing the corporeal properties of things made, the other concentrating on the disembodied properties in the drawing, are diametrically opposed: in the one corner, involvement, substantiality, tangibility, presence, immediacy, direct action; in the other disengagement, obliqueness, abstraction, mediation and action at*

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[4] Steven Groák, *The Idea of Building: Thought and Action in the Design and Production of Buildings* (1992), p. 150

[5] See Neil Spiller (ed.) Drawing Architecture (September/October 2013) and Nat Chard, Drawing Out an Indeterminate Duration, in Bob Sheil (ed.), *Manufacturing the Bespoke: Making and Prototyping Architecture* (2012),

[6] I use tacit here referring to the work of Michael Polanyi, *The Tacit Dimension* (1966).

[7] This argument is made by Jeremy Till, *Architecture Depends* (2009), p. 45-63.

[8] Jo Van Den Berghe makes a similar argument, for a two-directional, reciprocal relationship between designing and making – or poetic image and substance in his words – in his PhD study titled, *The Theatre of Operations, or: Construction Site as Architectural Design.*, RMIT (2012), p.4. Axel Kilian develops a similar idea in his PhD *Design Exploration through Bidirectional Modelling of Constraints*. MIT (2006) See http://www.designexplorer.net/download/Kilian-phd-arch-2006.pdf. Consulted on 20/10/2014.

a distance. [...] architects might conceivably combine, in such a way as to enhance both, the abstract and the corporeal aspects in their work". [9] Instead of choosing either of these two extremes, Evans identifies the space in between, the translation between drawing and making, as the location for the architects' work... *"Taking advantage of the situation by extending their journey, maintaining sufficient control in transit so that more remote destinations might be reached".*[10]

Digital technologies have influenced all three of these areas of architectural practice: the process and medium of designing, the making and materialisation of an artefact and the translations in between. At the time of writing Evans' essay, digitalisation of architectural practice was limited to drafting and had not affected making and construction directly or the translations between drawing and making. I think Evans' essay is useful in understanding the influence of digital technologies on these three aspects, as it warns us against presumed transparent translations between design and making, which seem to be promised by digital technologies. The influence on fabrication and construction has been more indirect and slower; only more recently through the adoption of digital fabrication and building information modelling has digital technology directly influenced making and the translations between design and making.

This chapter explores what it means to make as a designer, across different scales – whether it is the making of a scale model that refers to an external material or spatial artefact, or a prototype exploring specific material properties, or a full scale installation. Furthermore, the cases deal explicitly with translations between different scales and different media. This chapter describes two cases that each deal in a different way with the distance between design and making and the impact of digital technologies on this distance. In the cases described in this chapter, the use of digital technology was limited to standard digital modelling; the later chapters focus on particular aspects of the impact of digitalisation on the act of designing and making and the translations in between. The second chapter focusses on code as design medium and its relation to matter, and the third chapter focusses on digital fabrication as means of making that bears traces of both computational and material processes.

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[9] Robin Evans, *Translations from Drawing to Building, and Other Essays* (1997), pp. 160-161

[10] Ibid. p.182

MAKING

> *"The architect would like to think that the complete building stands as a crystallisation of an original design concept, with all its components finally fixed in their proper places. As with the jigsaw puzzle, should any components be added, or taken away, the entire structure would be reduced to incoherence. In the ideal case, once it is finished the building should hold for all eternity to the form the architect intended for it".*[11]

The distancing between design and making has not only affected the practice of architecture, its modes of representation and interactions with other participants in a building process, but also how we come to think of architecture itself. Denouncing making as an important moment and critical contributor to architectural design freezes architecture in a static idealised state of coherence, far removed from practicalities of building and the contingencies of everyday reality. [12] Architectural production is reduced to a predetermined action, trying to reproduce a completely defined example without a contribution by the maker, the materials or the process of making. This idea of material as a passive receptacle for design ideas,[13] making as imposing a given form onto matter, is contrasted with the idea of making as an exploratory process:

> *"When we make, instead of predetermining action, we discover a map of engagement. We play by challenging and resisting material. It in turn, reveals an intentional resistance that provokes yet another challenge, and on and on. In fact, craft excels in less-than-ideal situations. When challenged by aberrant materials, geometry and craft are forced into innovative discovery: a knot of reaction wood within an otherwise homogeneous surface would force a novel adaptation of geometry generated by imperfection".*[14]

Exploring this map of engagement, the resistances and affordances found in material, through the act of making or crafting,[15] requires skills in manipulating materials, tools and techniques, which reside as much in the hand as in the mind of the maker. The knowledge needed for making is partly tacit and embodied; it is learned by doing and acted out in practice.[16] Digitalisation is often mentioned as one of the drivers for the erosion of this tacit knowledge, as "*the computer creates a distance between the maker and the object, whereas the drawing by hand as well as model-making put the designer into haptic contact with the object or space*".[17] A similar point is also made by Richard Sennett in his book *The Craftsman*; he states that the cyclical process of tracing and retracing, which ingrains a form in the mind of the designer, is in danger when using a computer.[18]

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[11] Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (2013). pp. 47-48.

[12] This static image of architecture is part of a larger notion of architecture as an autonomous activity which pervades architectural culture as is argued by Jeremy Till in *Architecture Depends* (2009). p.66.

[13] This idea is known as form-giving – *hylomorphism* – from the Greek hyle (matter) and morphe (form), and can be contrasted with *morphogenesis,* or form-generating. See Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (2013), pp. 20-25.

[14] Patrick Harrop, *Agents of Risk, Embedding Resistance in Architectural Production,* Proceedings of the 2004 ACADIA Fabrication Conference, 2004, p.1, for a description of reaction wood see http://en.wikipedia.org/wiki/Reaction_wood (consulted on 20/01/2015).

[15] See Michiel Riedijk, *Architecture as a Craft: Architecture, Drawing, Model and Position* (2010). pp. 16-18.

While these critical voices on the use of computers in design remind us to look critically at digital technologies and their effects, some of the argumentation clearly has nostalgic overtones and stresses an opposition which is no longer relevant in design practice, from my experience. With the normalisation of digital technology, shedding its status as being new, and the increased accessibility of digital fabrication and scanning technologies, we can move beyond such an oppositional approach and embrace and value both digital and material design processes – or find an in-between that combines the abstract and the corporeal, to use Evans' words.

In *Abstracting Craft*, Malcolm McCullough defines what he calls the 'seeming paradox of digital craft',[19] a set of material practices based on digital media that incorporate both hands and mind. McCullough's definition of craft as a verb is useful to frame the processes of making described in this chapter: *"As a verb, 'to craft' seemingly means to participate skillfully in some small-scale process. This implies several things. First, it affirms that the results of involved work still surpass the results of detached work. To craft is to care. Second, it suggests that partnerships with technology are better than autonomous technology … Third, to craft implies working at a personal scale – acting locally in reaction to anonymous, globalized, industrial production […]. Finally, the usage of 'craft' as a verb evades the persistent stigma that has attached itself to the noun". [20]*

Currently, we see a renewed interest in making and materiality in architecture and design, partly fuelled by innovations in digital fabrication and computational design. In order to frame the contemporary, digitally mediated practices of making, Branko Kolarevic refers[21] to David Pye's description of craftsmanship. David

[16] Juhani Pallasmaa, *The Thinking Hand: Existential and Embodied Wisdom in Architecture* (2010). pp. 64-69.

[17] Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses* (2012), p.12.

[18] Sennett clearly doesn't speak from experience – as I do, belonging to the last generation that had to hatch by hand – when he praises hatching and drawing bricks by hand in a façade as they allow reflection on the materiality of each individual brick; while there is nothing in computer aided design that would not allow you to do that, you at least have a choice of speeding up the process. See Richard Sennett, *The Craftsman* (2009), p. 41.

[19] The term "digital craft", coined by McCullough in 1996, has been used more frequently and refers to the use of digital fabrication for prototypes and installations and pavilions. See digital-crafting.dk, consulted on 12/08/2014.

[20] Malcolm McCullough, *Abstracting Craft, The Practiced Digital Hand* (1996), p.21.

[21] Branko Kolarevic, "The (Risky) Craft of Digital Making, in Branko Kolarevic and Kevin Klinger (eds.), *Manufacturing Material Effects: Rethinking Design and Making in Architecture* (2008), p.120.

Pye introduces a distinction between the *workmanship of* certainty, which he found in industrial manufacturing, aimed at producing identical copies, and the *workmanship of risk*, where the quality of the work is continually at risk during its making, "… *where the quality of the result is not predetermined, but depends on the judgement, dexterity and care which the maker exercises as he works*"[22]. Talking from many years of experience as a craftsman, Pye argues that this does not depend on the use of tools, as hardly anything is made purely by hand, and that in a making process there is a balance between allowing risk and limiting risk using jigs and tools. According to Kolarevic[22a], this notion of workmanship of risk resonates with contemporary processes of design and making, where designers use digital fabrication machinery in an exploratory way, and design results are not predetermined or completely anticipated, but discovered or discerned among the many possible design variations.

This chapter deals with making, not as a way to materialise a predetermined existing idea, but as an exploratory process, where the quality of the work is at risk. In the cases described in this chapter, making is considered part of the design process, where materials, their imperfections and behaviours, and the process of making, all have an influence on the quality of the result. Instead of stressing an opposition between digital and material design media, this design process embraces both material and digital, both abstract and corporeal.

MODELLING

"Whatever their scale, models are united by their purpose which is to test some aspect of a subject. This testing is done on or through that aspect of the model which inhabits the real, i.e. that aspect which is not representational, but which interacts in the non-model world on its terms. […] This seems so utilitarian, so sensible, so practical. Yet those who make models know better. Testing reinforces and emphasises that the model is both tangible and intangible, and makes the model's dissonance of scale, material and craft more acute and more magical".[23]

In architectural design and its connection with practices of making, the model has an interesting position. Compared to the drawing, the model has not been as thoroughly theorised or extensively discussed.[24] The origins of this marginalised status of the model can be traced back to the divorce in the Renaissance, as outlined above; drawing was associated with intellectual activities such as writing and philosophy, whereas making models required skills and tools of the craftsmen and makers, which architects wanted to distinguish themselves from. Notwithstanding this disdain for model making, the model workshop has remained an important place for design experimentation, for those architects and designers who aspire to a tactile, hands-on approach to design.

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[22] David Pye, *The Nature and Art of Workmanship* (1968), p.2.

[22a] Branko Kolarevic, "The (Risky) Craft of Digital Making, in Branko Kolarevic and Kevin Klinger (eds.), *Manufacturing Material Effects: Rethinking Design and Making in Architecture* (2008), p.120.

[23] Alex Selenitsch, Small Real Large, in Mark Burry, Michael Ostwald, Peter Downton and Andrea Mina (eds.), *Homo Faber : Modelling Architecture* (Melbourne: Spatial Information Architecture Laboratory and the Melbourne Museum, 2007), p. 8.

Drawing requires a form of projection, the capturing of spatial entities as marks on paper, and implies a distancing, a positioning outside of what is being drawn. The model implies a more direct link with making and materiality, even while working on a representational model that refers to an external spatial and material artefact. Representational models are often constructed out of makeshift materials, paper or card, which have not much to do with the materials used on the construction site. Notwithstanding this difference in material, the model belongs to the same world of what is being modelled and does not imply a dimensional shift as the drawing. Interpreting or reading a model does not require conventions or learning jargon, as some architectural drawings do, mainly those used in construction; therefore, the model has often been used to represent and communicate design ideas with people not trained as architects, designers or builders.[25]

Coinciding with a renewed interest in making and materiality in architecture and design the last decades, the model has been subject to increased attention in practice and academia; this has led to a number of exhibitions[26] and publications[27] explicitly focussing on the role of the model in design. These differ in nature, from providing a historical overview, showing collections of models over the last five hundred years, offices providing a glimpse into their design process by displaying working models,[28] to a host of speculative research models. The model remains a hard to pinpoint notion,[29] sometimes practical and self-evident means of communicating designs ideas,[30] at other times elusive, and ground for philosophical reflections.[31]

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[24] This point is made by a number of publications that do focus on the model; see Bradley Starkey, Post-Secular Architecture, Material, Intellectual, Spiritual Models, in Marco Frascari, Jonathan Hale and Bradley Starkey, *From Models to Drawings: Imagination and Representation in Architecture* (2007). p.231.

[25] Presentation models have often been used to sell architectural ideas and have only recently been out-staged the hyper-realistic renderings of computer models.

[26] Examples of exhibitions: *Idea as Model*, curated by Peter Eisenman at IAUS, 1976 *The Architectural Model: Tool, Fetish, Small Utopia, in* DAM, Deutsches Architekturmuseum Frankfurt, in 2012, or Maquettes, in STAM, Gent 2014.

[27] For a good historical overview, see Albert C. Smith, *Architectural Model as Machine: A New View of Models from Antiquity to the Present Day* (2004). pp. 1-39.

[28]. The exhibition of Herzog & de Meuron in Tate Modern in 2005 showed over 250 working models; see http://www.tate.org.uk/whats-on/tate-modern/exhibition/herzog-de-meuron, consulted on 10/11/2014.

[29] Karen Moon, *Modelling Messages: The Architect and the Model* (2005). p.47.

[30] See, for instance, Karen Moon, *Modelling Messages: The Architect and the Model* (2005).

[31] See Patrick Healy, *The Model and Its Architecture* (2008).

Models can be ordered and classified in different ways: by the materials used, their size or scale, or which role they play in the design process: from sketch model, over study model to presentation model, to mock-ups and prototypes. A more general distinction is made by Geeraard de Zeeuw, between *models of*, which try to represent an external reality, and *models for,* which try to bring about new realities.[32] Models *of* could be called illustrative or explanatory, whereas models *for* could be described as investigative or exploratory.

In architecture and design, models and modelling increasingly describe both digital and material artefacts and processes, and through the use digital fabrication, material models are increasingly being fabricated based on digital information. While this extension of modelling to include both digital and material provides opportunities for designers and architects to rethink their relationship with making, it has led to a blurring of the definition of model and modelling.[33] What does this shift mean for the practice of modelling, and more generally of making in architecture? Can digital models operate as models *for* rather than models *of* design?

In my practice, I have always had an interest in model making, which seemed to be a way to reconnect with the practices of making, through material experimentation, building scale models, and full-scale installations. When beginning this research, which would eventually lead to this PhD, modelling and model making were central concerns in my teaching and practice. Going through the PhD process has, for me, pushed the model and modelling out of the centre of the argument, but they remain important as they have fuelled many of the projects in the research. Although all the projects described in this chapter, were completed before the start of my PhD, I consider them a part of the body of work that supports the argument of the PhD, and this chapter can be read as a first inquiry into some recurrent interests in my work.

[32] G. d. Zeeuw, Onderzoek in verandering, in *Rede Als Richtsnoer,* (Mouton Uitgevers, The Hague, 1979), pp. 335-353.

[33] See Mark Burry, "Models, Prototypes and Archetypes, Fresh Dilemma's Emerging from the 'File to Factory' Era" in Bob Sheil, *Manufacturing the Bespoke: Making and Prototyping Architecture* (2012), pp. 42-57.

CASE 1.1 MATERIAL AND DIGITAL DESIGN WORLDS

Setting up the MMlab as research environment | 2009 -2011

> *“Designers often establish design worlds implicitly, through their choice of media and instruments. A drawing board and traditional drafting instruments, for example, establish an Euclidean design world populated by two kinds of graphic tokens – straight lines and circular arcs – that can vary in size and position and be related to each other as parallels, perpendiculars and so on. A designer toying with cardboard working models enters a design world populated by plane polygons that can be shaped in different ways and translated and rotated in three dimensional space. Designers shaping clay with their fingers or cutting polystyrene blocks with hot wires, enter yet other kinds of design worlds”.* [34]

MMLAB
labMedialab
labMedialab

Fig. 1. MMlab, as environment for experimentation.

DESIGN WORLDS

Architecture as a discipline has long understood digital technologies in terms of its own traditions; digital design tools were named after and developed as digital versions of the established practices of drafting, modelling and rendering. Notwithstanding the similarities between making a digital and a material model, as design media they are substantially different. The choice of medium and instruments establishes what Mitchell calls a design world, which defines both the basic tokens that can express design ideas and the possible transformations of them. The idea of the design process being acted out in a design world is fruitful, as it frees design media from being passive recipients for design ideas to being active contributors to the design process and suggests exploration rather than closure. This case explores the similarities and differences between digital and material model making as design worlds; it explores the differences in affordances and resistances[35] they provide during the design process and questions whether digital and material models can act as *models for* rather than *models of* design.

CONTEXT AND AIM

When I started teaching and researching at the mixed media unit of Sint-Lucas School of Architecture, modelling and drafting were part of a course called ”representational techniques”; its exercises consisted of modelling and drafting existing architectures and were judged by how well the drawing and models represented the examples and whether conventions were properly applied. Internally, this course was divided between proponents of digital and analogue representational techniques, the former gaining terrain on the latter. Parallel to this course, the mixed media department had a strong tradition in material experimentation and making, the origins of which can be traced back to the Vorkurs as taught by Jozef Albers at the Bauhaus.[36] The curriculum of these courses was aimed at formal and material exploration and gradually scaled up in complexity, from objects over spatial installations to experiments and a manifesto. Contrary to the courses in representational techniques, in these courses students worked directly with the material itself.

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[34] William Mitchell, *The Logic of Architecture: Design Computation and Cognition*, (1990). p. 38.

[35] I use affordance as coined by James J. Gibson throughout this exegesis, in the concluding chapter I explain how I understand the term in relation to the work. See James J. Gibson, “The Theory of Affordances”. In Robert Shaw and John Bransford (eds.), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology,*(1977).

[36] Carl Bourgeois, *Om te weten waar je naartoe wil... An conversation with Paul Gees, Lode Janssens & Patrick Labarque,* in Carl Bourgeois, Pieterjan Ginckels and Corneel Cannaerts (eds.),*MMMAG*, (2010), pp. 08-12.

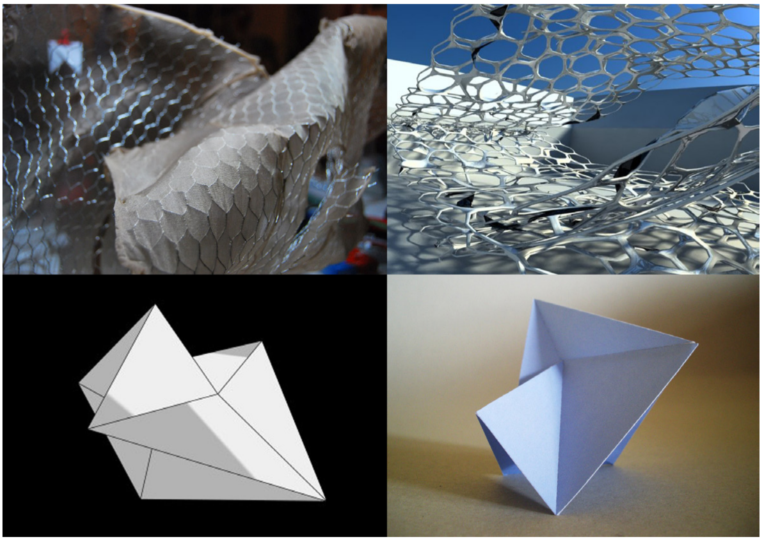


Fig. 2. Material and Digital Modelling Lab, combining digital and material design models.

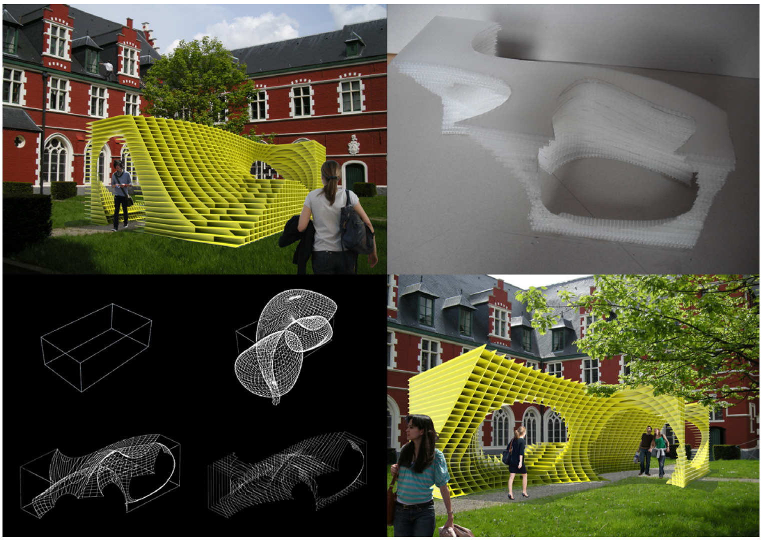


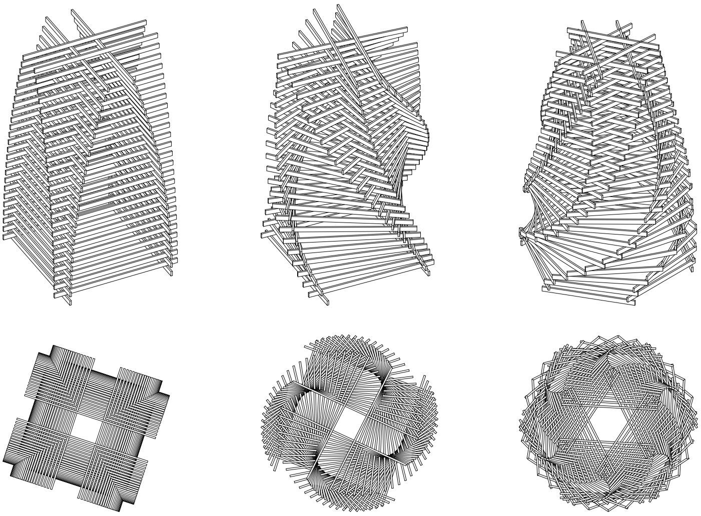
Fig. 3. Material and Digital Modelling Lab, digital inspired material models.

From practice I brought with me the experience of using both digital and material modelling in parallel, as media to explore and inform design ideas, rather than means of merely representing already formulated ideas. In order to address these issues, me and fellow tutors, Tiemen Schotsaert, Michiel Helbig and Pieterjan Ginckels, set up MMlab, as a research lab and learning environment, building on the existing practices of material experimentation and making, and introducing digital modelling and digital fabrication to the faculty. The aim was to overcome the dichotomies outlined above and incorporate both material and digital modelling, working both with representations and directly with material, and speculate on the role of media within design practice. The MMlab was conceived as a research lab and an environment for hands on experimentation, Its favourite mode of operating a combination of design experiments and intensive workshops, although it also operated within the curriculum of the architecture program through elective courses.

The aim of this case is to look into the similarities and differences between material and digital modelling as design worlds. It asks what the benefits might be from incorporating both in a design process, and whether a hybrid approach that combines both worlds is feasible. The case builds on a number of design experiments and models produced during the setting up of MMlab as an environment for experimentation, which hosted much of the research in further chapters.

MATERIAL CONSTRAINED DIGITAL MODELS

In digital models, being scale-less environments devoid of forces such as gravity and friction, it is often hard to keep track notions of scale, tectonics and materiality. By using digital modelling tools alongside material experimentation, stressing the importance of the differences and similarities, and deliberately switching between the two led to a materially informed digital modelling. An example of this can be found in this series of models that explore stacking of simple wooden elements as a constructing principle. After a series of initial prototypes, the principle of stacking was built into a digital



4. Material and Digital Modelling Lab, digital exploration of stacking.

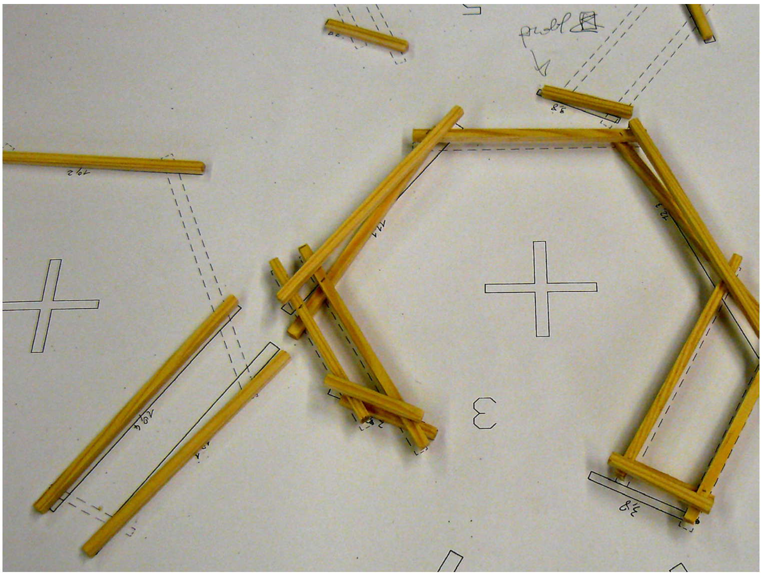


Fig. 5. Material and Digital Modelling Lab, building a material model from a digital model.

model that was used to iterate a large number of variations before finally deciding on spatially interesting proposition, to be further tested in a physical model.(Figs. 4-5).

DIGITALLY INSPIRED MATERIAL MODELS

Similarly working in both material and digital modelling environments simultaneously can inspire to materialise spatial formally interesting designs inspired by qualities of digital models. In other words, the fact digital design world only operate on geometric entities does not need to work as a limit, but instead can inspire design. Examples of this can be seen in the earlier mentioned smooth and double curved nurbs surfaces, which are notoriously hard to materialise. Materialisation generally relies on approximating the geometry by tessellation, or slicing the geometry, reassembling them from parts. (Fig. 3).

AUGMENTED HYBRID MODELS

The digital world interacts with the material world through interfaces: screens, prints, keyboards, scanners, cameras... There is an increase in technologies that allow crossovers and blending between those two worlds, from scanners, depth sensors and apps that turn any smart phone in a spatial scanner, to digital fabrication technologies. Within the MMlab we developed experiments that looked into these technologies and the resulting models in between material and digital. Augmenting material models through digital projection, allowing models to be animated and take on a changing expression over time (Fig. 7). Or abusing the specific qualities, artefacts, noise introduced by the processes of making 3D scans to make digital models. The interface here is not used as invisible, easily transgressable, as technology is often promoted, but as a contributor to design. (Fig. 6-8).

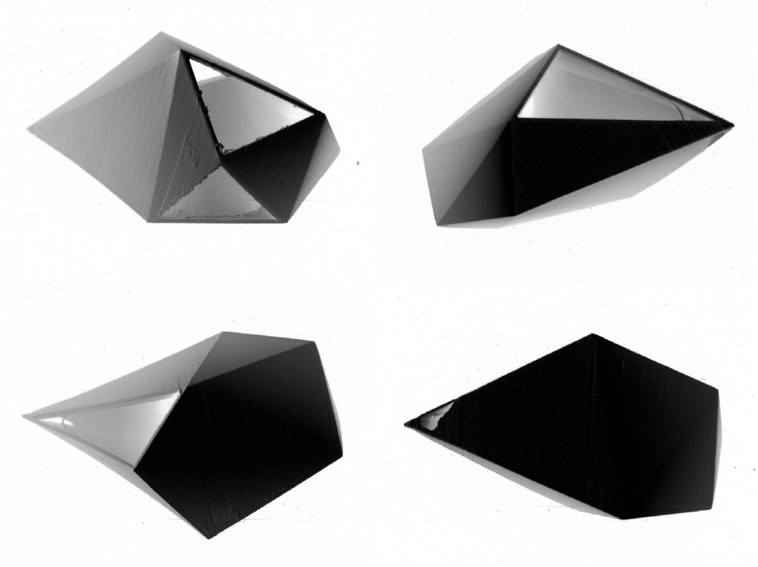


Fig. 6. SuperModels, augmented hybrid model scan.

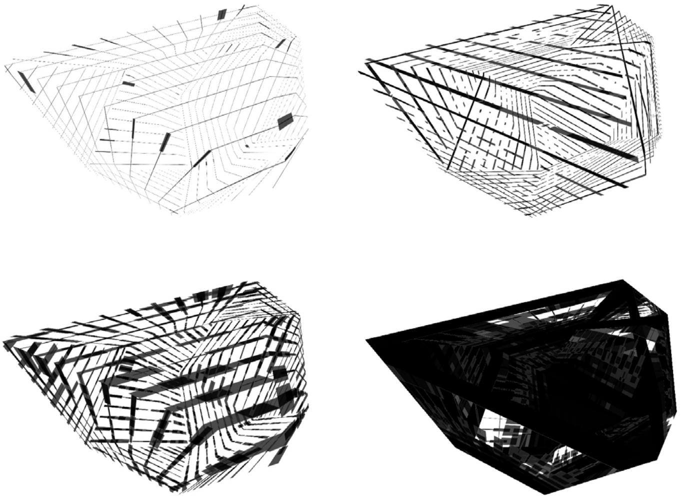


Fig. 7. SuperModels, augmented model, texture as volume.

ENVIRONMENTS FOR MATERIAL AND DIGITAL EXPERIMENTATION

The models described above show that both digital and material models have the potential of becoming *models for* rather than *models of* architecture. These models were deliberately free from programmatic, conceptual constraints and which allowed for a play with tools materials and techniques and generated a quite messy workshop environment, producing a large quantity of design models. Both material and digital work as models that trigger, constrain and inspire design decisions; they can both work as *models for* rather than *models of* design. In other words they can become a design world in which the design process can be played out, but the nature of that play is different.

While manipulating material, making sketch models, is a skill all of us have to a certain degree mastered through years of playing and manipulating objects, digital models require different set of skills that need to be learned. Material modelling, allows for experimentation, resulting in a large variety of materials and modelling techniques being used, clay, meshing, paper, glue, foam, wire, to name a few. Digital modelling happens through an interface, both hardware and software, which requires time to get familiar with, and take experimentation beyond the happy accidents of trying different tools and effects provided by the modelling software.

The hardware and software interfaces of digital modelling did not only imply a time to familiarise oneself with these interfaces, but also impacted the design process in terms of collaboration. While making a material model facilitates collaboration, having an extra pair of hands is often helpful. Digital modelling technology is geared at an individual design process, both in hardware and in software. The experience of looking at a screen where somebody is manipulating a digital model, orbiting, panning and zooming, can be really hard to follow. In a collaborative environment, this often results in one participant becoming responsible for maintaining the digital model. Obviously digital media allow for sharing and collaboration, communicating and spreading design ideas, especially through online services, but this nature of sharing tends to be discontinuous.

REFLECTION

This case demonstrates that both digital and material models can operate as active design media, and that deliberate switching between digital and material design models enriches the design process, as they both have different affordances and resistances. Digital models allow for a fast and reversible exploration of many design variations but limit the design space to geometric elements and transformations and tend to be an individual activity. Material modelling allows for an open-ended, tectonic informed exploration of an open design world, but requires a substantial amount of effort and time.

In his description of design worlds, Mitchell describes modelling with cardboard as a design world populated with planar polygon shapes. Looking at the many models at MMlab produced from cardboard, it is clear that the possible manipulations of cardboard are not limited to just cutting, and the resulting forms are not confined to geometric categories such as planar or polygon. Digital modelling programs can only work with geometric entities, and the manipulations are limited to a finite number – in other words, the digital design world is closed both in the tokens it contains and the manipulations on these tokens. In contrast, judging by the variation of material and found objects and the number of manipulations on them, material modelling constitutes an inherently open design world.

While manipulating and making material models, many actions are irreversible – a sanded piece of wood cannot be un-sanded. However, in digital models, all actions can be undone, backtracked, explored and saved and evaluated with no extra cost except time. In 3D modelling, manipulations can be made directly on objects themselves (moving, scaling, mirroring etc.) or on the sub-geometries that make up an object (its faces, edges and vertices, control points). Other specialised actions are contained in modifiers, some of which are digital approximations of material manipulations, whereas others exist only in the digital world. These levels of manipulating an object are all reversible to some degree – a model can be seen as an accumulation of these manipulations, and each step along the way can be saved and later reverted to.

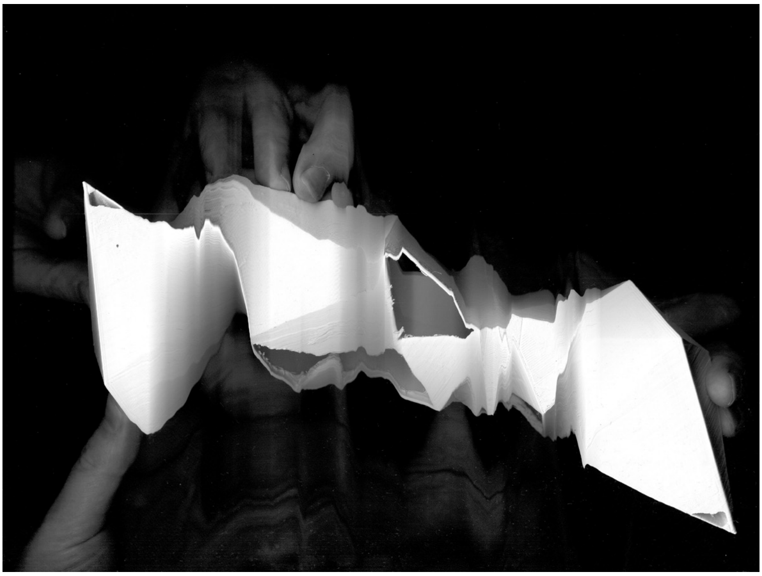


Fig. 8. SuperModels, deformed scan of material model.

DISSEMINATION

The ideas of the role of the model discussed in this case formed the basis for a number of workshops and elective courses organised around the MMlab, where the ideas were disseminated, and further developed.

Digital and Material Modelling Lab, elective course with Tiemen Schotsaert, 2009 and 2010.

SuperModels, workshop with Tiemen Schotseart, Michiel Helbig and Pieterjan Ginckels, 2010.

MOD, workshop with Michiel Helbig and Pieterjan Ginckels, 2011.

The topics discussed in this case were published in a research paper:

Corneel Cannaerts, Models of / Models for Architecture: Physical and Digital Modelling in Early Design Stages, *Computation: The New Realm of Architectural Design* [27th eCAADe Conference Proceedings], Istanbul (Turkey). (2009), pp. 781-786.

CASE 1.2: ENGAGING MATERIAL

Making | Scale 1:1 | Installations | 2009-2011

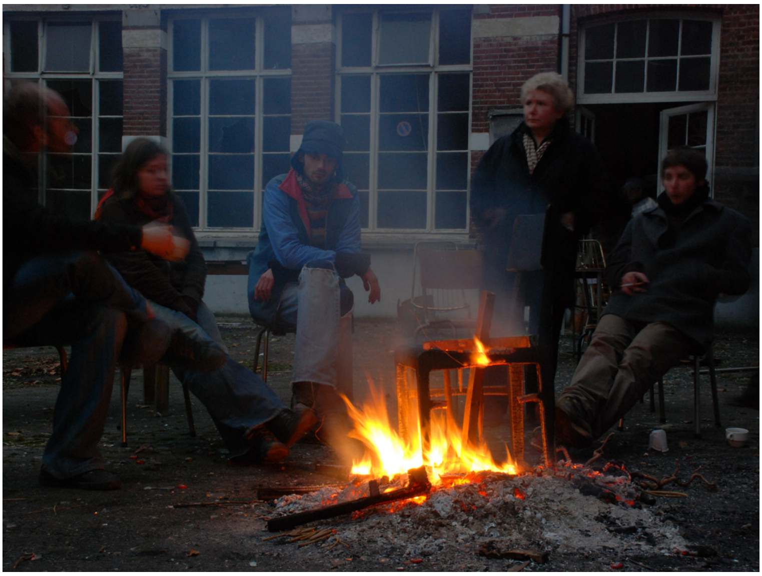


Fig. 9. Manifest, engaging materiality, on site, at full scale.

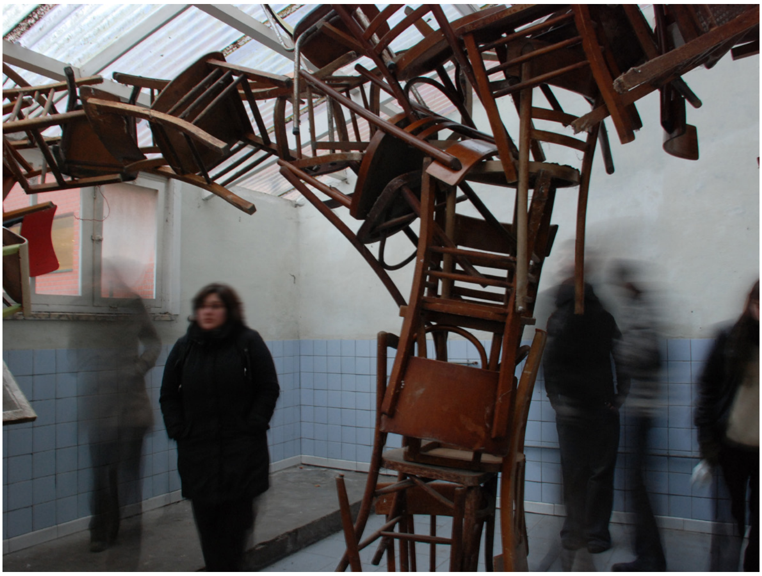


Fig. 10. Manifest, engaging materiality, on site, at full scale.

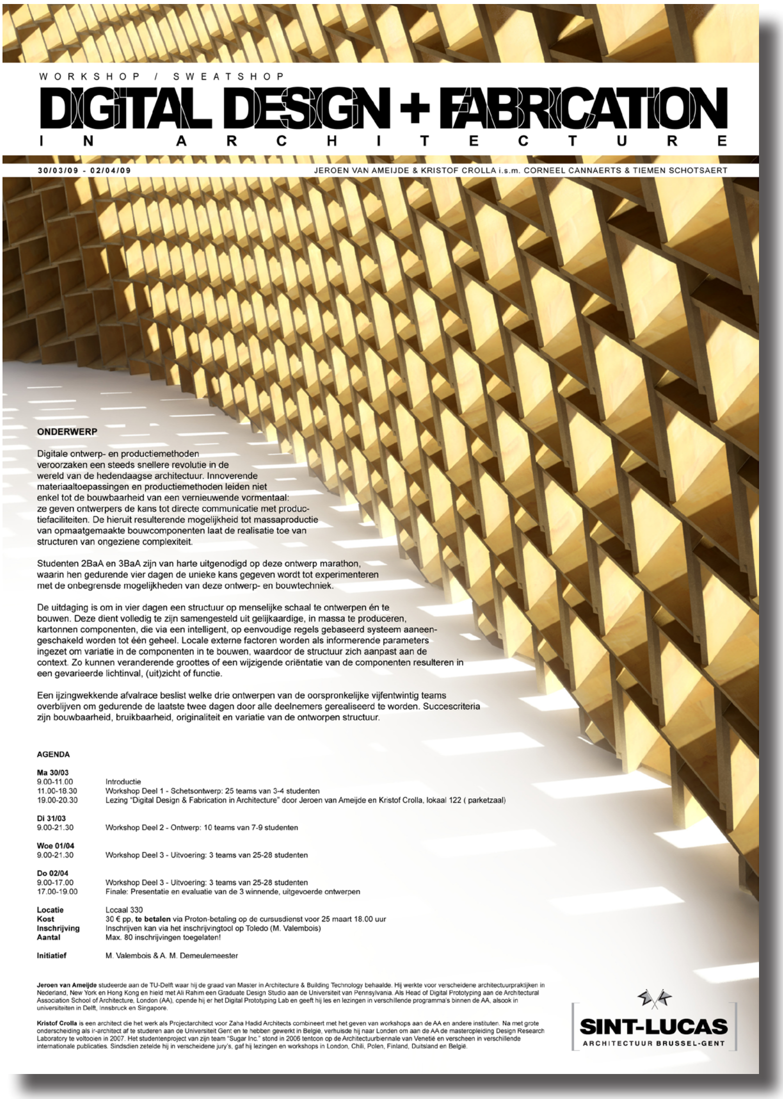
INTRODUCTION

In the design processes I have experienced both during my education and as a practising architect, design tended to progress from the larger scale to the smaller, eventually arriving at drawing and description of the components and construction, only to be materialised later in time. Concerns for materiality and making usually informed the design process rather late when other concerns such as program, spatial layout had been decided upon. Furthermore, materiality and making were mostly based on convention and rules of thumb instead of first-hand experience and experimentation. Directly engaging with matter through experimentation, making prototypes and mock ups, can complement this top down tendency in architecture, and inform a design process with tacit knowledge found in making, finding inspiration in matter.

MANIFEST: OUT OF THE LAB

Establishing MMlab as environment for experimentation, bringing experience from practice within the school, was important as a context for this work and research. But it was equally important to break out of the confines and scale of the lab environment, and directly deal with issues of site context, scale and logistics. Building full scale installations, with students and other participants, on site and in context, has been a welcome antidote for working within the confines of the lab.

Having experiences of working within architecture and visual art, it was my assumption that architecture and art can learn from each other, particularly in engaging with site, context and materiality. During *manifest* we invited participants with a background in both architecture and arts to for a two day studio, on location, building installations, staging performances and making site specific work. The location was an old primary school in a small village, which had been closed for a few years and was about to be demolished to be replaced by a housing project. This setting full, of traces of occupancy and vacancy, the freedom to alter, demolish and destroy all things on site, and sleeping, eating and making on site, provided a freedom,



WORKSHOP / SWEATSHOP

DIGITAL DESIGN + FABRICATION

IN ARCHITECTURE

30/03/09 - 02/04/09

JEROEN VAN AMEIJDE & KRISTOF CROLLA i.s.m. CORNEEL CANNAERTS & TIEMEN SCHOTSAERT

ONDERWERP

Digitale ontwerp- en productiemethoden veroorzaken een steeds snellere revolutie in de wereld van de hedendaagse architectuur. Innoverende materiaaltoepassingen en productiemethoden leiden niet enkel tot de bouwbaarheid van een vernieuwende vormentaal: ze geven ontwerpers de kans tot directe communicatie met productiefaciliteiten. De hieruit resulterende mogelijkheid tot massaproductie van opmaatgemaakte bouwcomponenten laat de realisatie toe van structuren van ongeziene complexiteit.

Studenten 2BaA en 3BaA zijn van harte uitgenodigd op deze ontwerp marathon, waarin hen gedurende vier dagen de unieke kans gegeven wordt tot experimenteren met de onbegrensde mogelijkheden van deze ontwerp- en bouwtechniek.

De uitdaging is om in vier dagen een structuur op menselijke schaal te ontwerpen én te bouwen. Deze dient volledig te zijn samengesteld uit gelijkaardige, in massa te produceren, kartonnen componenten, die via een intelligent, op eenvoudige regels gebaseerd systeem aaneengeschakeld worden tot één geheel. Locale externe factoren worden als informerende parameters ingezet om variatie in de componenten in te bouwen, waardoor de structuur zich aanpast aan de context. Zo kunnen veranderende groottes of een wijzigende oriëntatie van de componenten resulteren in een gevarieerde lichtinval, (uit)zicht of functie.

Een ijzingwekkende afvalrace beslist welke drie ontwerpen van de oorspronkelijke vijfentwintig teams overblijven om gedurende de laatste twee dagen door alle deelnemers gerealiseerd te worden. Succescriteria zijn bouwbaarheid, bruikbaarheid, originaliteit en variatie van de ontworpen structuur.

AGENDA

Ma 30/03	
9.00-11.00	Introductie
11.00-18.30	Workshop Deel 1 - Schetsontwerp: 25 teams van 3-4 studenten
19.00-20.30	Lezing "Digital Design & Fabrication in Architecture" door Jeroen van Ameijde en Kristof Crolla, lokaal 122 (parketzaal)
Di 31/03	
9.00-21.30	Workshop Deel 2 - Ontwerp: 10 teams van 7-9 studenten
Woe 01/04	
9.00-21.30	Workshop Deel 3 - Uitvoering: 3 teams van 25-28 studenten
Do 02/04	
9.00-17.00	Workshop Deel 3 - Uitvoering: 3 teams van 25-28 studenten
17.00-19.00	Finale: Presentatie en evaluatie van de 3 winnende, uitgevoerde ontwerpen
Locatie	Locaal 330
Kost	30 € pp, **te betalen** via Proton-betaling op de cursusdienst voor 25 maart 18.00 uur
Inschrijving	Inschrijven kan via het inschrijvingtool op Toledo (M. Valembois)
Aantal	Max. 80 inschrijvingen toegelaten!
Initiatief	M. Valembois & A. M. Demeulemeester

Jeroen van Ameijde studeerde aan de TU-Delft waar hij de graad van Master in Architecture & Building Technology behaalde. Hij werkte voor verscheidene architectuurpraktijken in Nederland, New York en Hong Kong en hield met Ali Rahim een Graduate Design Studio aan de Universiteit van Pennsylvania. Als Head of Digital Prototyping aan de Architectural Association School of Architecture, London (AA), opende hij er het Digital Prototyping Lab en geeft hij les en lezingen in verschillende programma's binnen de AA, alsook in universiteiten in Delft, Innsbruck en Singapore.

Kristof Crolla is een architect die het werk als Projectarchitect voor Zaha Hadid Architects combineert met het geven van workshops aan de AA en andere instituten. Na met grote onderscheiding als ir-architect af te studeren aan de Universiteit Gent en te hebben gewerkt in Belgie, verhuisde hij naar Londen om aan de AA de masteropleiding Design Research Laboratory te voltooien in 2007. Het studentenproject van zijn team "Sugar Inc." stond in 2006 tentoon op de Architectuurbiennale van Venetië en verscheen in verschillende internationale publicaties. Sindsdien zetelde hij in verscheidene jury's, gaf hij lezingen en workshops in London, Chili, Polen, Finland, Duitsland en België.

SINT-LUCAS
ARCHITECTUUR BRUSSEL-GENT

Fig. 11. Digital Design & Fabrication in Architecture Workshop, poster.

and directness engagement. It resulted in a number of interventions, installations and performances, often playful, using and abusing, clues, objects and traces found on site.

This event was organised together with Tiemen Schotsaert and Floris Debruyn, in the first semester we started teaching, without any connection to the curriculum and in our spare time. In retrospect, after getting to know the other side of the institution, endless meetings, committees, abbreviations, and forms, I'm surprised at the freedom and time we had. I mention it here not for nostalgic reasons, but as the start of a thread within my creative practice and teaching, which I have maintained till today[37]. While this case focusses on the engagement with materials, at full scale, it is important to situate this within the context of an architecture school, which is increasingly becoming academic and the difficulties this entails.

PART AND WHOLE

Architectural constructions are seldom monolithic; due to their scale and required performance, constructions are built-up from smaller parts. Materials themselves have inherent scales, the size of building components is linked to how materials are formed, prepared and handled during construction. The relationship between the whole and its parts, the assembly and components, the tectonic expression of this relationship, is a central issue in architectural design and construction, with a rich and complex history.[38] In the exchange between design and making, to what level and resolution components are specified or overall assembly is communicated is a balancing exercise.

The impact of digital technologies on architectural design can be read in this light. The initial adoption of digital technologies mimicked well-known practices of drafting and modelling and did not directly impact making and materiality. While digital modelling fuelled an exploration of formal and composition concerns, one of the short-comings of the digital architecture of the 90s was its reliance on smooth, fluid and unarticulated surfaces[38b], which did not hint at any materiality or anticipate construction from constituting parts.

[37] Just last semester I guided a design studio called Werk.Plaats.Werk, working on site in collaboration with both an artist's collective, and a project developer. We worked for 14 weeks in a vacant factory and office building, exploring ideas of new workplaces, temporary occupations of industrial heritage, and designing and building our own workplaces. See http://werkplaatswerk.tumblr.com/, (consulted on 20/01/2015).

[38] It has been extensively discussed by Jeffrey Kipnis amongst others; see http://sma.sciarc.edu/video/jeffrey-kipnis/ and Thomas Schröpfer, *Material Design: Informing Architecture by Materiality* (2011), p. 48 and Jesse Reiser, *Atlas of Novel Tectonics*, (2006), p.50

[38b] See for example the work of Markos Novak on Liquid Architecture, which defines itself as 'dematerialized' see Novak, Markos., Liquid Architecture in Cyberspace, in Benedikt, M. (ed), *Cyberspace: First Steps,* (Cambridge: MIT Press, 1992)

Around the turn of the millennium, we saw a renewed interest in tectonics and construction within digitally inspired architecture, fuelled by innovations in digital fabrication and digital design software.[39] The combined adoption of scripting and parametric modelling on the one hand and digital fabrication on the other provided a framework for architects to not only engage in making and materiality more directly, but also to rethink the relationship between part and whole, component and assembly. Parametric modelling and scripting provide the necessary control to leverage the potential of mass-customised components provided by digital fabrication.

CONTEXT AND AIM

In order to investigate the premise outlined above we organised *Digital Design and Fabrication in Architecture workshop,* aimed designing and making, full scale architectural structures within four days. The aim of the workshop was to engage with materials as a trigger for design by devising a component from a given material and investigate the architectural and spatial potential of these structural systems, by exploring possible variation in the system afforded by the relationships between part and whole, between component and assembly. The workshop set out to evaluate digital and material design strategies, instead of stressing their differences, material experiments were used as a trigger for introducing digital design techniques. The digital models were used to iterate design process and finally inform the making of full scale installations. The material experimentation and prototyping used the same material as the final installation; as such, it can be seen as an exercise in designing by directly engaging at full scale, where digital models work as an in-between.

We invited Jeroen Van Ameijde, tutor and coordinator at the FabLab at the AA in London, and Kristof Crolla, with whom I studied at the University of Ghent, who graduated from the AADRL in London and is currently practising and teaching in Hong Kong. This workshop was the second in a series of international digital fabrication workshops run by the Digital Prototyping Lab of the Architectural Association collaboration with other institutions.[40] As a secondary

[39] See Neil Leach, David Turnbull, and Chris Williams (eds.), *Digital Tectonics*, (2004). Stephen Kieran and James Timberlake, *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction* (2004). Michael Stacey (ed.), *Digital Fabricators*: Cambridge Galleries, November 11, 2004-January 30, 2005 (2004).

goal of the workshop and lecture was to introduce the faculty of Sint-Lucas School of Architecture to the developments in digital design and fabrication outlined above and convince the school to invest in a digital fabrication lab, which would eventually lead to starting up the MMlab.

MATERIAL AS TRIGGER FOR DESIGN

Since the MMlab was still being set up, we lacked digital fabrication equipment and, considering the large number of participants, we decided to focus the workshop on hands-on material experimentation and full scale construction. We found a material sponsor that provided us with 2000m² of corrugated cardboard in sheets of 240cm by 120cm and a thickness of 6mm and 3mm. The design process started from questioning the qualities, potential and limits of this material. The brief was to build component-based structures larger than the provided sheets, so it would have to be built up from smaller parts. The first day we investigated ways of manipulating and connecting the material; this led to a wide variety of prototypes for material components and joining strategies: stacking, gluing, stapling, weaving, slotting, stitching etc. (Fig. 12).

FROM COMPONENT TO MATERIAL SYSTEM

The second phase started with an introduction into digital design tools, geometric possibilities and constraints of component-based structures: both top down and bottom up design strategies were introduced, based on the components developed during the first day. Based on the knowledge gained in the material experimentation on how to connect components in developing a component-based system, and special attention was given to the parameters defining the system and the possible variation it suggested. The total number of types of components was kept small, and attention was directed to the ease of construction of each component. Since we lacked precision digital fabrication equipment to make every component precisely and differently, the variance in the material system was largely derived from the parameters of connecting the components rather than from a difference in the geometry of the components themselves (Fig. 12-13).

40 Results of the workshops are documented on www.digitalfabrication.net (consulted on 23/08/2014).

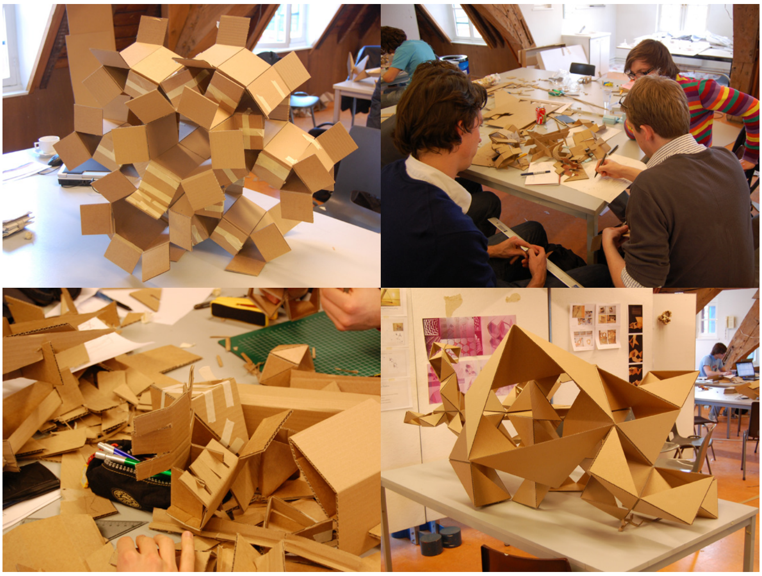


Fig. 12. Digital Design & Fabrication in Architecture Workshop, material as trigger for design, from component to material system.

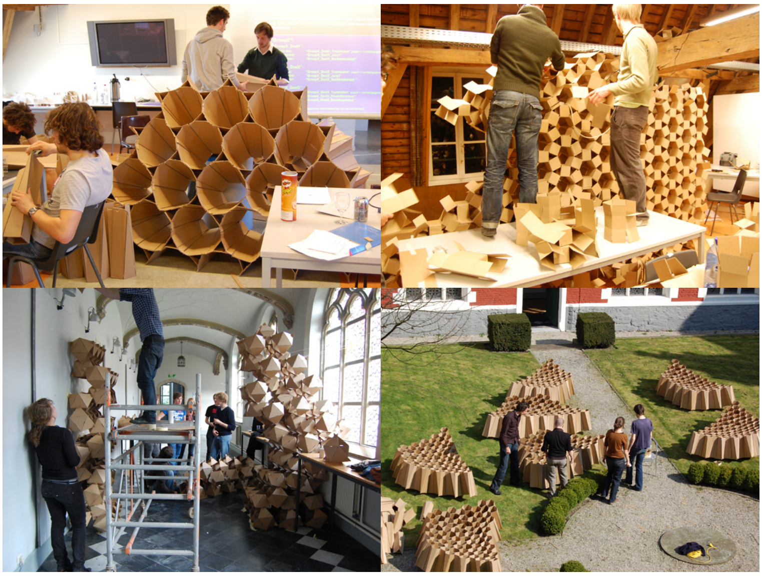


Fig. 13. Digital Design & Fabrication in Architecture Workshop, adapting material system to site conditions.

FULL SCALE INSTALLATION

The last phase started by collectively deciding the three material systems that showed the most potential to be developed into a spatial proposition. Based on the proposed system, a site was selected within the campus of Sint-Lucas. Selection was based on the design intent, how the proposed installation integrated with the chosen site, assembly logic and the feasibility of the proposals. Scaling up from prototypes to full scale installations and adapting to site conditions, either by increasing the number of components or scaling the components themselves often required changes to the proposed material system.

Three installations were built: a dome construction in the central courtyard, a stacked passageway in the hallway and a hybrid between a bar, wall, and roof construction in the attic of the old abbey that houses the school. All installations responded to clues in the chosen places, the circular patch in the courtyard determined the size of the dome, the passageway was chosen because the patterns of tiles and windows matched the pattern of the component system, the bar construction used the beam structure of the roof for support.

The three structures show a different ways in which the component and assembly influence each other. In the dome the overall form of the dome and the articulation of its openings, result from the specific tapered component. In the passage way, the component formed a space-filling aggregation, and the design was achieved by selectively removing components to form an arch. In the bar structure, the components were all identical but the curvature was achieve by varying the connections between components.

The three proposed designs had to deal with constraints of assembly and minimise the use of material, 2000m² of cardboard disappeared surprisingly fast with 50 something participants. Each of the components was made from pieces of cardboard that could be efficiently cut from the sheets, without much loss. The components for the dome and bar structure were stapled and glued. In the half scale prototype of the passageway structure, the components were made by sliding and slots, not needing glue or staples.

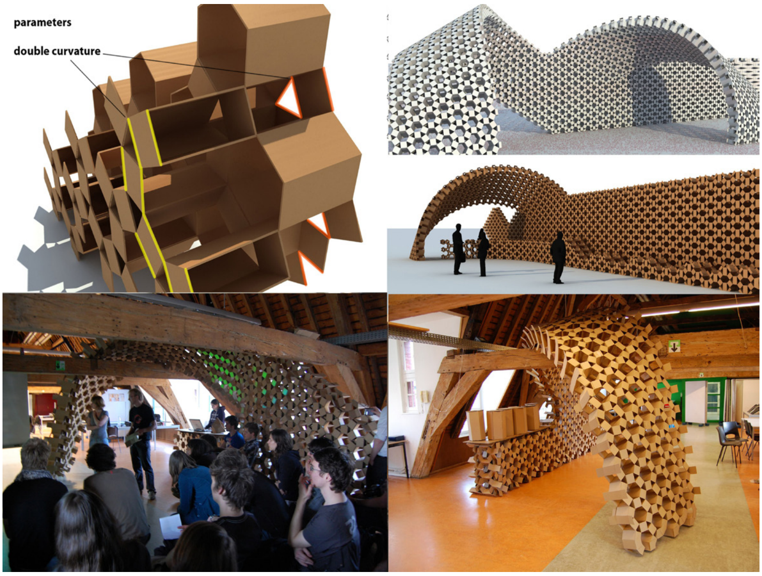
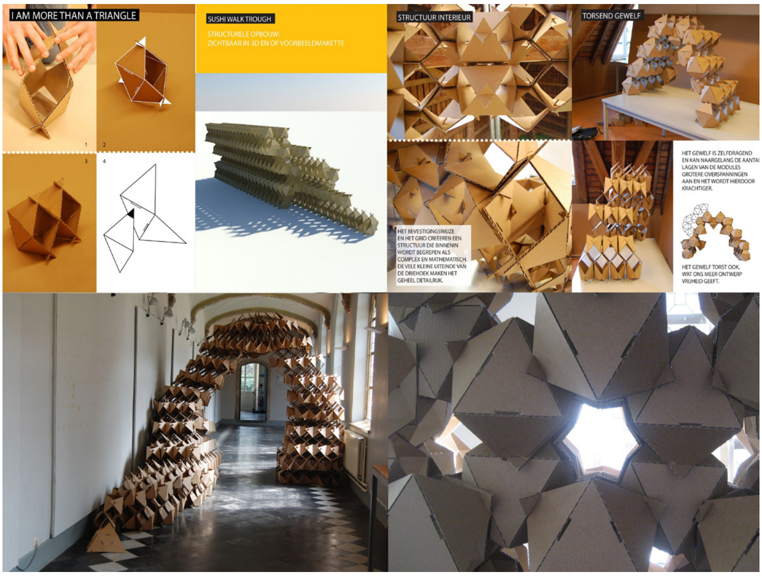

parameters
double curvature

Fig. 14. Digital Design & Fabrication in Architecture Workshop, bar/wall/roof installation


I AM MORE THAN A TRIANGLE
1
2
3
4
SUSHI WALK TROUGH
STRUCTURELE OPBOUW:
ZICHTBAAR IN 3D EN OP VOORBEELDMAKETTE
STRUCTUUR INTERIEUR
TORSEND GEWELF

HET BEVESTIGINGSWIJZE EN HET GRID CREËEREN EEN STRUCTUUR DIE BINNENIN WORDT BEGREPEN ALS COMPLEX EN MATHEMATISCH. DE VELE KLEINE UITEINDE VAN DE DRIEHOEK MAKEN HET GEHEEL DETAILRIJK.

HET GEWELF IS ZELFDRAGEND EN KAN NAARGELANG DE AANTAI LAGEN VAN DE MODULES GROTERE OVERSPANNINGEN AAN EN HET WORDT HIERDOOR KRACHTIGER.

HET GEWELF TORST OOK, WAT ONS MEER ONTWERP VRIJHEID GEEFT.

Fig. 15. Digital Design & Fabrication in Architecture Workshop, arched passageway.

REFLECTION

This case demonstrates that making and direct engagement with matter can trigger design exploration and can engender design ideas about space, structure, pattern, enclosure and tectonics. It shows and that making and materialisation can be integrated into the design process from the beginning and not just be seen as a final step in realising a design. Whether it are found materials such as chairs, or debris, as in the *manifest* event, or cardboard, provided by a sponsor, rather than have ideas imposed on matter, it can inspire design ideas. It also demonstrates that digital design techniques can be used to capture the tacit knowledge gained through material making, that digital design models can be informed by material constraints, ways of connecting, fabrication limits etc. and that design can be developed with these material concerns in mind.

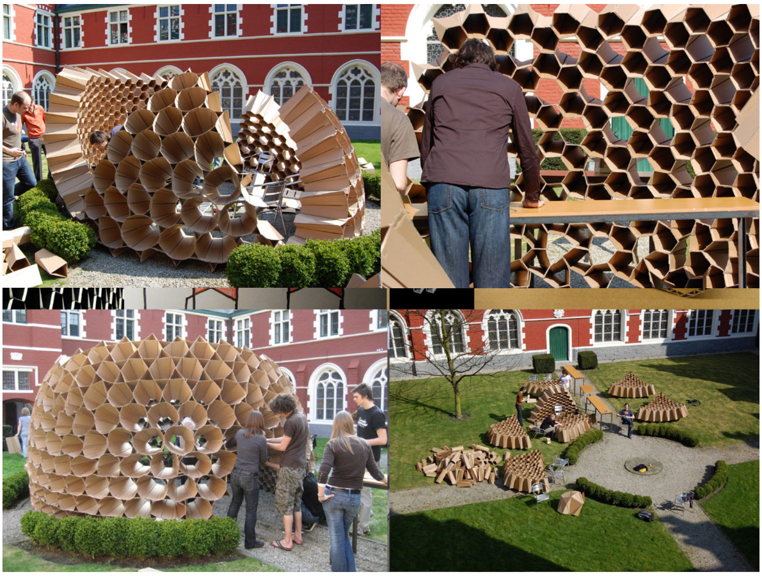


Fig. 16. Digital Design & Fabrication in Architecture Workshop, dome structure.

DISSEMINATION

Manifest was organised by Floris De Bruyn, Tiemen Schotsaert and Corneel Cannaerts, in collaboration with Carl Bourgeois, in 2008.

The *Digital Design and Fabrication in Architecture* workshop was organised by Kristof Crolla, Jeroen van Ameijde, Tiemen Schotsaert and Corneel Cannaerts, in collaboration with Annemie Demeulemeester and Martine Valembois, the material was provided by SCA Packaging, in 2009

Material discussed in this case was presented at the Berlin Design Modelling Symposium:

See Corneel Cannaerts, *Physical and Digital Modelling in Architecture,* Proceedings of the Design Modelling Symposium Berlin 2009: Concepts Beyond Geometry: 05.10 - 7.10.2009, University of the Arts Berlin (Berlin: Univ. der Künste, 2009).

Fig. 17. Digital Design & Fabrication in Architecture Workshop, dome structure. (next page).

CONCLUSION: AGENCY IN BETWEEN

“Previously models were conceived as rationalized stations on the way to a perfect object. A model of a house, for instance, would be part of a temporal sequence, as the refinement of the image of the house, but the actual and real house was considered a static, final consequence of the model. Thus the model was merely an image, a representation of reality without being real itself. What we are witnessing is a shift in the traditional relationship between reality and representation. We no longer progress from model to reality, but from model to model while acknowledging that both models are, in fact, real. As a result we may work in a very productive manner with reality experienced as a conglomeration of models. Rather than seeing model and reality as polarized modes, they now function on the same level. Models have become coproducers of reality”.[42]

The two cases each deal in different ways with the distance between design and making and how the model in different guises operates in a continuum between design medium and unmediated artefact. As Olafur Eliasson describes in the quote above, it is not fruitful to see them as polarised modes. In this sense the installations and models described in this chapter can be seen as an example of *protoarchitecture*, a term coined by Bob Sheil as a combination of prototype and architecture.[43] While we could say that the model brings designing and making closer, or incorporates making as a significant moment in the design process, the reason for doing this is extending the journey and reaching further destinations, to paraphrase Evans, ending up with a design that is grounded in context, taps into tacit knowledge found in making and begins to address ineffable spatial qualities and potential.

These cardboard architectures and installations can be seen as transgressing the space between designing and making in two directions. On the one hand, these installations can be seen as built artefacts, bringing the techniques, materials and tools of model making to the scale of architecture, as they can be approached, entered and experienced and are grounded in site conditions. On the other hand, they could be seen as models, bringing concerns of site,

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42 Olafur Eliasson, Models are Real, in Jonathan D. Solomon, Emily Abruzzo and Eric Ellingsen (eds.), *Models: 306090 Books*, Vol. 11, (2008), pp. 18-19.

43 Bob Sheil (ed.), *Protoarchitecture: Analogue and Digital Hybrids* (A.D. July/August 2008), p.7.

logistics of assembly and construction and the tacit understanding of making and tectonics into the design process within the reach of designers. These installations have to be seen as experiments in relation to the context of a school of architecture; they expand the design process with a tacit knowledge of making, bring concerns of constructability, scale and logistics into an academic environment and, by working in situ, make participants more attuned to experiential, properties and qualities of site and context. The goal is not to provide a thorough understanding of the intricacies of the building site and practices of construction – to make the participants into builders – but to enrich their design practice.

The cases in this chapter demonstrated that both digital and material modelling can take on this role and operate as *models for* rather than *models of* design. Notwithstanding the similarities, digital modelling and material modelling operate differently as design worlds. Material modelling is an essentially open design world in terms of its limits, what can be considered part of the design world and what kind of actions one can perform within this world. Making material models is both time consuming and many actions are irreversible. The material model provides feedback through all the senses. Digital models, on the other hand, have a clearly defined set of geometric tokens and manipulations one can perform; a mesh modeller will always imply a world of lines, points and surfaces with a finite amount of operations. Making digital models takes less effort and actions tend to be reversible. Operating in this design world happens through a set of interfaces that have to be learned. The feedback provided by a digital model is reduced to a number of projected images displayed on a flat screen, which are scale less, and allows the model to be visualised in many ways.

The cases in this chapter describe design processes that work simultaneously with digital and material models, as showcased by the *Digital and Material Modelling Lab* project, or deliberately shifting between digital and material modelling, as shown in the *Digital Design and Fabrication Workshop.* Such a combined or hybrid approach can overcome the limits of each of these design media, and the design world they imply, or inspire design solutions not probable when working within a single medium. Furthermore, by working deliberately within the in-between, the transition between media anticipates further translations across different material, different scales or different contexts and helps in "*extending the journey*".[44]

While in this chapter digital modelling was found to have the capability to inform and steer the design process, being a model for rather than a model of design, it was found to establish a design world that was closed in terms of its tokens and manipulations. Digital modelling was approached through standard modelling and drafting software, so at least part of the agency ascribed to digital modelling resides in the algorithms that run this software and with the people who programmed it. In the next chapter, I will go beyond the interfaces of standard software and explore algorithms not as a given hiding behind interfaces, but as a field of exploration: as matter we can engage with as designers.

All the projects described in this exploration have been completed before the start of the PhD inquiry, and have been published before the enrolment in the PhD. I present them here as a retrospective reflection on previous work and the urges that propel my creative practice. In other words it is a re-examining of prior published work from current insights that haven been developed during my PhD.

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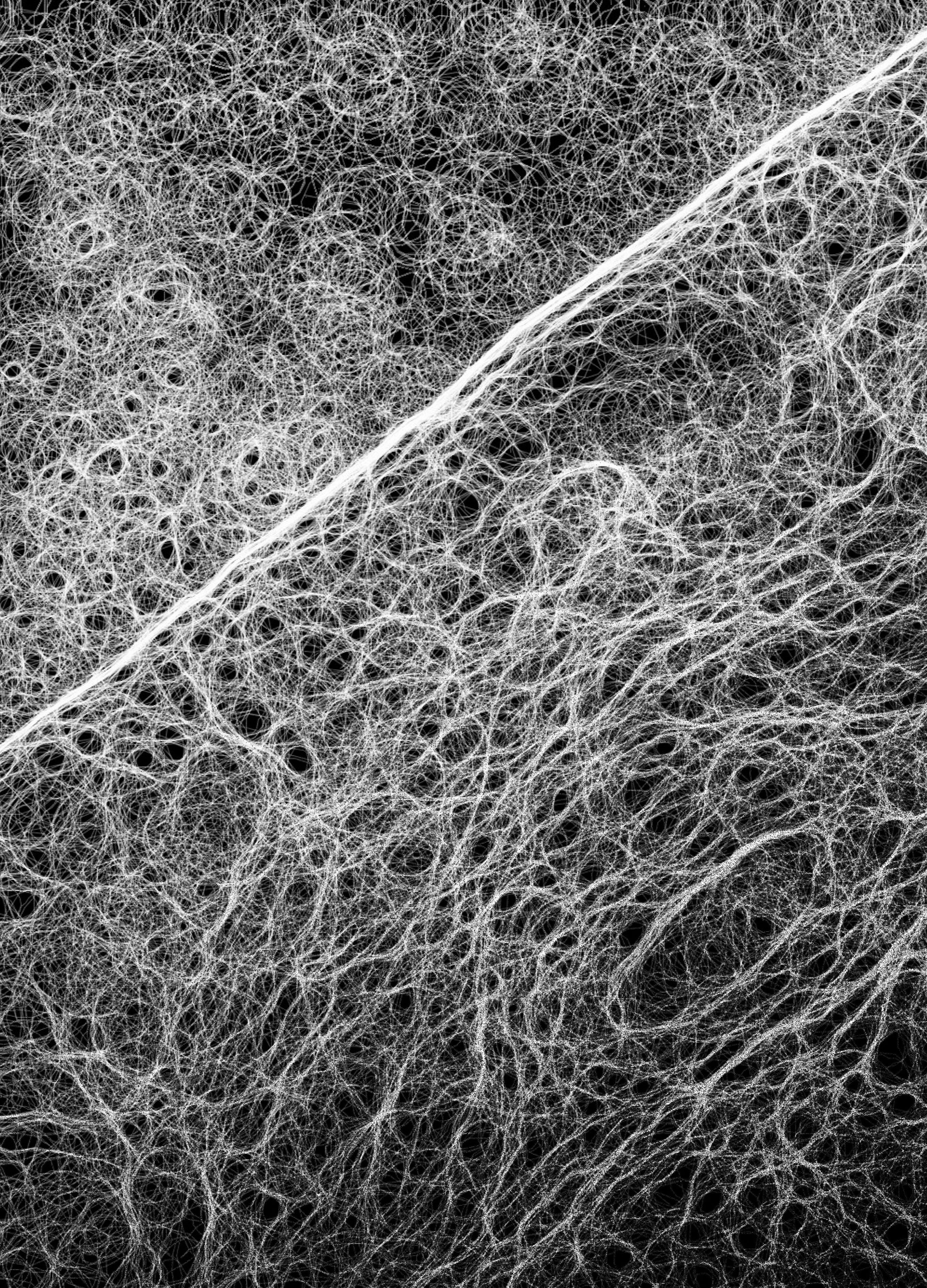
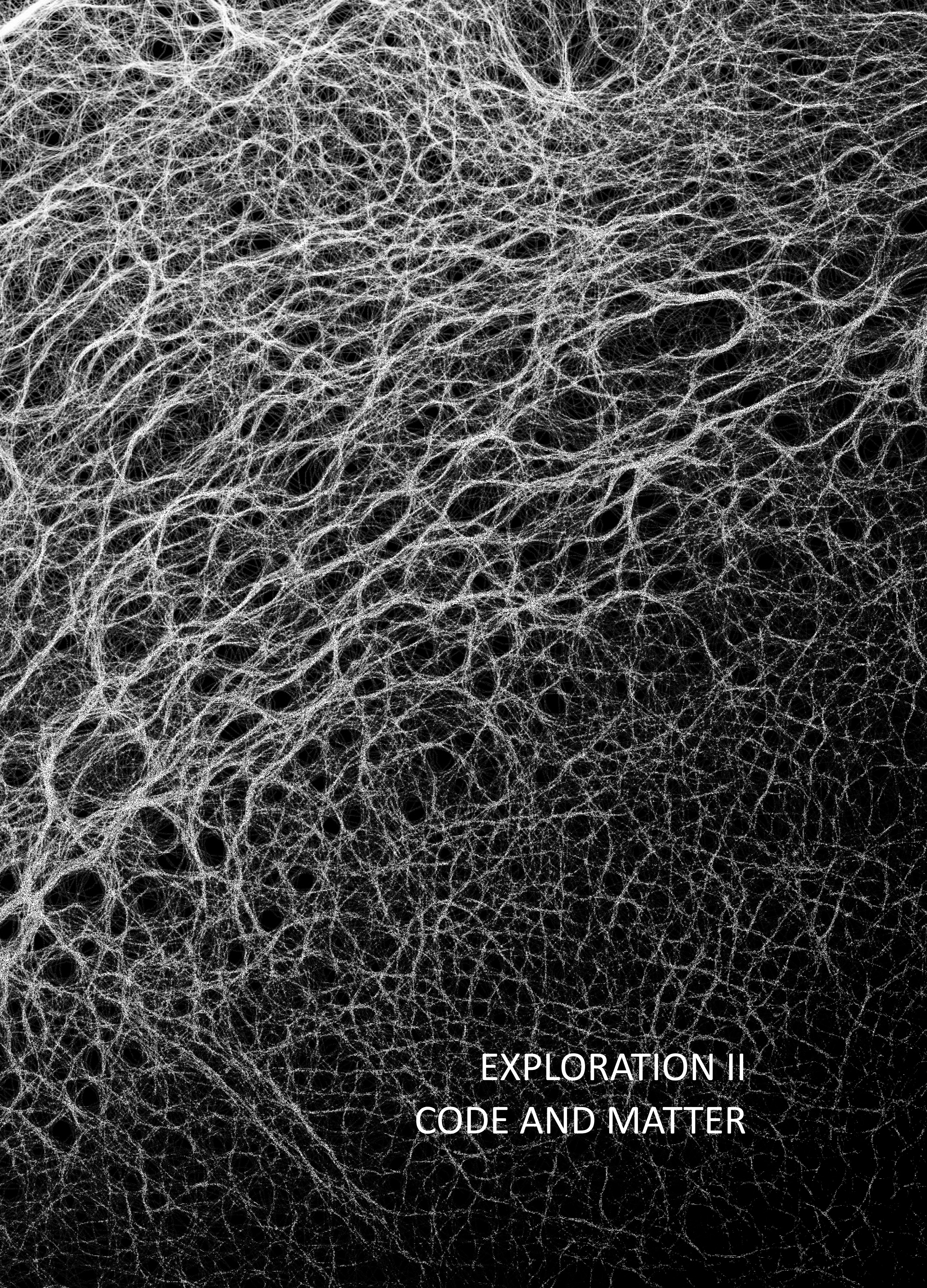
[44] Robin Evans, *Translations from Drawing to Building, and Other Essays* (1997). p.173.





EXPLORATION II

CODE AND MATTER

“Long gone are the days when computer code was exclusively used by programmers. Over the last two decades designers have mastered algorithms alongside visual thinking, and today we see the first generation of computational designers mature. The coming generation of designers sees code as a kind of material just as a potter sees clay. Only through the deep understanding of the material qualities of the clay, and the ways in which one can shape it, can one communicate through it and create relevant works”.[1]

INTRODUCTION

In the previous chapter I explored the importance of materiality and making in my design practice and uncovered the agency that can be found in engaging with matter: in the open-endedness of a material design world, both in its tokens as in the actions it affords; in the tacit knowledge evident in making and in ineffable material qualities that are hard to quantify. In order to highlight these aspects of materiality and making, I described the digital contrastingly as a closed and descriptive medium, limited to representing quantifiable aspects of design. This description could be read as a rejection of the digital as an exploratory design medium, but this tentative understanding has to do with how the digital was approached throughout the projects in the previous chapter: The use of digital media was limited to standard drafting and modelling tools that hide their underlying working behind user interfaces and do not allow a direct engagement with the code that runs them.

The opening quote refers to the potter's engagement with clay as a metaphor for developing a meaningful coding practice. Obviously, at first glance code appears to be very different stuff than clay; as it is highly designed and cultural, manipulating code relies more on explicit thought than tacit touch. This chapter describes a deeper engagement with the code, going beyond the interfaces of software – or getting my hands dirty, to keep with the metaphor. Rather than looking at the world of code in isolation, this chapter explores what coding can bring to the practice of architecture and design; specifically, I will look at code in relation to matter. On the one hand, I will look at how matter, its properties and behaviours can be encoded and simulated in the digital world; on the other hand, I will look into code as matter, the stuff that makes up the digital world, and explore its affordances and resistances and how it manifests itself in the material world.

This introduction works as a framework and introduces some notions that drive this exploration and that have triggered the projects described in this chapter. The introduction sketches the plural cultures of code and sets the stage for the case studies, which

1 Joachim Sauter in Preface to Klanten, Robert, Ehmann, Sven, Hanschke, Verena and Lukas Feireiss (eds.)., *A Touch of Code: Interactive Installations and Experiences,* (2011), p. 5.

each provide a different angle on the role code plays in my practice. *Tinkering with Code* looks at the process of creative coding and how I came to understand code as a design medium, and highlights a number of aspects of how code enables and informs the design process. In contrast to other case studies, this will draw from a large array of smaller design experiments rather than centring on one specific design project. *Nested Simulations* starts from material form experiments and encodes the discovered material properties and behaviours into digital models. The case looks into simulating material behaviours, how simulations operate on different scales and how design can emerge out of a negotiation with and between these nested simulations.

PROGRAMMING, SCRIPTING OR CODING?

Before looking into the recent past of coding in design and situating my practice in the current cultures of code, I want to explain why I use the terms code and coding instead of script and scripting or program and programming, as these terms are often used interchangeably.[2] A distinction can be made between scripting languages, which allow access to certain functionalities of existing software and are generally limited in scope and abstraction, and programming languages, which allow more complex software applications to be programmed from scratch – both require coding, or formulating precise instructions for the computer in a human-readable language.

As a verb, differences are minimal, although scripting and programming seem to emphasise a more planned approach aimed at an external goal, programming or scripting something, whereas coding emphasises the act itself – that is, writing code. As noun, both script and program seem to imply a finished and more or less complete whole – a script or a program – while code describes the stuff, or medium, this whole is made of. To describe my practice of exploring computation in design, I chose coding and code[3] specifically because they emphasise the process and the medium, respectively, rather than the end result.

[2] A similar blurriness exists in the respective roles and titles people claim, or have stamped on them: script kiddie, code monkey, coder, programmer, software engineer, developer... Ironically, *software architect* seems to be one of the highest ranking roles in this ecology, as someone understanding the larger structure or the *architecture* of software, leaving mere coding to others.

[3] For an extensive definition of code and its role in design, art and architecture, see Casey Reas and Chandler McWilliams, *Form+Code in Design, Art, and Architecture,* (2010). pp. 11-23.

In this chapter, I will use a broad definition of code that does not make an explicit difference between instructions, executed by the computer, and data, information stored in computer memory. There are historical and practical reasons for this: the functioning of a Turing Machine, the theoretical model invented by Alan Turing[4] that is at the basis of serial computers today, relies on the interchangeability between data and code. When using computation in design practice, a similar interchangeability happens, data becomes instructions for drawing and making. For clarity, generally when I use the term code it will refer to executable instructions, and when I use code as data it will be explicitly mentioned.

PERVASIVENESS OF CODE

Code is everywhere in our environment and culture. While this exegesis is not the place to describe broad technological and cultural changes, even during the time of engaging with this PhD, code has become increasingly pervasive. Looking around my apartment – which doubles as design studio and is shared with an architectural office – I count eight devices which are readably recognisable as computers, that is, they have an operating system, applications, a screen and a way to interact with them and can be connected to a network. This count does not include devices not directly recognisable as computers: cameras, thermostats and other gadgetry, which would raise the count to twenty-eight devices that run on code in one way or another.[5]

Architecture and design have not been immune to these changes in technology: digital technology has replaced or complemented the traditional modelling and drafting tools used by designers and architects and has extended into fabrication and construction, revolutionised the way we communicate in general and invaded how design and architectural culture is shared and consumed. Digital technology has also affected the environment in which we live, and code is increasingly becoming embedded in the very matter with which we build.[6] While architecture in general seems to have a hard time incorporating these changes, digital technology and code have

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[4] Paul Coates stresses this fundamental reciprocity between code and data: In a Turing machine a piece of data can also be an instruction, and an instruction can generate a piece of data. This inbuilt reflexivity is what allows computers to bootstrap themselves using code, in Paul Coates, *Programming.Architecture* (2010), p. 3.

[5] However, this count is anecdotal, and my personal interest in coding and technology in general might have influenced the count. Malcolm McCullough goes as far as to call this condition digital ground. Malcolm McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing* (2004). p. 171.

[6] For the opening of the Biennale of Architecture in Venice in 2014, Koolhaas was joined by Tony Fadell, CEO of Nest, a company that develops intelligent thermostats. See http://www.archdaily.com/583642/video-rem-koolhaas-and-nest-ceo-tony-fadell-on-architecture-and-technology/ (consulted on 20/12/2014).

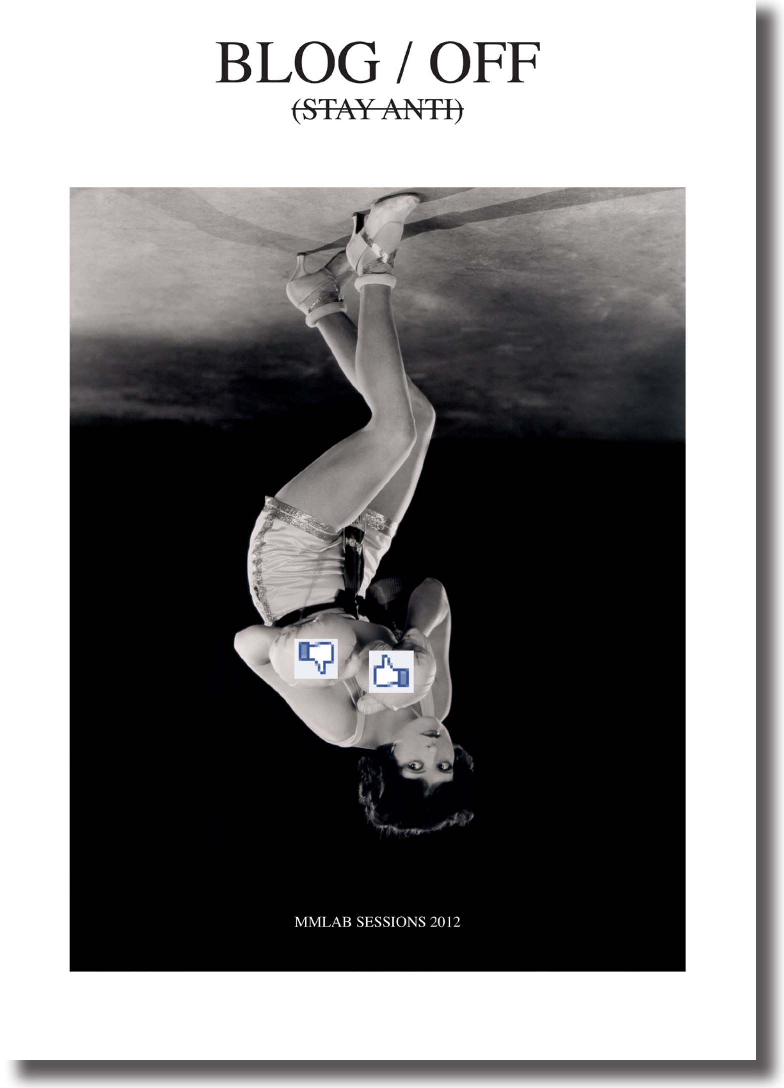
BLOG / OFF
~~(STAY ANTI)~~
MMLAB SESSIONS 2012

Fig. 1. BLOG OFF, MMlab elective course on it-architecture and the blogosphere, with Pieterjan Ginckels, 2012.

become an integral part of our environment and design culture. Whether or not architecture has to come to terms with code is not a question; how this will unfold and who will determine in what direction is.[7]

While this exegesis does not directly deal with the potential or problems related to ubiquitous computing, it is important to frame my coding practice in context and time. In order to understand coding as a design medium, it is important to take into account the modes of engaging with code: that writing code mostly still means sitting at a desk, looking at a screen and interfacing through keyboard and mouse and that sharing code through workshops happens in dim rooms with participants lit by the gloomy light of their screens. If I try to position a coding practice in the cultures of code and design, it has to be understood in the context of a constant stream of social media updates, online video archives of lectures, the endless number of design blogs and tutorials online (Fig. 1). A meaningful understanding of code in design practice can only happen through locating it within practice and its technologically saturated contexts.

[7] However, in the school where I teach, and more generally in local contexts, there seem to be very few practitioners and academics that take up this challenge.

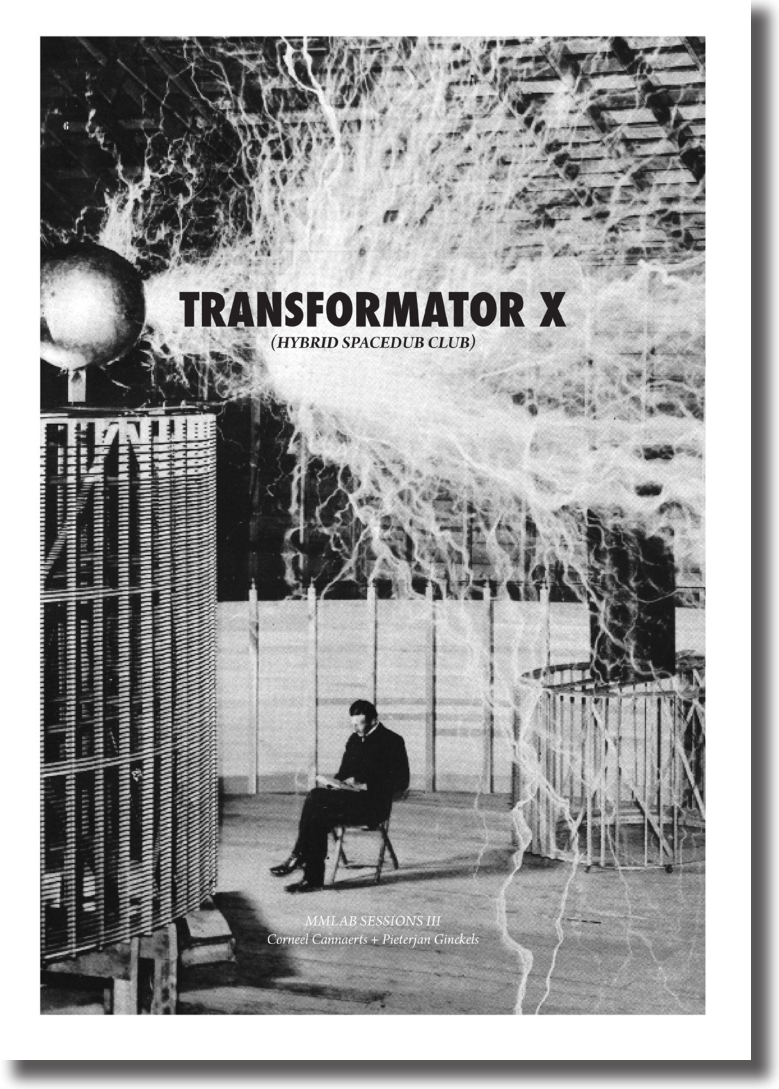
TRANSFORMATOR X
(HYBRID SPACEDUB CLUB)
MMLAB SESSIONS III
Corneel Cannaerts + Pieterjan Ginckels

Fig. 2. TRANSFORMATOR X, MMlab elective course on hybrid space, architecture as software and hardware, with Pieterjan Ginckels, 2013.

CODING PIONEERS

"Code is not purely abstract and mathematical; it has significant social, political, and aesthetic dimensions. The way in which code connects to culture, affecting it and being influenced by it, can be traced by examining the specifics of programs by reading the code itself attentively".[8]

Code is cultural, it is authored and designed and the relationship between code and our design culture are profound and rapidly changing. While code is still considered a subject for engineers and computer scientists, an increasing interest can be noticed in the humanities, the arts and design, as is showcased by emerging fields of digital humanities, software studies and critical code studies.[9] While reading code might be of interest for theoretical studies, even for the theory and history of architecture and design, as a design practitioner my interest lies foremost in writing code to further design projects. In order to position my coding practice, it is necessary to look at the contribution made by pioneers of coding in design.

The history of the development of digital technology[10] – especially the design of design software[11] – provides essential reading material for anybody interested in coding as an artistic or design practice. The work of pioneers such as Ivan Sutherland, Ted Nelson, Douglas Engelbart, Alan Kay and Nicholas Negroponte,[12] to more recent work by people like Robert Aish,[13] has made a substantial contribution to design culture. This contribution is situated more in providing the tools and frameworks for design rather than pursuing design practice itself through coding. In the recent past, there have been a number of key pioneers that do operate in this intersection of code and design, that have inspired my work or that have helped frame my coding practice while undertaking this research. Rather than providing an extensive list of architects, designers, researchers and their publications and works that influenced this research, I will instead highlight some figures and their ideas and notions that influenced this research.

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[8] Nick Montfort, e.a. (eds.), *10 PRINT CHR$(205.5+RND(1));:GOTO 10*, Software Studies (2013). p.3.

[9] See Kevin Driscoll,"*Critical Code Studies 2010*". http://kevindriscoll.org/wiki/Critical_code_studies_2010 (consulted on 20/12/2014).

[10] See Bill Moggridge, *Designing Interactions* (2007).

[11] For a good overview of both history and the present day situation, see: Lev Manovich, *Software Takes Command: Extending the Language of New Media,* International Texts in Critical Media Aesthetics (2013). pp. 39-43.

[12] See Bill Moggridge, *Designing Interactions* (2007) and Lev Manovich, *Software Takes Command: Extending the Language of New Media, International Texts in Critical Media Aesthetics* (2013). p. 40.

[13] Robert Aish, Extensible Computational Design Tools for Exploratory Architecture, in Branko Kolarevic (ed.), *Architecture in the Digital Age: Design and Manufacturing* (2003). pp. 243-252.

Early publications on the use of computers in design were centred on the notion of the digital as a design medium.[14] In *The Logic of Architecture*[15], his most influential book, William J. Mitchell develops the idea that the choice of design medium establishes a design world, and that this design world is not neutral but allows certain actions and ideas while inhibiting others, and determines what can be described. This is true for all design media, but computation is specific because the tokens and actions are captured in computable entities – Mitchell mentions, for example, point worlds, line worlds, vector worlds and planar worlds. While I do not agree with the arguments for a logic of architecture Mitchell subsequently develops within these design worlds, the idea of design worlds informs my understanding of digital media and code.[16]

A similar understanding of digital design media can be found in the work of Malcolm McCullough, who co-authored *Digital Design Media* with Mitchell. In his book *Abstracting Craft*[17], McCullough links the practice of coding with the practices of making and argues that a meaningful digital practice still involves human hands, eyes and minds and that a sense of wonder and discovery is crucial in design, whether it is digital or not. The book provides a thorough grounding for aligning code and matter, coding and making and has been influential in my understanding of coding as an embodied practice. McCullough extends this embodied and human centred understanding of code in later works to culture and the environment.[18]

Computation has always held the promise of automating parts of the design process, and often this was limited to mundane tasks, whether it was automating planning, drafting, or scheduling. Early on in the history of design computing, this promise triggered more ambitious design explorations that use computation not only to capture design ideas, but to actively generate them. In the field of generative design, the pioneering work of John Frazer and Paul Coates needs to be mentioned. In *An Evolutionary Architecture*[19], John Frazer proposes architecture as a set of evolving artefacts and sees computation as a means to accelerate this evolution by compressing time. His proposition for architecture is modelled on nature, more specifically on the biological processes of evolution and morphogenesis, and his work explores cellular automata and genetic algorithms linked with a concern for environmental performance.

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[14] William J. Mitchell, *Computer Aided Design* (1977), William Mitchell and Malcolm McCullough, *Digital Design Media: a handbook for architects and design professionals*. (1991).

[15] William J. Mitchell, *The Logic of Architecture* (1990).

[16] Mitchell establishes a language of architectural form, linking design thinking with the logical syntax of computer language, and develops shape grammars based on this. While the argument is eloquently written and richly illustrated, the assumption that design thinking can be completely captured in the logical syntax of code seems flawed; the grammars are developed based on existing designs – Palladian villas again – and their usefulness for tackling wicked design problems is questionable. See William J. Mitchell, *The Logic of Architecture* (1990), p. 131.

[17] Malcolm McCullough, *Abstracting Craft: The Practiced Digital Hand* (1996).

[18] See Malcolm McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing* (2004) and Malcolm McCullough, *Ambient Commons: Attention in the Age of Embodied Information* (2013).

[19] John Frazer, *An Evolutionary Architecture* (1995).

Paul Coates book *Programming Architecture*[20], is built up as a series of essays on the algorithm as text and describes a number of pioneering studies in generative design. Coates builds on Mitchell's idea of design worlds but emphasises the different levels of observation within this world, from the global overview of the designer to the local observation of an agents that occupy this world. Higher level order, only observable by the designer, emerges out of the behaviour of agents with a local view on the design world. Rather than merely capturing design intent in code, design emerges out of a negotiation between the designer and autonomous running code. While I do not necessarily share the interest in modelling natural or biological processes, what I learn from these pioneers in generative design is that code can be given a degree of autonomy in the form of an agent. As such, code can become an active contributor to design, rather than merely capturing design intent.

Kostas Terzidis has contributed to the practice of coding in design mainly through teaching and publications. His works and publications range from more instructional books, such as *Algorithms for Visual Design*[21], to more reflective, conceptual and critical approaches to coding in design in *Expressive Form*.[22] His most influential book is *Algorithmic Architecture,* which finds middle ground between the instructional and conceptual approaches and showcases an understanding of both design culture and computation. Essential for my exegesis is the difference he draws between computerisation in design, where existing concepts are simply stored and manipulated using computer technology, and computational design, where the code actually contributes to design outcomes. Terzidis sees code as an extension of human thought, which is fundamentally different, or what Terzidis calls *allo,* derived from Greek, meaning other. Design can benefit from collaboration between human thought and the algorithmic agency of code.

Of these coding pioneers John Maeda, designer and artist, who

[20] Paul Coates, *Programming.Architecture* (2010).

[21] Kostas Terzidis, *Algorithms for Visual Design Using the Processing Language* (2009).

[22] Kostas Terzidis, *Expressive Form: A Conceptual Approach to Computational Design* (2003).

established the Aesthetics and Computation group at MIT, has had the most direct influence on my coding practice. Through his work, projects, teaching and publications – *Design by Number*s, *Maeda @ Media* and *Creative Code* – he has influenced a generation of designers and artists to explore code as an important medium in their practice. A number of Maeda's students, Golan Levin, Dan Shiffman and most specifically Ben Fry and Casey Reas, who initiated processing.org, have authored an extensive amount of artworks, exhibitions and designs and have published on the subject of creative coding.[23]

When using code as a design medium, it establishes a design world that captures and describes design as computable and thus quantifiable elements. By operating on code the digital design world can be programmed to achieve a degree of autonomy and become an active contributor to the design process and, as such, acquire agency. Rather than modelling this code as a design on language (Mitchell and Coates), or nature (Frazer and Coates), this world is fundamentally different or *allo* (Terzidis); it is my tentative understanding that the agency of code resides in this otherness.

SHIFTING CODING CULTURES

Looking back on the work of pioneers in the intersection of design and computation has the advantage of being a reflection from a certain distance in time; dissecting the cultures of code today is a much more difficult task. Digital technologies have democratised not only software and hardware for design, but also the means of spreading design ideas. Computational design has spread out not only in its application, but also in its development and reception and forms a diverse and layered landscape that some have compared to an ecosystem.[24] Tools have changed from large corporate-developed and bulky standalone applications to an array of custom tools, plug-ins, platforms and libraries often developed by practitioners missing certain tools for their needs. Notwithstanding the increased number of practitioners' involved and different forms of exchange emerging in the form of online communities and networks, this landscape still seems to cluster around a relatively small number of schools, institutes and conferences.[25]

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[23] Casey Reas and Ben Fry, *Processing: A Programming Handbook for Visual Designers and Artists* (2007).

[24] Daniel Davis and Brady Peters, Designing Ecosystems, Customising the Architectural Design Environment with Software Plug-ins, in Brady Peters and Xavier De Kestelier (eds.), *Computation Works: The Building of Algorithmic Thought* (2013). pp. 124-131.

[25] These schools remain dominant: AADRL, Bartlett, SCI-Arc, MIT media Lab, ETH, SIAL RMIT.

[26] See amongst others: James Steele, *Architecture and Computers: Action and Reaction in the Digital Design Revolution* (2002).Branko Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*, (2005).

While there is an extensive number of publications[26] – not to mention videos, blog-posts and tutorials[27] – on the impact of digital technologies on architecture and design, few explicitly focus on coding, and those that do tend to take either the form of instruction books[28] or merely discuss the design outcomes. Most instruction books include some examples of work and will hint at the reasons for engaging with code and reveal some of its cultural traits; likewise, publications focussed on works will provide some but limited insight into the codes behind the works, and few publications find middle ground between showing crucial work and acknowledging the role of code.[29]

Even fewer publications look into the cultural dimensions of coding in design.[30] The most comprehensive account on the cultures of coding in architectural design to date is Mark Burry's *Scripting Cultures: Architectural Design and Programming* (2011).[31] This book raises a number of questions on the role of coding in design practice: Why do designers and architects engage with code? What added value does scripting brings to the design process? What does scripting entail for collaborating in teams, and what are its implications for authorship in design? The book provides tentative answers to these questions by sketching a brief history of computation in design, providing a number of in depth personal accounts on scripting in design practice and teaching and an inquiry of thirty highly renowned practitioners in architecture and design that use scripting as an important part of their practice. The overall image *Scripting Cultures* draws is one of scripting as a hard won skill and a highly diverse and articulated map of coding practices – hence the plural cultures. Rather than trying to summarise this map here and trying to pinpoint my coding practice on this map, this introduction is intended to set the stage; the cases that follow will each show ways in which I have incorporated coding into my design practice. The central question threaded through this chapter is: What agency can be ascribed to code in the design process? This introduction is intended to demonstrate that code is not just technical and to acknowledge the cultural dimension of code.

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[27] See for example http://designreform.net/, http://www.designalyze.com/ or http://www.plethora-project.com/ (consulted on 26/01/2015).

[28] For example, Casey Reas and Ben Fry, Processing: *A Programming Handbook for Visual Designers and Artists* (2007). Or Ira Greenberg, *Processing: Creative Coding and Computational Art*, (2007). Or the Grasshopper Pirmer by ModeLab see http://modelab.is/grasshopper-primer/ (consulted on 26/01/2015).

[29] An exception to this is Casey Reas and Chandler McWilliams, *Form+Code in Design, Art, and Architecture* (2010). This provides an interesting and broad overview of works from the disciplines mentioned in the title, spanning the last 50 years, and is organised according to the principles the authors see as crucial traits of code – repeat, transform, parameterize, visualize and simulate – and for each they provide example code.

[30] Two editions of Architectural Design provide insight in the cultures of code: *Programming Cultures: Art and Architecture in the Age of Software (2006)* and *Computation Works: The Building of Algorithmic Thought (2014)*, although they both provide a quite selective overview of coding practices.

[31] Although Mark Burry would not be out of place in the selective list of coding pioneers outlined above, which was partly fuelled by *Scripting Cultures,* his continued involvement in practice, teaching and publishing, in particular this book, merit a separate lemma in describing the cultures of code. See Mark Burry, *Scripting Cultures: Architectural Design and Programming,* (2011).

CASE 2.1: TINKERING WITH CODE

Design Explorations | Collaborations | Experiments | 2007 – 2014

tinker

1. (noun) : a person who in the past travelled to different places and made money by selling or repairing small items (such as pots and pans)

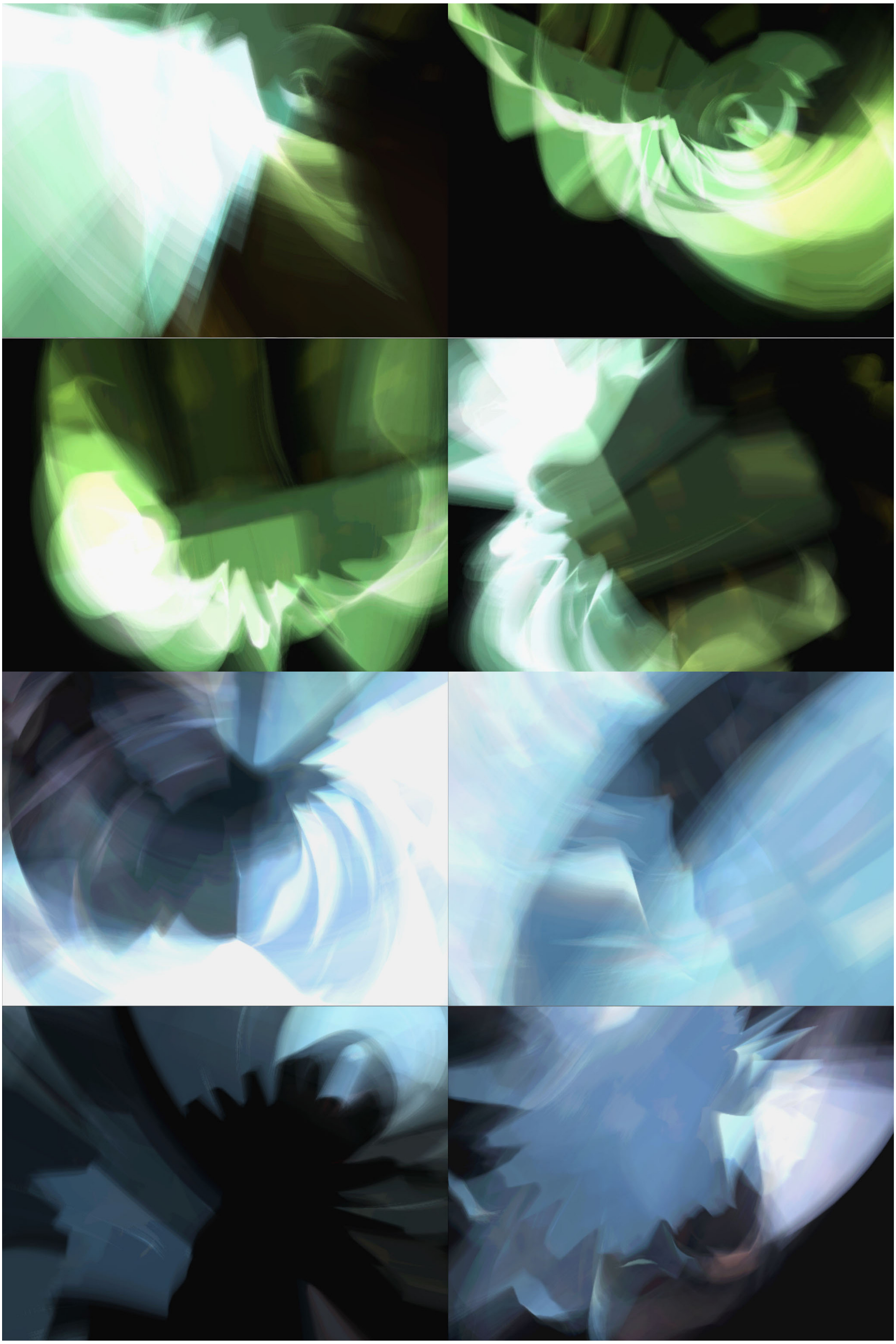
2. (verb) : to try to repair or improve something (such as a machine) by making small changes or adjustments to it

As stated in the introduction of this chapter, code is rapidly becoming pervasive in our environment and culture and is affecting all aspects of architecture and design. This raises the question: how should we respond to these rapidly evolving technologies and what does this mean for designers and architects? Design and architecture are typically generalist practices that rely on diverse forms of knowledge from different disciplines to negotiate the multiple aspects that make up the wicked problems we are faced with. Is computation just another layer of this complex world we operate in? Is it a mere tool to make our design practices more productive? How much do we need to understand code in order to meaningfully use computation in design and architecture? How do we approach code as an open design medium?

This case study formulates tentative answers to these questions for my own design practice by looking into the different ways I have appropriated and integrated code. Although the gained insights are tied to a personal engagement with code, the described projects point towards aspects of code as a design medium that might be more generally applicable. In contrast to most other cases in this exegesis, this case does not centre on one central project but rather focusses on a modus operandi, a way of approaching technology, looking at what a technology affords for a design practice rather than what it is designed to do. I have labelled this approach *tinkering with code*.

Tinkering can be read as a disclaimer, as I do not approach computation with an aim toward the fundamental understanding of a computer scientist or the professional understanding of a software developer, but rather as a designer confronted with code and being intrigued by its potential for design practice. Tinkering also hints at the exploratory nature of my engagement with code and computation during the design process – that is, rather than merely a means of capturing or developing design intent, code often triggers design ideas or derails the design process into new paths. The subject matter of this case is not code and computation itself, but rather how they enable, inform and shape my design practice.

The material discussed in this case is diverse in its scope, subject



matter and nature; it draws from design experiments, workshops and projects undertaken during the last seven years.[32] Their duration ranges from a few hours to two or more years; some of the projects are self-initiated, others are collaborations initiated by others; the format of the work varies from design sketches, design experiments, projects and workshops. As code and computation and their associated cultures are changing rapidly, so did my understanding and appropriation of its role in design practice. Instead of placing the projects central in the discussion, I have selected a number of key moments and instances in this unfolding understanding of code in my design practice.

Fig. 3. MeshUp installation, screenshots of software.

CODING BETWEEN MEDIA

My interest in and engagement with digital media, in the form of graphic design, music, live visuals and interactive installations, dates from before my architectural education and has been developing as a parallel practice during and after my studies and work. The roots for engaging with code can be found in these practices; only later did code become an integral part of my architecture and design practice. In retrospect, the distinction between architectural practice and these other kinds of practice has faded as my understanding of architecture has broadened, and it is the fringes of the expanded field of architecture and design that interest me. Teaching at the mixed media unit of Sint-Lucas School of Architecture has strengthened this position, being located within the architecture school, but at the same time feeding on friction with other design and artistic disciplines.

The origins of my coding practice and this position on the fringe of architectural practice informed my understanding of code in design. A number of these early coding experiments I undertook explored translations between diverse media, in particular between sound and image. For example, *MeshUp* was an installation built in 2008 consisting of a projector, a camera, a speaker and a microphone all set up in one room and connected to custom software patched in vvvv[33] and PureData.[34] The image registered by the camera was transcoded

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[32] While I have collaborated with other practitioners and researchers, in the descriptions I have indicated what my role in the project was, the work that makes up this PhD is my creative contribution to these projects.

[33] vvvv is a graphical programming environment aimed at graphic, audio visual design. See vvvv.org (consulted on 30/10/2014).

[34] puredata graphical programming environment developed by Miller Puckette, who also developed mas/msp. See puredata.info (consulted on 30/10/2014).

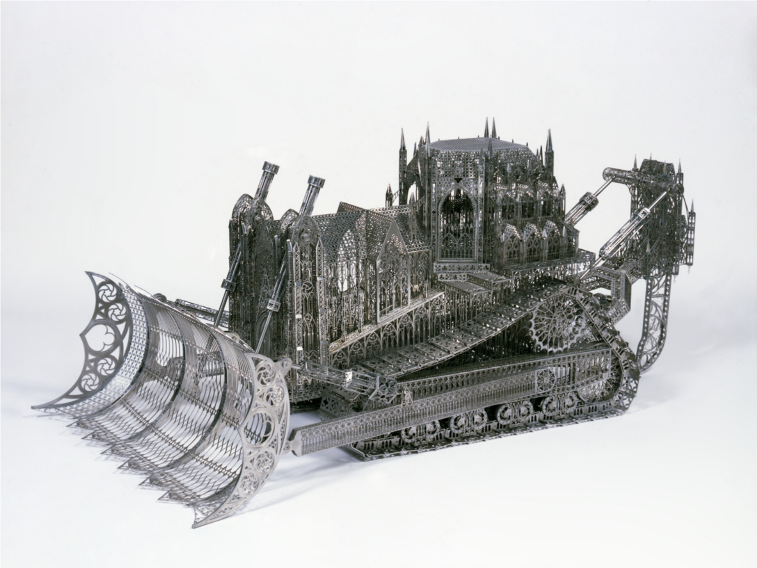

Fig. 4. D11 Bulldozer, prototype for Wim Delvoye, 2006.

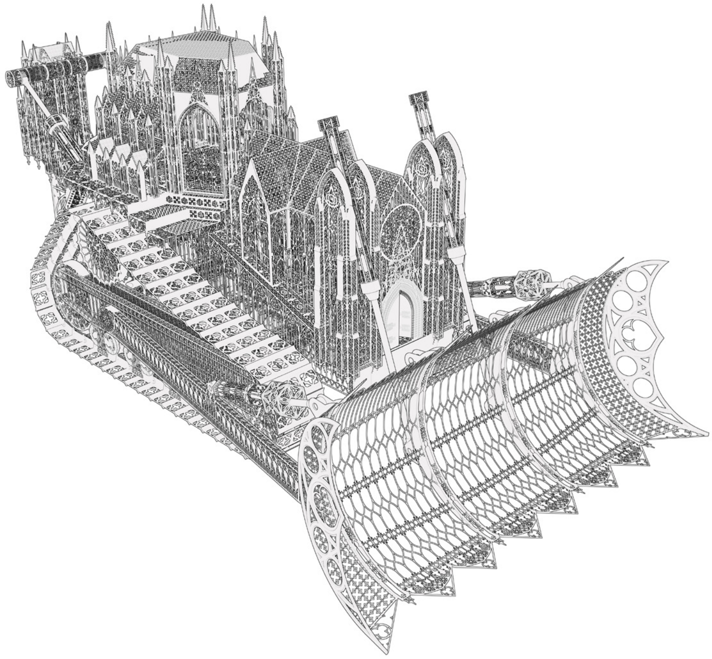

Fig. 5. D11 Bulldozer, design model, for Wim Delvoye, 2006.

in a sound-scape, and the sound was picked up by the microphone translated in an image by deforming a mesh; both the generated image and sound were brought back into the room again through the projector and speaker. This created a double feedback loop, travelling two times through physical space and being transcoded in the software two times. If left alone, the installation would reach an equilibrium, only to be disturbed by changing conditions in the room, like light or the presence of people (Figs. 3).

While this early coding experiment was a first attempt at bringing an audiovisual experiment into a spatial setting – and its approach might be seen as naïve – I was not aware at that time of the work of Ruairi Glynn or Usman Haque[35] and others. But it reveals an interesting quality of code: The binary nature digital data is not linked to a specific medium; coding can be used to transcode between different media. In his book *Software Takes Command,*[36] Lev Manovic traces the development of the current media software based on the idea of computation as a meta-medium.[37]

The timing and context of these early experiments with digital media is important: My interest in coding did not start from – in my perception back then – tiresome world CAD, but from more open-ended software tools that allowed one to interactively engage with different media. Around 2000, when I started these early experimentations, computers were entering many people's homes, and early versions of design software had been developed. My understanding of code at that time was limited, as is reflected in the title of the *MeshUp* project, which was literally patched together from bits and pieces of examples in a graphic programming environment.

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[35] Usman Haque, Distinguishing Concepts: Lexicons of Interactive Art & Architecture, in *4d Social – Interactive Design Environments* (2007). pp. 24-31

[36] Lev Manovich, *Software Takes Command: Extending the Language of New Media, International Texts in Critical Media Aesthetics* (2013). p.107.

[37] This idea dates from a paper at the end of the 70s by Kay and Goldberg, although it was it was only by the mid-90s becoming a reality. Alan Kay and Adele Goldberg, "Personal Dynamic Media", in Noah Wardrip-Fruin and Nick Montfort (eds.), *New Media Reader,* (2003), p. 399.

AVOIDING REPETITIVE WORK

As the experiments with digital media began to infiltrate and take over my day job as an architect, I started working as a freelancer for several artists, mainly designing and making installations and sculptures. Between 2006 and 2007, I worked as a freelance designer for Belgian artist Wim Delvoye, among other projects on his Gothic works series. This series consists of intricately ornamented, full scale replicas of construction machinery: cranes, concrete mixers, trucks and bulldozers. The series was later extended into architectural scale installations and even buildings. The work combines the high art of Gothic structures, patterns and ornamentation, which are said to be derived from underlying constructive principles, with the image of brute power of contemporary construction machinery.

The sculptures were modelled in AutoCAD, laser-cut from steel sheets and welded together as a giant jigsaw puzzle. The modelling of a particularly intricate piece, the Caterpillar D11(Figs. 4-6), the largest bulldozer in the series, took me three months; the fabrication of the first prototype on a scale of 1:5 two weeks and half scale model one more month. The relative speed of this process, going from sketch design, to modelling to the actual making of the sculpture was liberating compared to my experiences in architecture. Equally liberating was the direct involvement with making and getting rid of the designerly assumptions and stylistic reflexes picked up during my architectural education.[38]

The modelling process of the sculptures started by approximating the construction machinery as a set of interlocking sheets; the individual sheets were then extracted and ornamented in 2D and afterwards reassembled in the 3D model. The larger and more intricate pieces consisted of multiple nested assemblies, which pushed the limits of what was computationally possible at the time. The frequently going back and forth between 3D model and the 2D ornament required a set of commands to be repeated again and again.

Next to exploring digital media, a second incentive to get into coding came from avoiding this repetitive work.[39] In the first instance this was done by chaining a specific ordered set of commands into one macro command, so one keystroke would replace a whole series of commands. A step up from macro commands was developing scripts that facilitated the fabrication of the sculptures: The laser cutter used by the contractor could not handle splines and required all curves to be drawn as arcs or polylines; an AutoLisp script would check all curves and approximate them as polylines if necessary.[40] Next to avoiding repetitive work, optimising processes of fabrication and making were important reasons for integrating coding in my design practice.

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[38] I studied architecture between 1998 and 2004, under neo-modernist, superdutch rule; architectural design was limited to questions about program, context and construction.

[39] Mark Burry mentions a similar reason for getting into scripting; see Mark Burry, *Scripting Cultures: Architectural Design and Programming* (2011). p. 28.

While chaining macro commands and scripts to avoid repetitive work might seem modest, this is what coding essentially entails: defining a set of precise instructions for the computer to execute. Introducing coding into a design process implies a shift from addressing a design problem one command at a time to defining a chain of instructions, whether it takes the form of a macro command or script working on top of a modelling application, an associative parametric model or writing code from scratch.

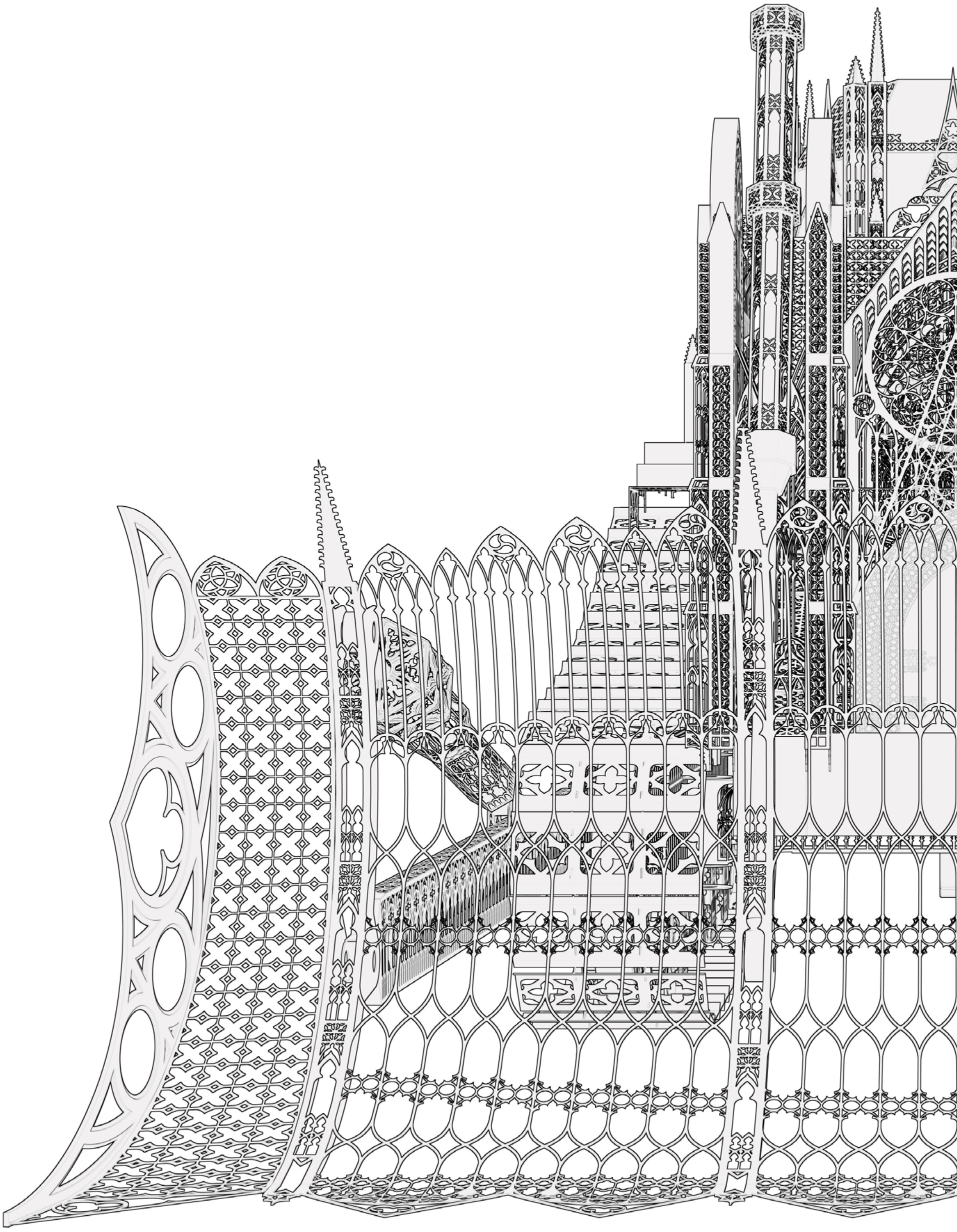
While using code to avoid repetitive work is probably applicable to other designers and architects,[41] it also tells us something about the nature of computation itself. Computers "*are designed to accurately perform the same calculations over and over*";[42] repetition can be called the computer's *unique talent*. Just as essential to computation is variation, as embodied by the *variable*. Computation decouples the logic of the algorithm as a precise set of instructions from the specific numeric instances it operates on. Although algorithms are inherently repeatable, each iteration can be different, based on variables. This tension between repetition and variation has not only been used to increase productivity but has also been explored as a quality by many practitioners using code in their art or design practice. It is a theme prominent in the work of early practitioners in computer arts such as Frieder Nake, Vera Molnar, Manfred Mohr and Peter Beyls.[43]

[40] This was developed with Piet Lelieur, who further developed it into a script for automating exporting a database and part numbering, which greatly improved the fabrication process.

[41] It is explicitly mentioned as a reason to explore generative systems by John Frazer and Paul Coates and some of the respondents of Mark Burry's *Scripting Cultures*. See Mark Burry, *Scripting Cultures: Architectural Design and Programming* (2011), p. 28.

[42] Casey Reas and Chandler McWilliams, *Form+Code in Design, Art, and Architecture* (2010), p. 53.

[43] I organised a hackaton session for the recode project (see recodeproject.com), where we invited Peter Beyls for a lecture, an artist based in Belgium working with computer code in artistic practice since the '60s.



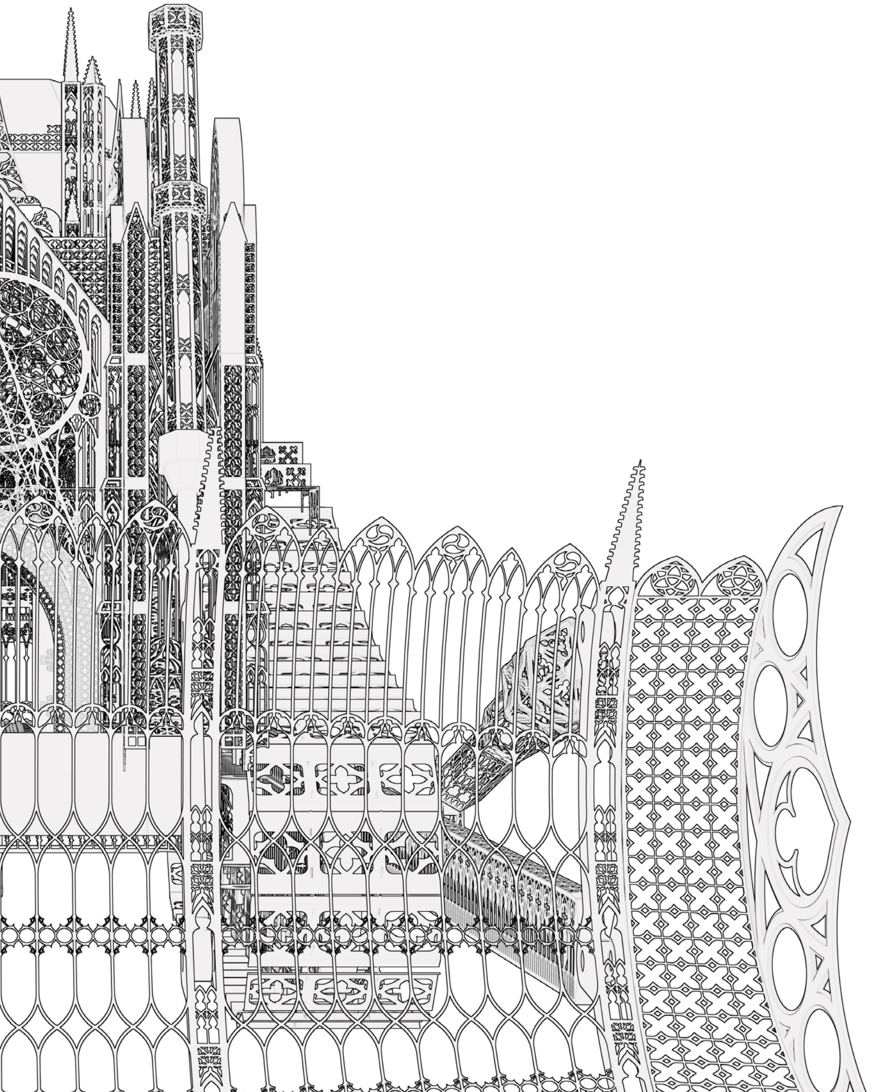


Fig. 6. D11 Bulldozer, design model, front view, for Wim Delvoye, 2006.
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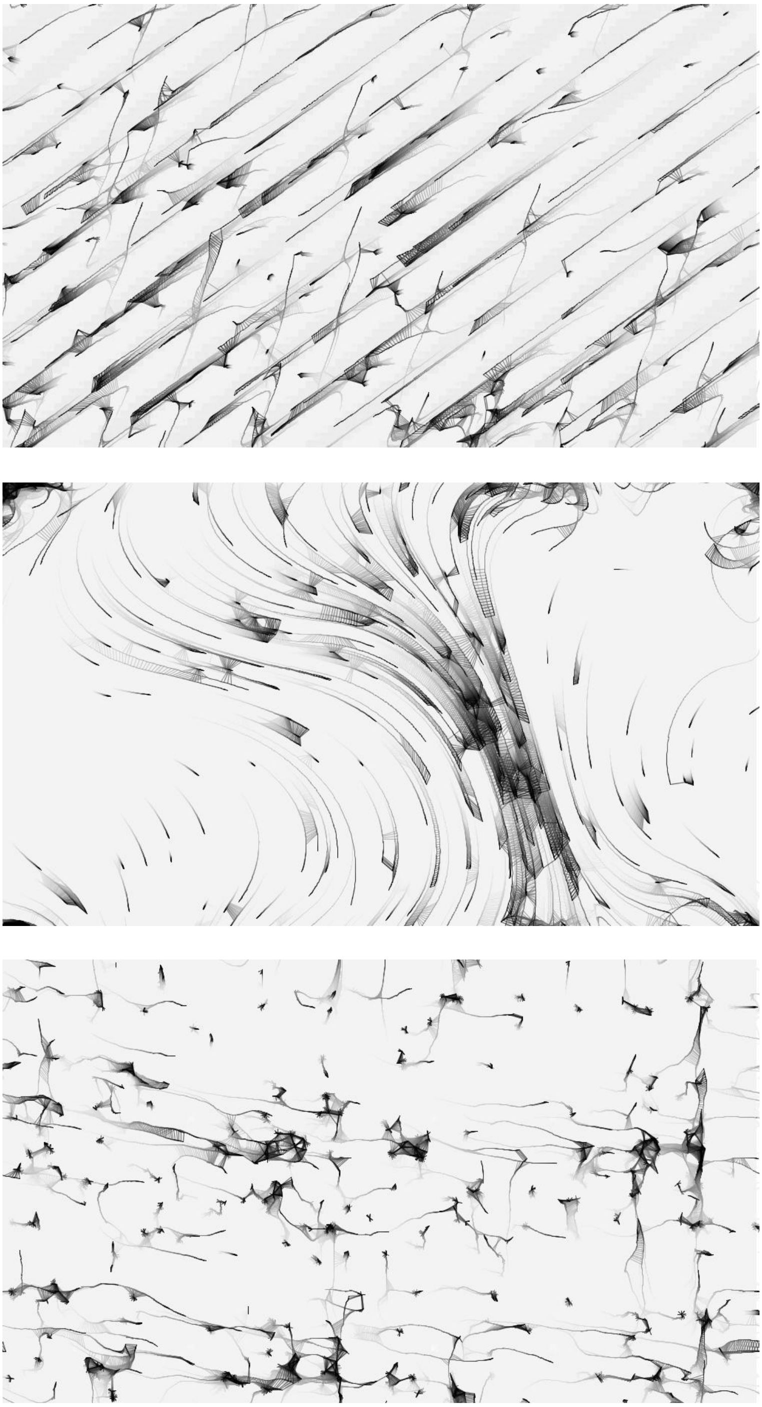


Fig. 7-9. FlowField sketch, formation 1-3.

SKETCHING WITH CODE

The two projects described above, coding to achieve a goal (in this case translation between media) and coding to avoid repetitive work and to increase productivity, are reflected in Mark Burry's account on different reasons to script.[44] Burry identifies a third reason, which is scripting for the voyage, or the exploration of an idea rather than aiming for a specific goal (Figs. 7-15). After the two encounters with code described above, I was intrigued by the possibilities for architecture and design and made the conscious decision to learn to code. While transcoding between media and increasing productivity remained important parts of my coding practice, it was complemented by coding for design exploration.

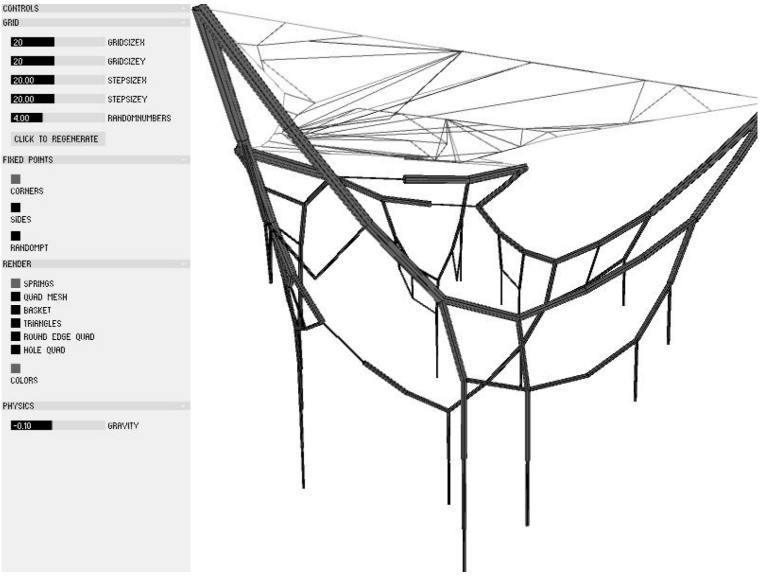
Processing is a programming language, development environment and online community aimed at opening up computer programming to artists, designers, architects and students. It was initiated by Casey Reas and Ben Fry when they were studying at the Aesthetics and Computation Group at MIT led by John Maeda.[45] It is an open-source project, which has a large community of users, and its core functionality can be extended with third party libraries developed by the community. I am very thankful for this community and the generous information and source code it shares and have actively contributed to it myself through sharing code and organising workshops and events.[46]

Processing embraces the idea of coding to explore ideas which are not fully formed. The practice of sketching is a central idea behind Processing: Programs are called sketches, the collection of works is called a sketchbook and the part of the code that is continuously repeated while running is called the draw loop. Where in other development environments it takes a considerable amount of time to start a new project, import relevant libraries and start coding, Processing reduces the amount of time spent between writing code and having visual feedback on the screen. For designers, architects and artist, who tend to have a strongly developed visual sense, Processing is one of the least painful ways to learn how to code.

[44] See Mark Burry, *Scripting Cultures: Architectural Design and Programming* (2011), p. 32.

[45] See John Maeda, *Creative Code* (2004), John Maeda, *maeda@media* (2000) and John Maeda, *Design By Numbers* (1999).

[46] I have co-organised Share&&Tell and Processing Ghent, a series of informal lectures and workshops where practitioners using code as a substantial part of their work share insights and source code. See Processing Ghent and Processing Cities, www.processingghent.org and www.processingcities.org (consulted on 05/08/2014).



GRIDSIZEX: 20
GRIDSIZEY: 20
STEPSIZEX: 20.00
STEPSIZEY: 20.00
RANDOMNUMBERS: 4.00
GRAVITY: -0.10

CONTROLS
GRID
CLICK TO REGENERATE
FIXED POINTS
CORNERS
SIDES
RANDOMPT
RENDER
SPRINGS
QUAD MESH
BASKET
TRIANGLES
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HOLE QUAD
COLORS
PHYSICS

Fig. 10. Dook sketch, catenary simulation, form follows failure, 2009.

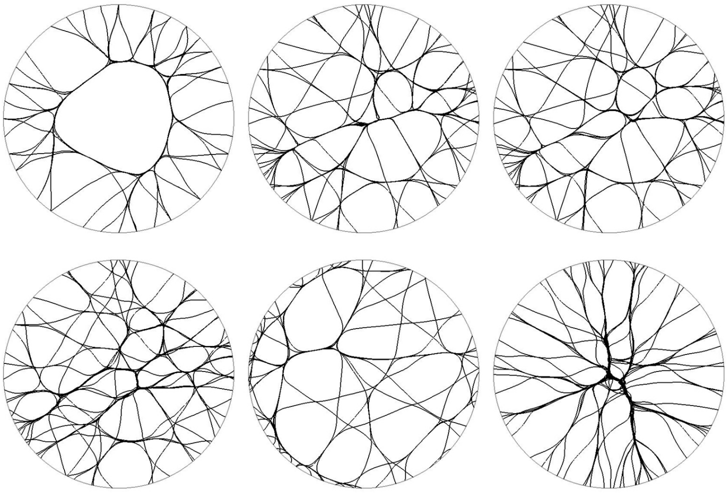


Fig. 11 Woolthread sketch, recreating a form finding experiment by Frei Otto .

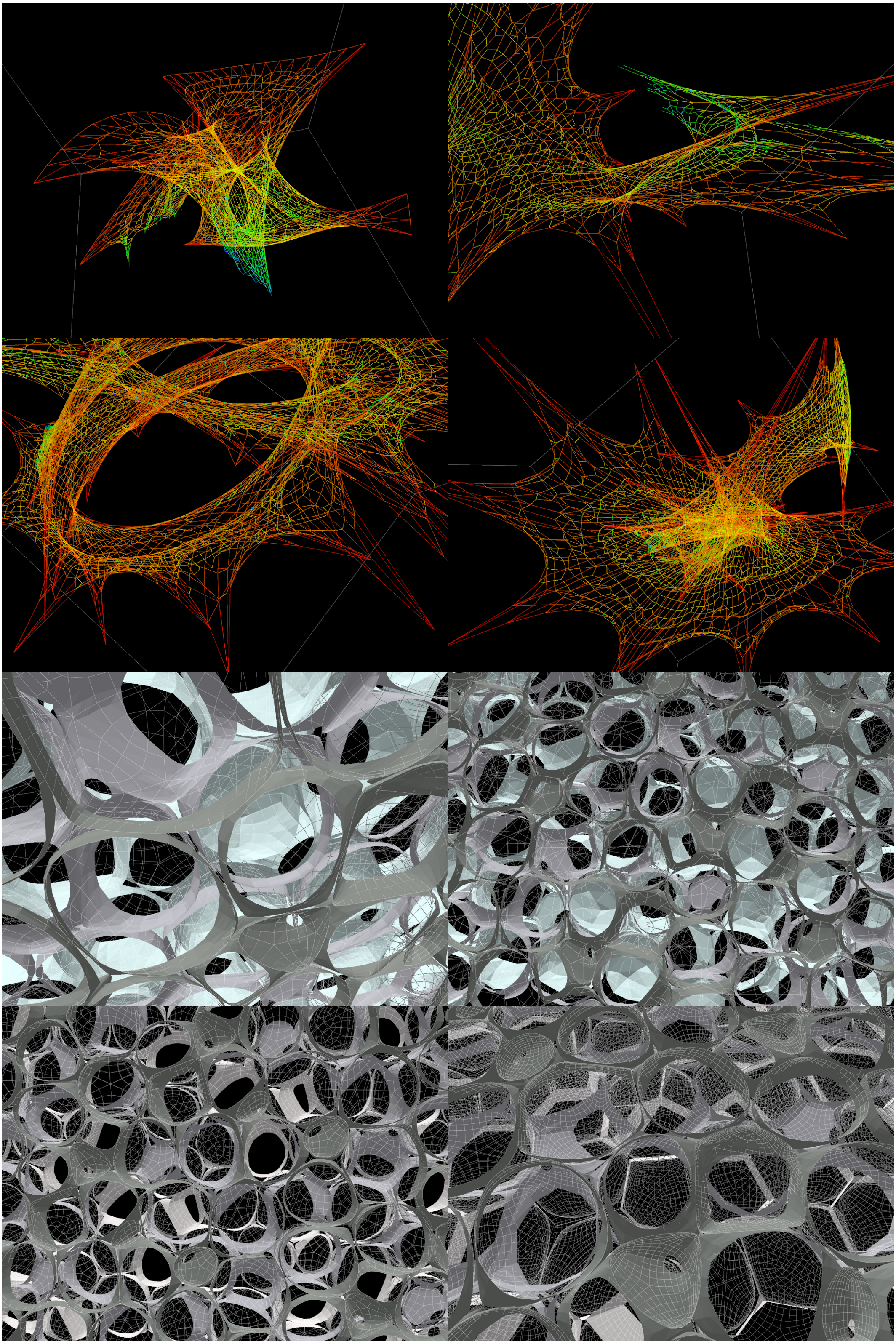
Working with code as a design medium in Processing provides you with different kinds of feedback on the screen: a graphical window showing the result of the running code, a textual one showing the actual code itself and possibly textual feedback through the console. Although the running code can be made to respond to various inputs, for example mouse and keyboard, the design mainly progresses by working on the code itself. Text-based coding is an unforgiving medium – forgetting even one character will lead to a syntax error, and it is often hard to tell from the visual feedback alone what is exactly going on in an algorithm. These limitations can be overcome by continuously testing the code, incrementally building on working versions of the code and using the console to provide textual feedback, or by developing a debug mode that renders certain information on the screen. Graphic coding interfaces tend to be a bit more forgiving, as code is contained within blocks with clearly defined inputs and outputs, but they tend to become quite hard to read once definitions get larger.[47]

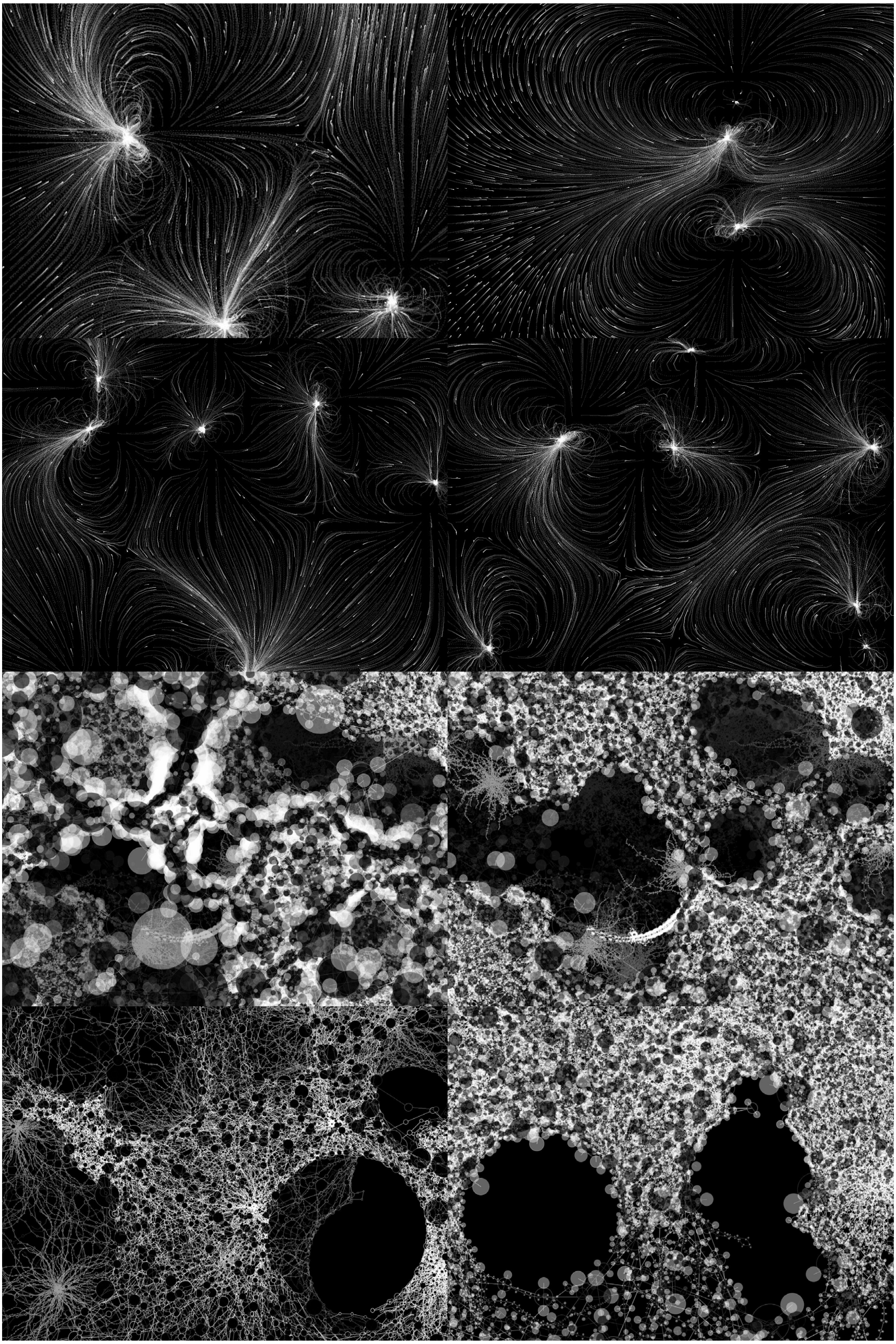
Sketching with code does not replace actual sketching with pen and paper but rather complements it. While coding, I tend to have a piece of paper at hand to help with visualising ideas while simultaneously testing them out in code. Different from sketching with pen and paper, sketches with code develop incrementally, not by retracing a sketch but by building on working previous blocks of code. The reuse of code and gradual increase in complexity allows sketches to be turned into blue prints and actual design projects.

Code as a medium to develop ideas tends to progress in chunks as parts of the underlying algorithm get defined, evaluated and refined. While developing an algorithm, I tend to work with a simplified version of the design problem at hand, which can take the form of simpler input geometry or low number iterations or variables. Once an algorithm reaches a certain state of development, I tend to increase the complexity, which is often a revealing moment. Moments of playing, interacting with the graphical representation of code and tweaking values are alternated with changes to the code itself. In graphical programming, a similarly layered feedback exists, allowing work on the geometrical and the algorithmic simultaneously.

Fig. 12-15. Various design experiments and sketches: *Flocking Knitter, Bubble Grid, Magnetic Field, Recursive Growth*. Some more are collected here: www.flickr.com/introspector/. (next page).

[47] Davis, Daniel, Jane Burry and Mark Burry, Untangling Parametric Schemata: Enhancing Collaboration Through Modular Programming, in *Designing Together*: Proceedings of the 14th International Conference on Computer Aided Architectural Design Futures, eds. Pierre Leclercq, Ann Heylighen and Geneviève Martin, Liège: Les Éditions de l'Université de Liège (2011), pp. 55–68.





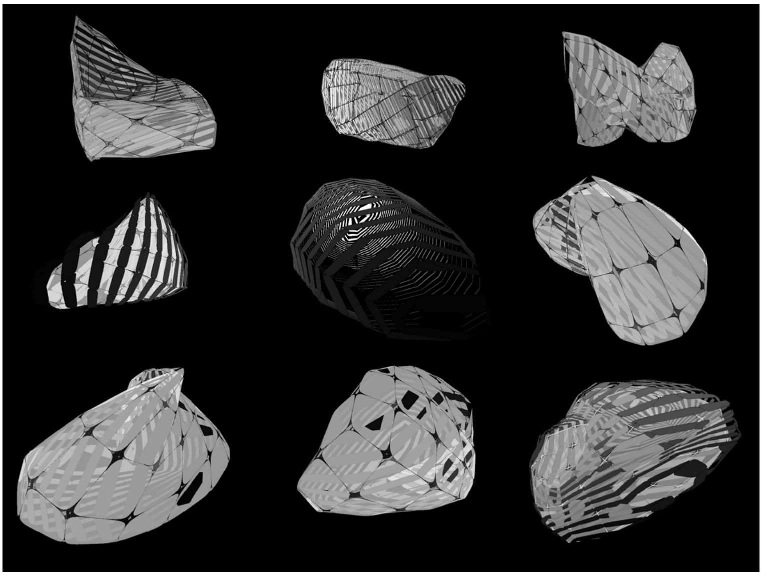


Fig. 16. Slicer sketch, variations.

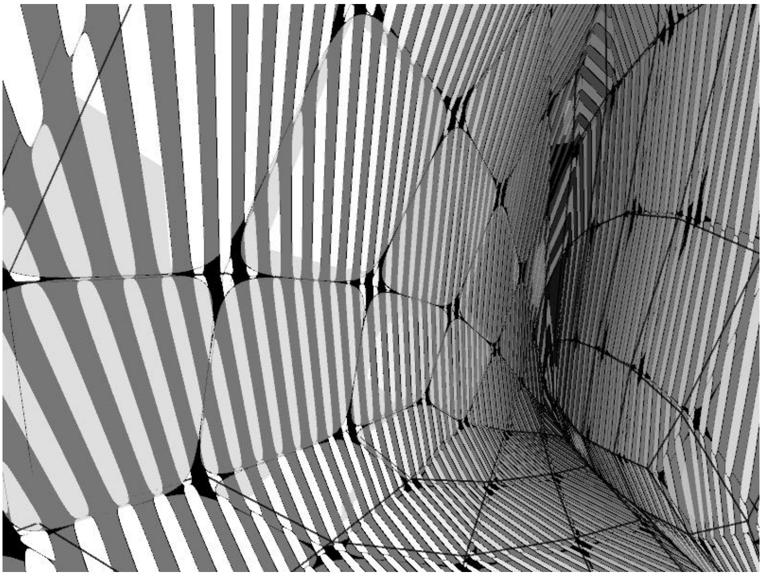


Fig. 17. Slicer sketch, interior.

STRUCTURING CODE

The effort and time spent on coding only becomes meaningful if some degree of repetition and variation is involved.[48] Drawing one, or even a few, circles will work fine by explicitly defining them; drawing thousands of circles will benefit from using code – regardless of whether the circles represent drill holes on a complex structure or explore a recursive growing formation. Code becomes useful when repetition and variation is involved, and it can operate on collections, lists or arrays of elements. Code has a bias towards the many and the multiple, and designing with code tends to shift the focus from the one off and the unique to the systemic and the general.[49]

Much of the syntax of code has to do with structuring repetition and meaningful variation. In text-based coding – my understanding here is based on using Processing – this is reflected in defining and declaring variables, loops, conditionals, functions, classes etc., which are all means of efficiently structuring code and determine the flow of instructions passed to the computer.[50] The elements for structuring code are highly hierarchical and are geared toward modularity and reuse, and splitting up a design problem into reusable chunks.

In visual programming languages – based on my experiences with Grasshopper, PureData and vvvv – code is structured as a network of components, where each component computes an output based on data it receives as an input. Different than in text-based programming, the flow of execution is explicitly visualised, which provides a clear feedback of the algorithm. When definitions become more complex, components can work on lists of data or even nested lists of data, and it becomes harder to understand what is happening in the algorithm. Managing data trees, as nested lists are called in Grasshopper, can be quite a daunting task, especially if the design reaches some level of complexity.

While these elements for structuring code are both aimed at human understanding and computational efficiency, they form a technical, discursive and conceptual support for design ideas, and they form the grain of code as a design medium, to stay with matter

Fig. 18-19. Object Oriented Eclecticism, result group 1. (next page)

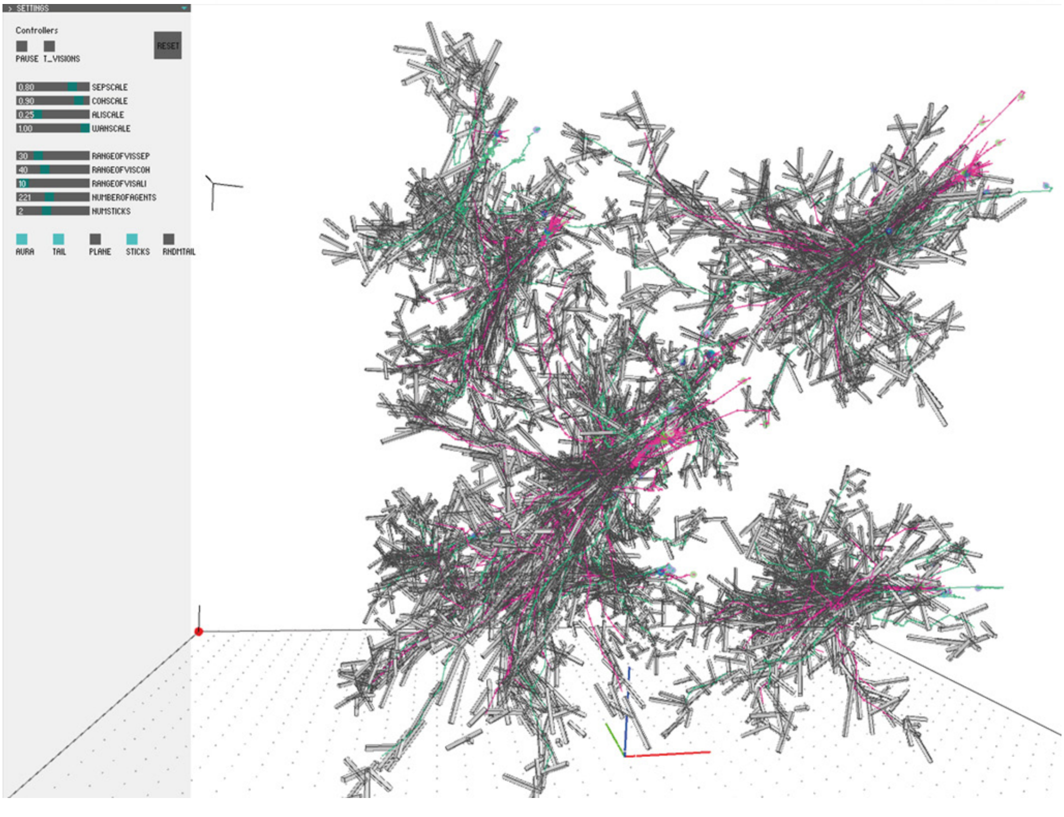
Fig. 20-21. Object Oriented Eclecticism, result, group 2. (next page).

[48] Coding is a hard won skill, it takes a substantial amount of time to learn, but when it can help in avoiding repetitive work, that time can made back.

[49] This observation is also made in Casey Reas and Chandler McWilliams, *Form+Code in Design, Art, and Architecture*, (2010). p.45

[50] Ben Fry visualises the flow of execution in code beautifully in *Disarticulate,* a project that visually overlays the text of the code with lines indicating the flow of execution. See http://benfry.com/deprocess/ (consulted on 24/11/2014).

WORKSHOP
OBJECT ORIENTED
ECLECTICISM (OOE)
SINT-LUCAS
ARCHITECTUUR
MMLAB


SETTINGS
Controllers
RESET

☐ PAUSE ☐ T_VISIONS

0.80 SEPSCALE
0.90 COHSCALE
0.25 ALISCALE
1.00 WANSCALE

30 RANGEOFVISSEP
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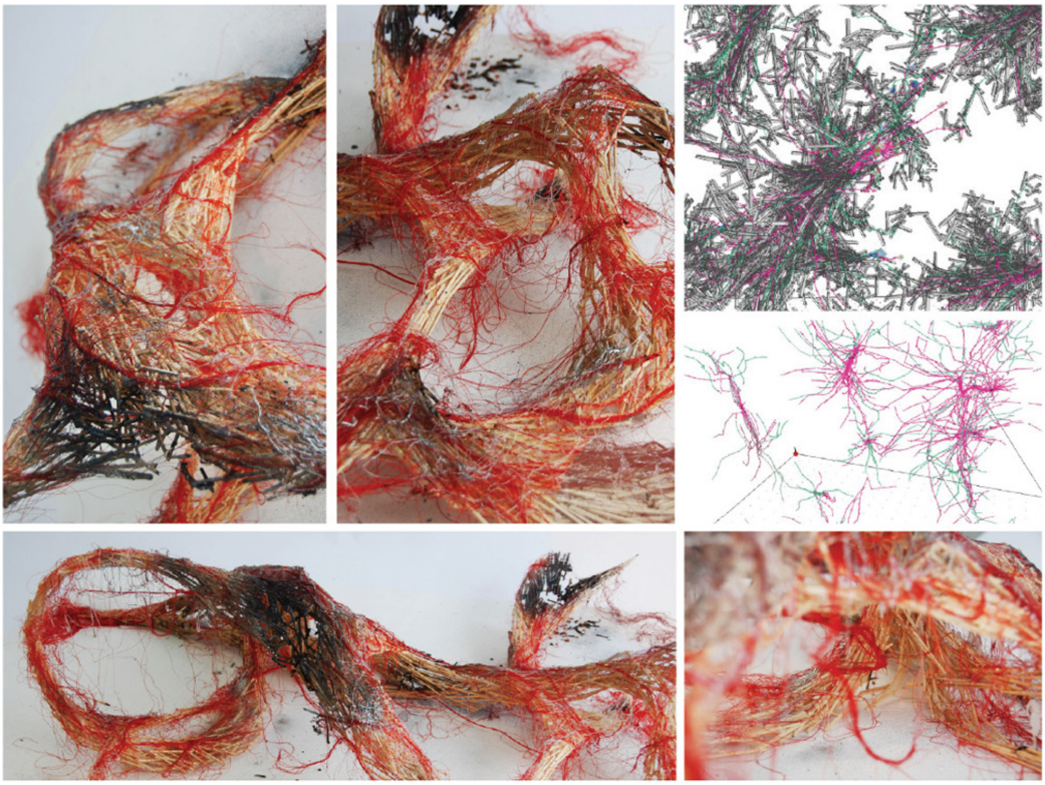
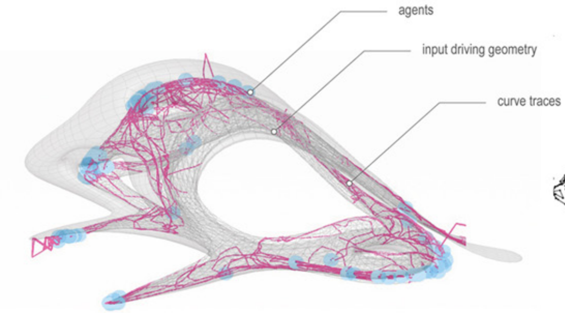
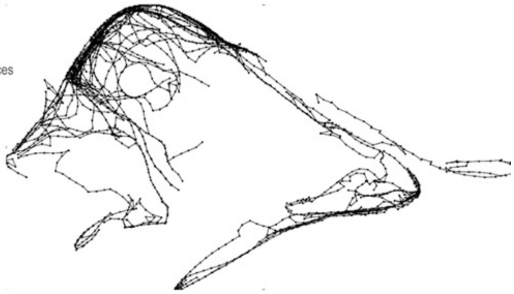
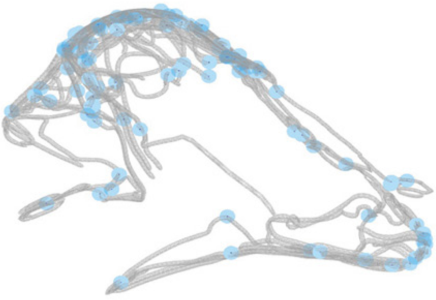



agents
input driving geometry
curve traces

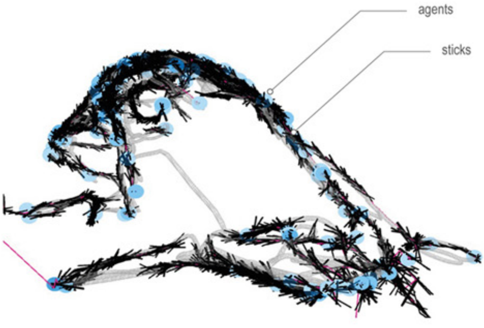
1 _ agents run over initial geometry



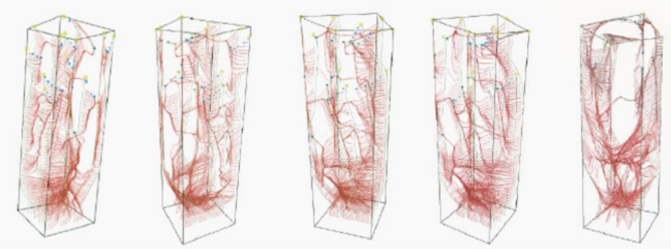
2 _ vector trail traces

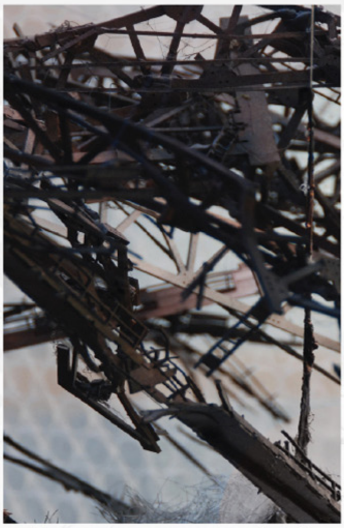


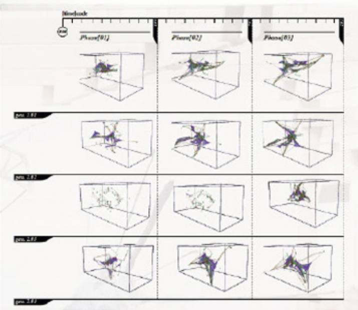
3 _ trails trace extrusions


agents
sticks

4 _ agents deposit sticks over geometry






Phase[01]
Phase[02]
Phase[03]

as a metaphor. An example of this can be found in *object oriented eclecticism*, a workshop I organised in the summer of 2012 with Gilles Retsin and Isaie Bloch, which was conceptually modelled on object-oriented programming (Figs. 18-23). This programming paradigm, which is at the basis of Java and thus Processing, is organised around the concept of objects. Objects are autonomous blocks of code that contain their own variables and functions, and objects are of a certain class, where the class works as a blue print for each of the instantiated objects. In the workshop, design emerged out of the interaction between a collection of heterogeneous objects and an environment and was coupled with a similarly heterogeneous materialisation.[51]

TOOLING

Using code as a design medium affords control over the algorithms that are beneath the surface of software tools and, as such, allows designers to develop their own design tools. Going beyond the intended use of a tool or developing your own tools is frequently mentioned by practitioners as a main motivation for using code as part of their creative practice.[52] In architecture, this is a prominent argument in many publications on parametric and algorithmic design. This position is most explicitly stated by Aranda and Lash in their contribution to the Pamphlet Architecture series under the name *Tooling.*[53] They describe a number of algorithmic techniques which are illustrated by a recipe, a version of the algorithm in pseudo code, a number of experiments and a project developed with this technique.

Having access to the code that drives software tools can allow for a deeper understanding of the design issues at hand and uncover the assumptions inherent in the tools. Actively developing this code allows for these assumptions to be questioned and explored differently. To that extent, I think the tooling metaphor is useful, but it also introduces an opposition between tool making and tool using, which in my practice of using code as a design medium are not separate activities, rather they mutually inform each other. The

Fig. 22. Object Oriented Eclecticism, result group 3. (left top)

Fig. 23. Object Oriented Eclecticism, result group 4. (left bottom)

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[51] This workshop fits within the larger agenda of Object Oriented Ontology, a trend in philosophy based on objects rather than humans. My interest in this lies with the practice of design and coding, not with philosophy. For an introduction into Object Orientation for architecture, see Graham Harman, "Objects and Architecture" in Marie-Ange Brauer and Frederic Migayrou (eds.), *Archilab 2013: Naturalizing Architecture* (2013). pp. 234-243.

[52] Most instructional manuals that introduce 'creative coding' contain this argument; it is also prominently used by the contributors to John Maeda's book *Creative Code* (2004). pp. 113-114.

[53] Benjamin Aranda and Chris Lash, *Tooling,* Pamphlet Architecture, 27 (2006).

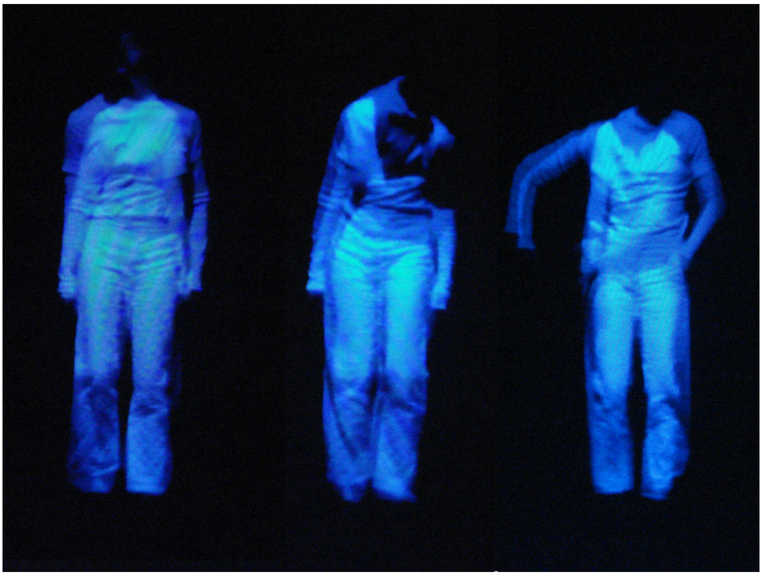
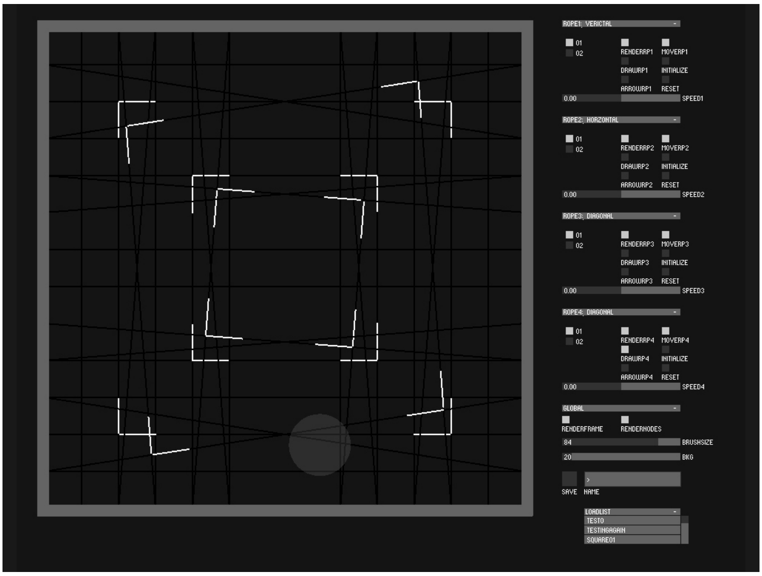


Fig. 24. Performing Qualia 2, photograph of dancers.



ROPE1; VERICTAL
01
02
RENDERRP1
MOVERP1
DRAWRP1
INITIALIZE
ARROWRP1
RESET
ROPE2; HORZONTAL
01
02
RENDERRP2
MOVERP2
DRAWRP2
INITIALIZE
ARROWRP2
RESET
ROPE3; DIAGONAL
01
02
RENDERRP3
MOVERP3
DRAWRP3
INITIALIZE
ARROWRP3
RESET
ROPE4; DIAGONAL
01
02
RENDERRP4
MOVERP4
DRAWRP4
INITIALIZE
ARROWRP4
RESET
GLOBAL
RENDERFRAME
RENDERNODES
SAVE
NAME
LOADLIST
TESTO
TESTINGAGAIN
SQUARE01

0.00 SPEED1

0.00 SPEED2

0.00 SPEED3

0.00 SPEED4

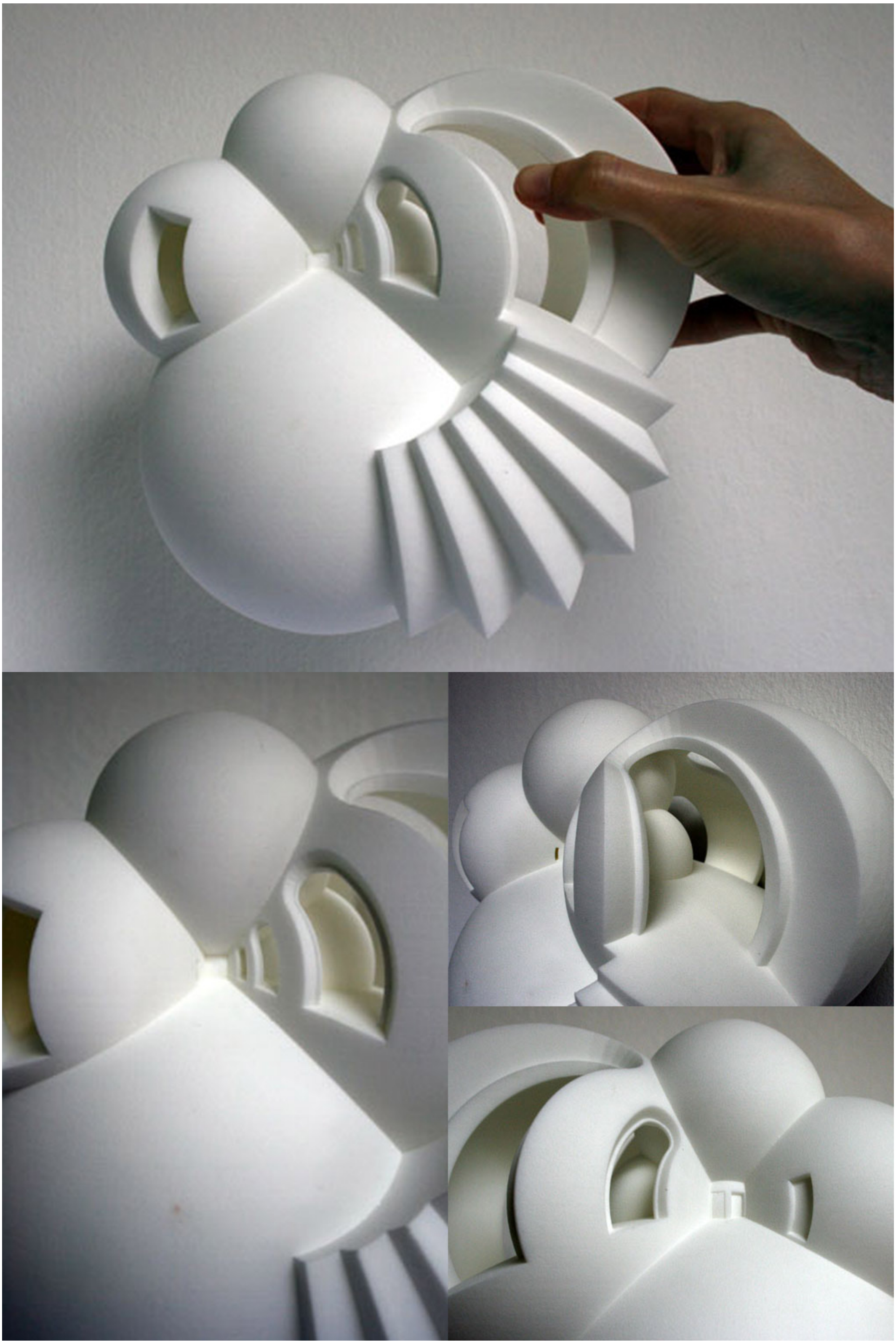
84 BRUSHSIZE

20 BKG

Fig. 25. Performing Qualia 2, performance software.

process of making a tool gradually unravels the design problem at hand. Furthermore, coding your own design tools does not generally start from a blank canvas but is instead based on examples, code snippets, add-ons and libraries developed by others or by yourself in the past. The environments in which you code are obviously tools themselves, with their own assumptions, limits and potential, programmed by someone else.

In collaborative projects I have used code as an enabler, making algorithms for communicating between various partners involved in the design process. In such a case there is a clear distinction between the users and the maker of the tool. Between 2010 and 2011, I collaborated with the design collective Noumenon and dancer and choreographer Dolores Hulan on *Performing Qualia,* a dance performance that used an elaborate stage set-up to fuse the motion of two dancers with the abstract mechanical motion of a machine (Figs. 24-25). A large transparent mirror was placed at a 45° angle between a dancer on a stage and a dancer lying on the ground and, depending on the light set-up, either one or both of the dancers were visible, visually fusing both bodies. Above the dancer on the ground was a large stage-machine composed of four loops of ropes on a number of pulleys, driven by large industrial motors. The ropes were fluorescent and partially painted black so that when moved, different patterns could be formed. My role in this project was to write code to test and prototype different patterns and sequence different movements and communicate with the sound and light set-up. This was broken up into two tools: one for prototyping and rehearsing and one for performing.



SPHERE INVERSION: CODE AS LENS

Fig. 26. Sphere Inversion, 3D printed artwork, multiple photographs. For Patrick Labarque, 2011. (photographs by Tiemen Schotsaert)

Computers can only operate on computable entities which are essentially encoded as binary numbers; as such, computation works only with quantifiable data[54]. When using computation in design, material and spatial entities are captured or encoded into the quantifiable language of code. Code functions as a specific lens for looking at and describing material and spatial entities. In architecture and design, these descriptions are often geometric in nature and limited to describing the form of spaces and artefacts, although they can be extended to incorporate other quantifiable aspects. Code as a lens relies on data, which are essentially binary, discrete and finite: although all data are eventually captured in binary form, they are organised in hierarchies of data types – Boolean, integer numbers, floating point numbers, strings, points, vectors and matrices – and stored in file-types that encode data according to a certain convention. In order to capture continuous phenomena, which can be spatial, material or experiential, they are sampled at discrete intervals; digital data always have a resolution – dots per inch, bit depth, sample rate, frame rate etc.

In 2011, I was approached by Patrick Labarque, architect, artist and a former head of the Mixed Media unit at Sint-Lucas, with some questions on fabricating a piece of artwork he had been working on in the 90s.[55] The site-specific work consisted of a *sphere inversion* of an interior space, to be installed in the exact spot of the inversion (Figs. 26-28). A sphere inversion is a three dimensional mathematical transformation of space based on a sphere, where all points outside of the sphere before transformation end up inside the sphere after transformation, and vice versa. The points on the surface of the sphere remain in position, whereas points on infinity end up exactly in the centre of the sphere after transformation. In the past, Patrick had exported all the coordinates from a mesh in an early version of 3DS Max, calculated the transformation in a spreadsheet and painstakingly reassembled them as a mesh afterwards, which was only feasible for a small number of points. Rather than fabricating the low resolution version, I showed him how to model the same transformation in Rhinoceros3d and Grasshopper and agreed to help him make a 3D printed version of the artwork for an exhibition.

---

[54] See Casey Reas and Chandler McWilliams, *Form+Code in Design, Art, and Architecture*, (2010). p.15.

[55] Patrick had already retired when I started teaching, but I met him for the magazine we published in 2010 when we interviewed three former heads of the Mixed Media unit, See Carl Bourgeois, *Om te weten waar je naartoe wil... An conversation with Paul Gees, Lode Janssens & Patrick Labarque,* in Carl Bourgeois, Pieter-jan Ginckels and Corneel Cannaerts (eds.),*MMMAG*, (2010), pp. 08-12.

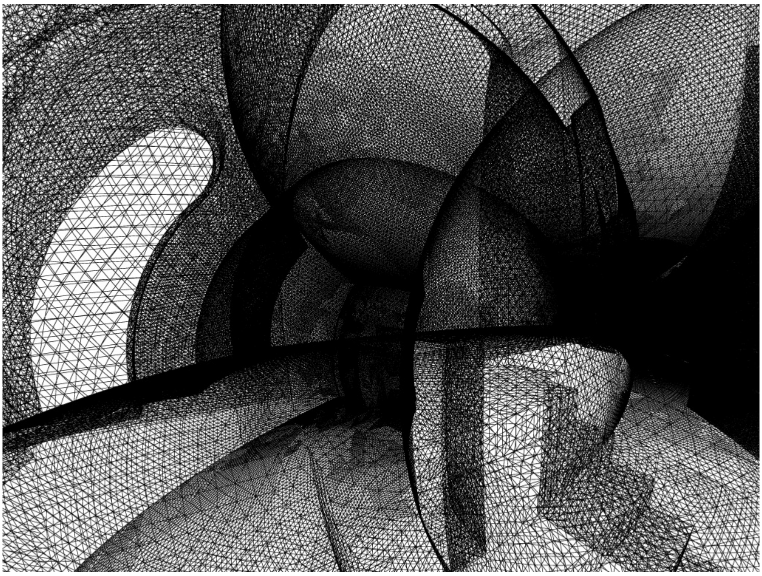


Fig. 27. Sphere Inversion, drawing. For Patrick Labarque, 2011.

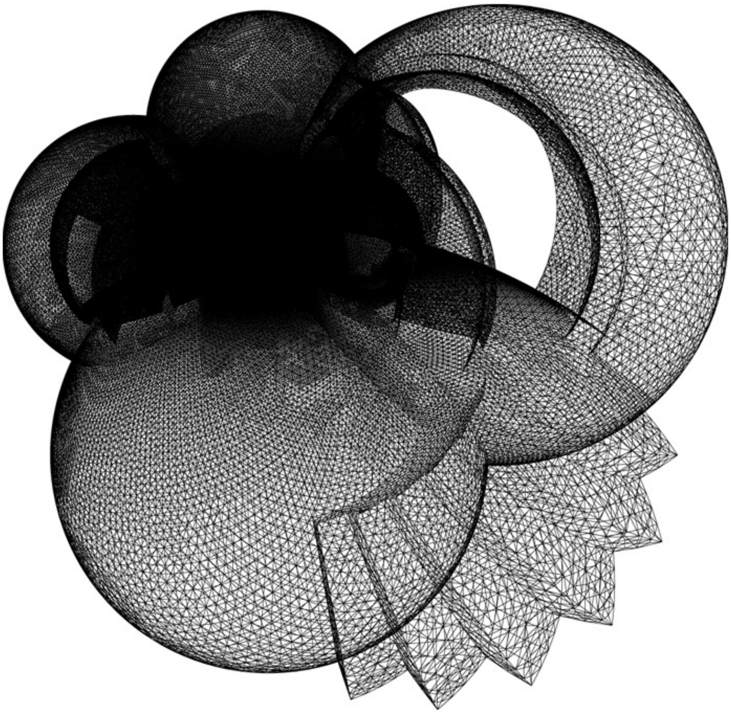


Fig. 28. Sphere Inversion, drawing. For Patrick Labarque, 2011.

When modelling the interior surface of a wall, we approximate it with a rectangle, basically defined by the four corner points; although we know this to be an approximation, it works fine in most applications. But the reduction of a continuous surface to four discrete points is obviously not enough when applying a sphere inversion, as the transformation turns the planar surface of the wall in a curved non-planar surface in the inversion. A first workaround was found in finely subdividing the mesh so that each surface would have a few hundred vertices and faces. This approximation was acceptable and worked for realising the artwork, but was hardly efficient. In order for the parts of the model close to the sphere to be detailed enough not to have the visible triangles of the mesh, the overall mesh needed to be finely subdivided and was over-detailed in other places. This pushed the number of vertices to almost 800,000, which was the limit of the technology used to fabricate the artwork.

Afterwards, I refined the algorithm for this specific application by reversing the idea of evenly subdividing the mesh before transformation and ending up with a final unevenly defined mesh. The mesh was subdivided by evenly distributing points on the surface of the sphere and intersecting the untransformed mesh with rays connecting these points to the centre of the sphere. The parts of the model close to the sphere would intersect with more rays and, as such, be more refined than parts far away, which results in an evenly divided mesh after transformation.

While encoding the algorithm in a parametric model was rather straightforward, the importance of this work for me was that it uncovered the assumptions we make when modelling an interior space digitally and showed the discrete characteristics of code as a lens. By using technology, digital modelling, for a rather unconventional application, sphere inversion, this project reveals how a technology implies, or at least promotes, a certain ”view” of the world. As the second workaround shows, taking control of the underlying algorithm through parametric modelling allows for actively changing that view.

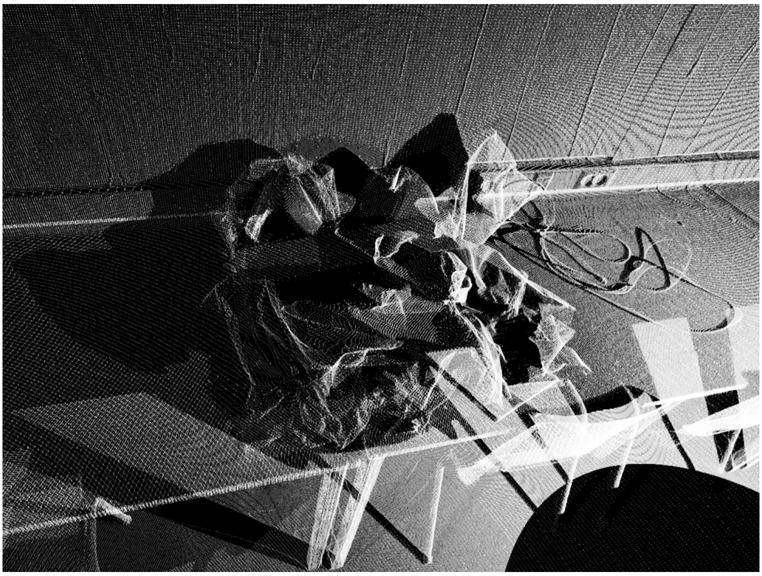


Fig. 29. MMlab, 3D scan, plastic wrapping material, cables.

ACKNOWLEDGMENTS

MeshUp was presented at dorkbot Gent on 21 November 2008.

D11 is part of the Gothic Works series and was designed for Wim Delvoye.

Object Oriented Ecclecticism, was organised by Gilles Retsin, Isaie Bloch and Corneel Cannaerts.

Performing Qualia II: was conceived by Dolores Hulan and Carl De Smet (Noumenon).

Sphere Inversion was developed for Patrick Labarque.

REFLECTION

As Mark Burry's questionnaire[56] outlines, there are different ways of using code in design practice, and different appreciations for the importance and of code in design practice, even with well-known practitioners. Furthermore, my use and understanding of code is still changing and unfolding, so what follows are tentative conclusions regarding how I, as a practitioner, understand code at the moment of writing.

Making the decision to start coding as a designer is both frightening and exciting and takes considerable amount of effort. As hinted at in the text, tinkering with code has had a destabilising effect and left its mark on my understanding of design and architecture. Not only has it taught me ways in which productivity gains can be made, it also has deepened my systemic understanding of architecture and design. Code is not only a technical means to and end but a conceptual and discursive medium that supports understanding. Through using code as a design medium, I have come to better understand variation and repetition in design, the relationship between part and whole and it has opened up worlds of ornamentation and detailing banned by my architectural education[57]. Furthermore, it has allowed me to explore aspects and layers of space, such as sound, time and motion, which were beyond the confines of traditional or standard software tools.

Sketching, tooling, steering and tinkering are all attempts at describing the use of coding in the design process. While these metaphors are each useful in describing an aspect of coding, none describes the use of coding in all its intricacy. Because of its re-usability and fluidity, code as a design medium can switch between these different modes of informing the design process. The fundamental difference code has from most other design media, is the layered-ness of the provided feedback and the simultaneous working on an instance of the design at hand and the logic that drives that design.

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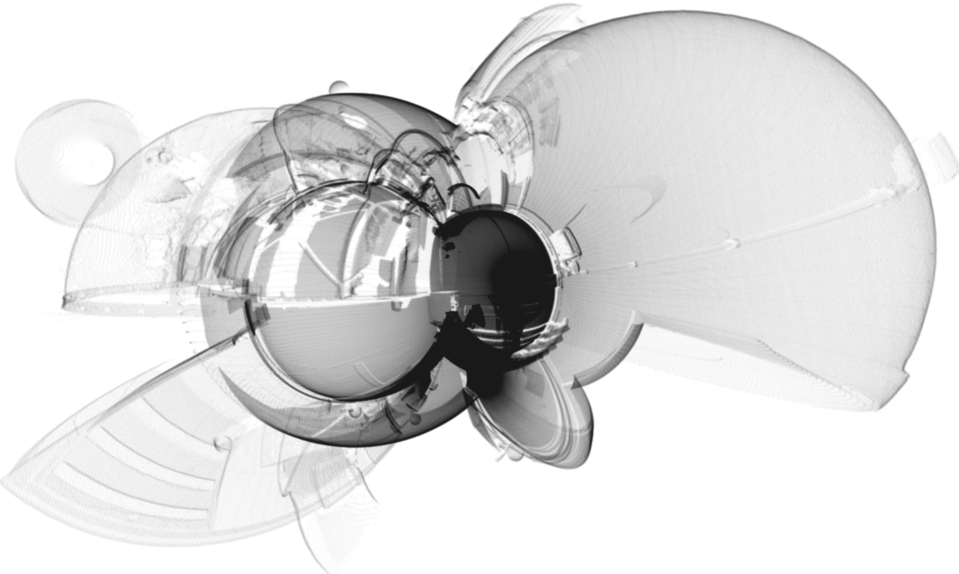
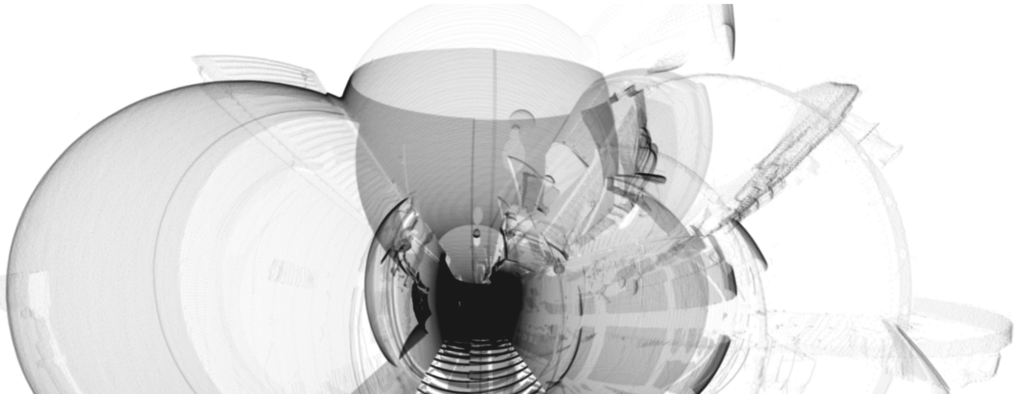
[56] See Mark Burry, *Scripting Cultures: Architectural Design and Programming*, (2011). pp. 33-70.

[57] During my architectural education there was no interest in such issues within design; architectural design was limited to questions about program, context and construction.





EPILOGUE: A SIMILAR VIEW

Fig. 30-31. MMlab, 3D scan, sphere inversion. (left)

I was reminded of the sphere inversion a year later when we made a lidar scan[58] of *Low Tech Adaptable,* an adaptable ceiling installation we had just completed within the hallway of the MMlab (Figs. 26-32). Lidar is a technology that uses a laser and a rotating mirror mounted in a rotating case to scan an environment, measuring the distance to the central point at discrete intervals and constructing a point cloud. The technology allows for highly exact measurements, capturing environments including all their everyday details, and through associating a colour with each point it is also a technique which produces high definition captivating imagery. This lead architects, designers and artists to approach lidar scanning as a means for exploring spatial phenomena rather than just measuring.[59]

Orbiting, zooming and panning through the point cloud of the scan of the MMlab reveals a precise and seemingly unbiased view. As this scan was conducted without preparation, it captured the MMlab in its everyday disordered state, making no difference between the walls that make up the corridor and the collection of models on the shelves, the clumsily post-fit electrical wiring and the dust bins and chairs. A crumpled sheet of plastic shows some strange deformations, as the technology apparently struggled with its reflection and transparency. As a typical scan would take about ten minutes, three were needed to map out the installation on the ceiling, it captures more than just a moment but condenses about half an hour into one image, as is revealed by the ghostly image of a curious student in the hallway.

The reason I refer to this here is that the view revealed by this technology is similar to the one needed for the sphere inversion – elements close to the scan will be registered in high detail, elements far away from the scan will be less detailed and elements obscured from view by the scanner will leave a blind spot in the point cloud. This is typically seen as a weak point of the technology, and is overcome by taking multiple scans, each taking considerable amount of time, and putting beacons in the scene in order for different scans to be joined afterwards. For application in a site-specific sphere inversion, a lidar scanner would be an ideal input device, as they both look at the world through a similar lens.

Fig. 32. MMlab, 3D scan, view of the hallway. (next page).

[58] Lidar stands for Light and Radar, see http://en.wikipedia.org/wiki/Lidar (consulted on 26/01/2015).

[59] The most notable is Scanlab Projects. Their work is widely published; among others is Bob Sheil (ed.), *High Definition: Zero Tolerance in Design and Production* (2014). See also http://scanlabprojects.co.uk/ (consulted on 04/12/14).

CASE 2.2: NESTED SIMULATIONS

Encoding Material Behaviour | 2011- 2013 | MMlab | CITA

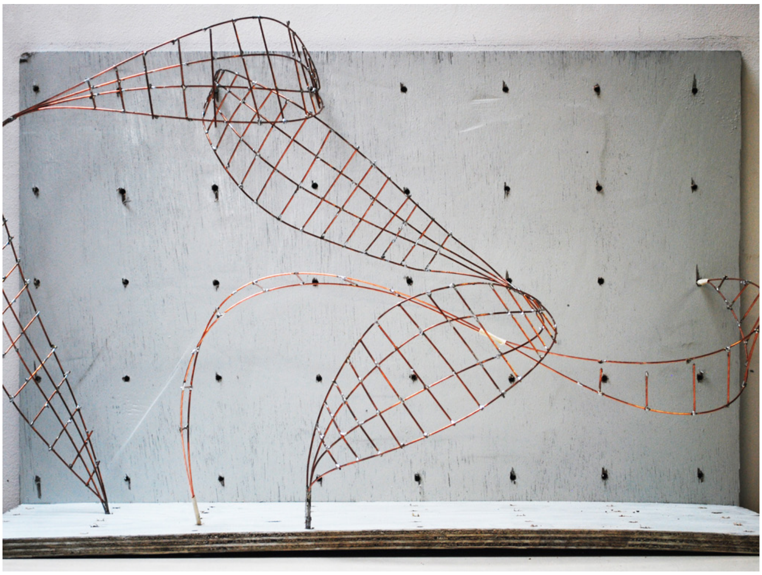


Fig. 33. Form Finding, bending metal rods.

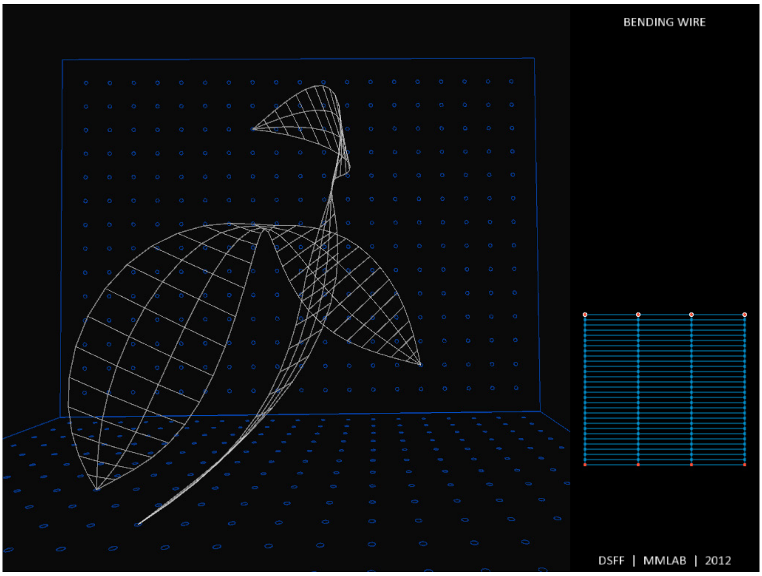

BENDING WIRE
DSFF | MMLAB | 2012

Fig. 34. Form Finding, bending metal rods, simulation.

SIMULATING MATERIAL BEHAVIOUR

As a design medium, code requires material and spatial quantities and qualities to be captured in computable and thus numeric elements. Standard drafting and modelling software include limited geometric tools that describe only the external form of material and spatial entities. Modelling or drafting in this software proceeds linearly, and explicit numerical values are determined during the modelling process. Exploring variations in standard modelling software requires either back-tracking to a previous, less defined variant or explicitly manipulating the geometric description.

Parametric associative modelling separates the input of numerical values from defining the associations and computational logic connecting these inputs to a desirable design output. As parameters can be altered after their associations are defined, this opens up for non-linear ways of exploring variants in the design process. Depending on how many parameters drive an associative definition, the parametric model can be seen as a tool for navigating a multi-dimensional solution space. Design advances by either altering the associations and thus the underlying algorithm or altering the input parameters.[60]

Parameters are not limited to the description of form and can encode anything that can be captured in numerical descriptions. A limit common to most parametric associative models is that they do not allow iteration: that is, a solution is calculated based on input parameters and the results of these calculations cannot be used again as input.[61] Even if design can progress in a non-linear way, a solution is computed one-directionally and procedurally. In most parametric models, this can be overcome by add-ons that allow text-based scripting or that are specifically designed to enable iteration.

Simulations extend digital models to capture material and spatial behaviour in addition to form, and as behaviours unfold in time, simulations need to explicitly encode time. In order to simulate continuous material behaviours, digital simulations will approximate material as discrete elements - particles, springs and finite elements - and they also have a discrete unit and resolution in time - clock

[60] See Robert Woodbury, *Elements of Parametric Design* (2010) for an in-depth discussion on solutions spaces, pp 275-287.

[61] In Grasshopper and Generative Components using output back as input is not possible; in visual programming packages aimed at media and animation such as vvvv, pure data and max/msp, this is possible because they explicitly define time, waiting one time frame for passing output back to an input.

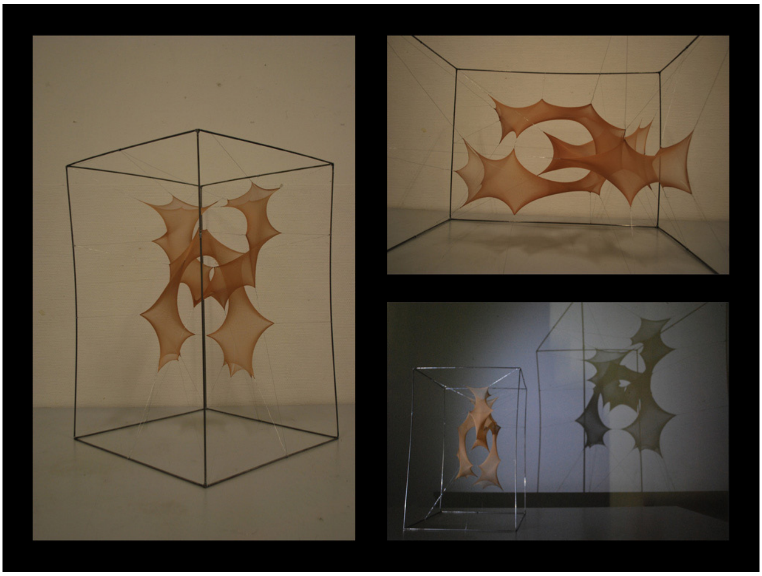
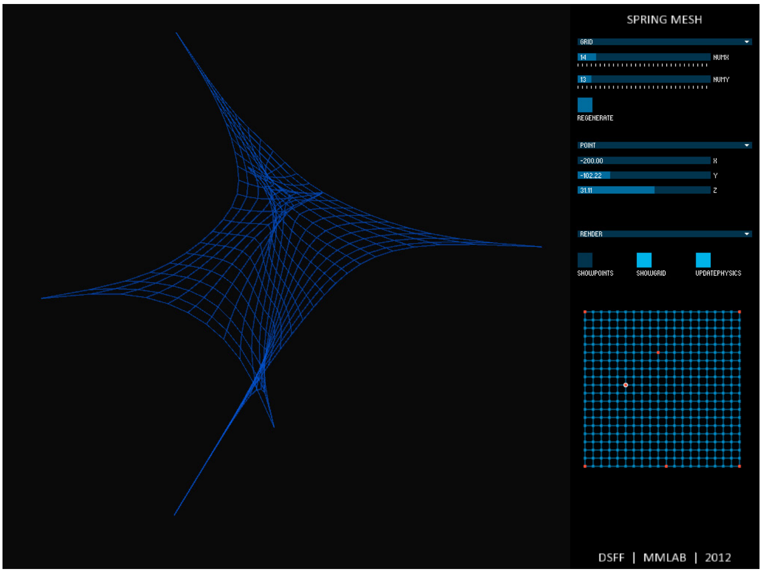


Fig. 35. Form Finding, tensile structures.



SPRING MESH

GRID

14 NUMX

13 NUMY

REGENERATE

POINT

-200.00 X

-102.22 Y

31.11 Z

RENDER

SHOWPOINTS

SHOWGRID

UPDATEPHYSICS

DSFF | MMLAB | 2012

Fig. 36. Form Finding, tensile structures, simulation.

cycles, ticks, frames, seconds and iterations - depending on the simulated behaviour.

Even more explicit than other design media, physics simulations make up a *design world*, as identified by Mitchell[62] – a box-like world in which the rules of the simulation can unfold in time. Unlike in explicit geometric modelling or even associative parametric modelling, the elements in this simulated design world are encoded in such a way that they can negotiate their behaviour within an environment, and with forces and other elements working on them. Design becomes a matter of setting up an environment, conditions and material properties and letting the simulation run – if necessary, steering the simulation while it is running. In other words, through simulations, the digital model gains in agency and becomes an active contributor in negotiating a design solution.

The case that follows is based on three projects that explore material simulation as a design medium on multiple scale levels. In all three projects, material models and prototypes were important for informing, steering and testing these simulations. While the three projects use different kinds of physics simulations, all three simulate quantifiable material properties as mass, elasticity and forces that work on these such as gravity, friction and collisions as a way to inform design.

MATERIAL AND DIGITAL FORM FINDING

Form finding[63] is a design strategy where form emerges out of the behaviour of a material set-up rather than form being imposed on matter. Form finding relies on material behaviour and does not require a computer, examples of form finding pre-date the development of digital technology. Well-known examples are Gaudí's hanging model for the Colonia Güell Chapel[64] and the many experiments undertaken by Frei Otto[65]. Through using physics simulations, digital models can be used to simulate such material behaviour, substantially speeding up the process of iterating design ideas, as is showcased by the work of Phillippe Block[66] and Achim Menges.[67]

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[62] William J. Mitchell, *The Logic of Architecture: Design, Computation, and Cognition* (1990).

[63] See Neil Leach, Digital Morphogenesis, in *Architectural Design* (2009). p.32-37

[64] This is widely published see amongst others: Santiago Huerta, *Structural Design in the Work of Gaudi*, University of Sydney Architectural Science Review Volume 49.4,(2006), pp.324-339. and Jane Burry, Peter Felicetti, Jiwu Tang, Mark Burry and Mike Xie, *Dynamical structural modeling, A collaborative design exploration International Journal of Architectural Computing* vol. 3 - no. 1 (2005), 27-42

[65] Frei Otto and Bodo Rasch, *Finding Form: Towards an Architecture of the Minimal* (1996).

[66] Philippe Block runs the Block Research Group at ETH; see http://block.arch.ethz.ch/ (consulted on 12/11/2014).

[67] Achim Menges runs the Institute for Computational Design at the University of Stuttgart; see http://icd.uni-stuttgart.de/ (consulted on 12/11/2014).

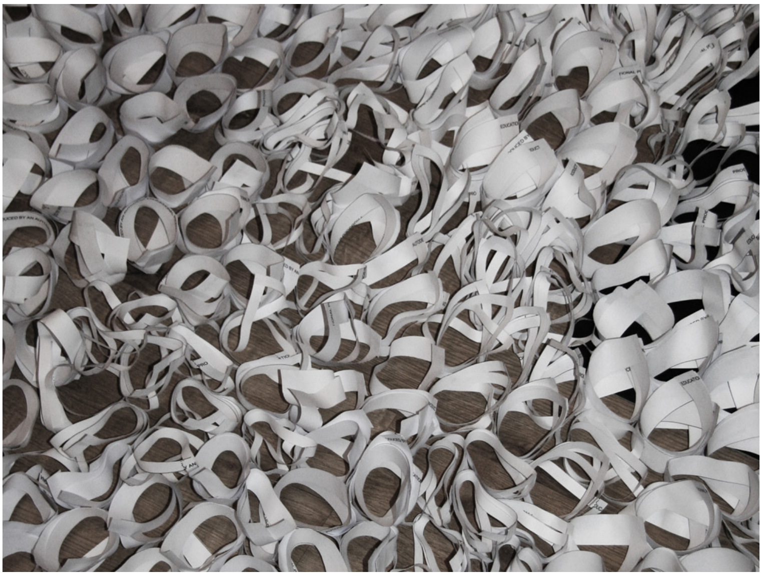
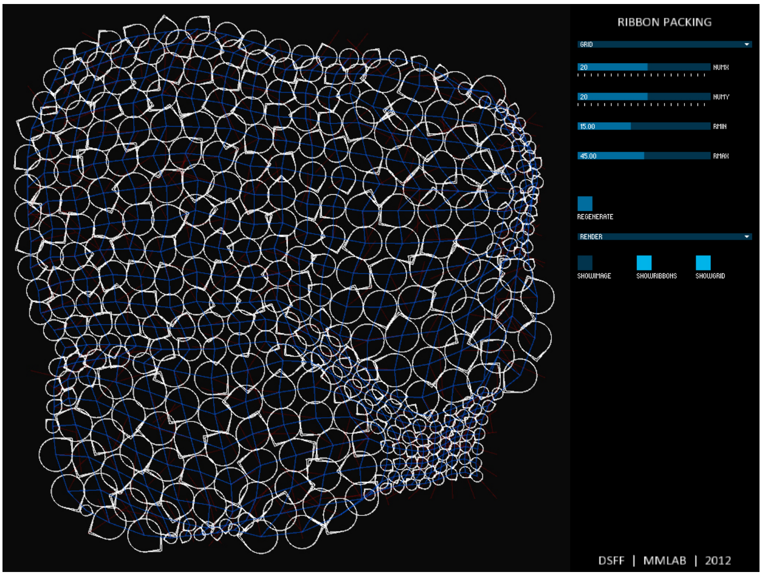


Fig. 37. Form Finding, aggregate weaving.



RIBBON PACKING
GRID
REGENERATE
RENDER
DSFF | MMLAB | 2012

NUMX 20

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☐ SHOWIMAGE ☑ SHOWRIBBONS ☑ SHOWGRID

Fig. 38. Form Finding, aggregate weaving, simulation.

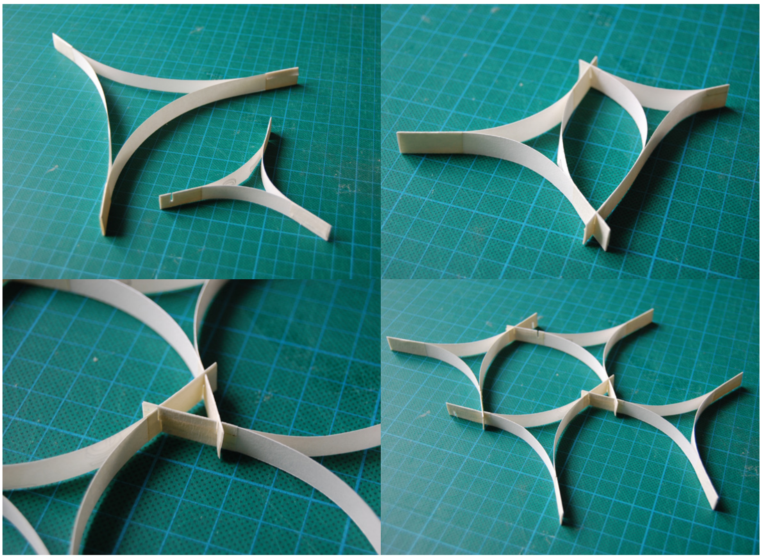
As I described in the previous chapter, materials have properties and behaviours that can play an active role within the design process, both when used for making scale models and prototypes and when building on a scale of 1:1. The *Material and Digital Form Finding* project was conceived as a research project at the MMlab and conducted in a workshop in 2011 (Figs. 33-38). A number of material behaviours were selected and explored for their design potential. The materials proposed contained tensile structures, elastic and plastic bending of metal rods, vacuum forming, moulding and casting, weaving and forming. Within these themes, a number of material experiments were conducted, and each of these material experiments was focussed on form finding: that is, it explored the formal potential of a material or principle, the parameters that drive the behaviour of the material and asks how we can design with this potential by setting up the conditions of the simulation? Do the where materials showed behaviours not anticipated?

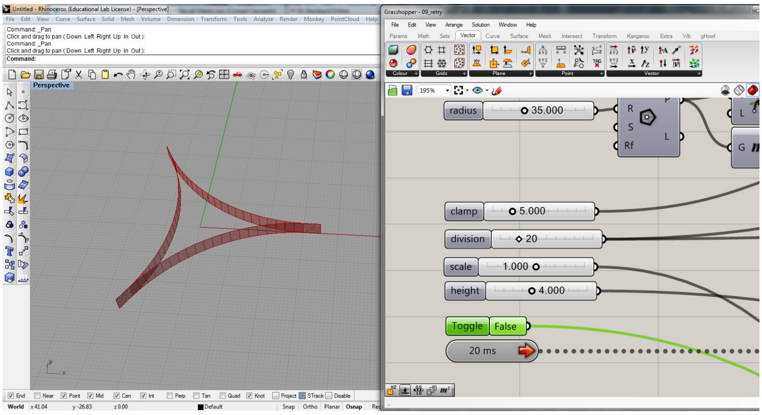
The workshop resulted in a series of small design tools I wrote in Processing that allows exploring the material simulations. Most of the tools rely on a particle spring model: particles, defined by position and a certain mass are connected by springs defined by a strength, rest length and damping factor; other forces such as gravity or attraction and repulsion can be applied to the particles. Particle spring models have been used in design computation, especially in form finding hanging chain models and tensile structures. One of the first projects to explore this idea was Axel Killian's Cadenary project[68] which linked form finding of catenary structures to digital fabrication. A more recent and rigorous exploration of said simulations can be found in the work of Sean Ahlquist, who explores combinations of bending active and tensile structures.[69]

Every frame, the simulation evaluates all the forces working on each particle and calculates a new position for said particle. The simulation can be altered in multiple ways: either altering the set-up of the simulation, its particles and the connections between them or by altering the parameters of the simulation – the forces working on the particles. If the simulation can be calculated at a fast enough

[68] See Axel Kilian's CADenary tool, http://designexplorer.net/newscreens/cadenarytool/cadenarytool.html (consulted on 15/11/14) and his paper on the project: Kilian, Axel. "Linking Hanging Chain Models to Fabrication", *Fabrication: Examining the Digital Practice of Architecture,* Proceedings of the 23rd Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) and the 2004 Conference of the AIA Technology in Architectural Practice Knowledge Community, Cambridge (Ontario) 8-14 November, 2004, pp.110-125.

[69] See Sean Ahlquist's work in "Physical Drivers: Synthesis of Evolutionary Developments and Forec-Driven Design"in Achim Menges, *Material Computation: Higher Integration in Morphogenetic Design Architectural Design*, 1st ed. (Wiley, 2012), pp. 60-67.





Untitled - Rhinoceros (Educational Lab License) - [Perspective]
Grasshopper - 09_retry
Perspective

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Command:
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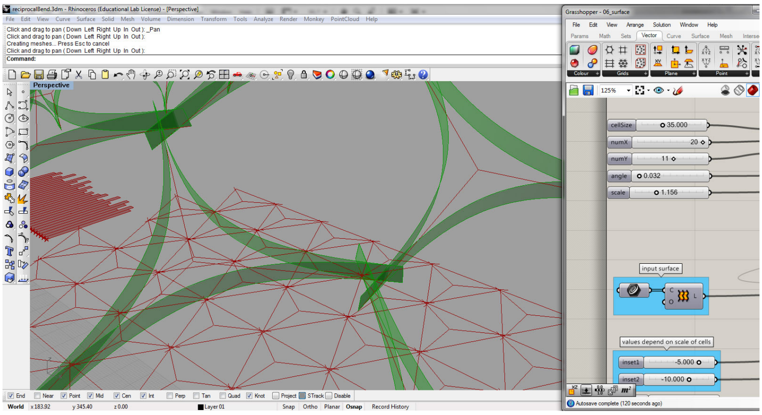
radius 35.000
clamp 5.000
division 20
scale 1.000
height 4.000
Toggle False
20 ms



reciprocalBend.3dm - Rhinoceros (Educational Lab License) - [Perspective]
Grasshopper - 06_surface
Perspective

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Click and drag to pan ( Down Left Right Up In Out ): _Pan
Click and drag to pan ( Down Left Right Up In Out ):
Creating meshes... Press Esc to cancel
Click and drag to pan ( Down Left Right Up In Out ):
Command:
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cellSize 35.000
numX 20
numY 11
angle 0.032
scale 1.156

input surface

values depend on scale of cells

inset1 -5.000
inset2 -10.000

Autosave complete (120 seconds ago)

Fig. 39-41. [Re]Active Prototypes: Bending Strips Prototype.

frame rate, the discrete steps of the simulation give the illusion of a continuously active model, updated in ”real time”. Instead of drawing or defining form, form is found by setting up a system and letting it play out over time.

The research goal was trying to capture the material behaviours in code, seeing whether secondary effects would also be visible in the translation from material form finding to the digital simulations. While the intention was never to have a perfect matching simulation of said phenomena and behaviours, it was to forward the design and use the strengths of both digital and material form finding to complement each other. Whereas making a material model and prototype takes a considerable amount of energy and time, the digital simulation affords a faster exploration of variants.

[RE]ACTIVE PROTOTYPES

In the *form finding* project, where the material experimentation was the driver and led me to developing digital simulations, the relation between material and digital models was one way, and the development of the digital design tools was limited to one iteration. This research project was further developed in the *(Re) Active Prototypes*, which built on the previous work and extended the relationship between material and digital to be more iterative and cyclical by also including digital fabrication[70] (Figs. 39-53). The material behaviour was explored through digital simulations and material prototypes. The project builds on the previous form finding project and a number of active material behaviours selected – bending, inflating, stretching, twisting, refracting – and during the workshop we developed different spatial propositions through exploration of the material and spatial potential afforded by these behaviours.

Since the project required digital fabrication, I decide to base the workflow on Rhino and Grasshopper as a more robust modelling environment, which was further extended with *Kangaroo,* a physics simulation add-on for Grasshopper; *KingKong,* an extension that allows for folding to be simulated and *Anemone*, which allows recursion within the Grasshopper environment.[71] The proposals all

---

[70] In the next chapter, I will deal more explicitly with digital fabrication.

[71] All of these overcome the procedural limitation of Grasshopper and allow elements to negotiate behaviour over time; they can be downloaded from http://www.food4rhino.com/ (consulted on 07/09/2014).

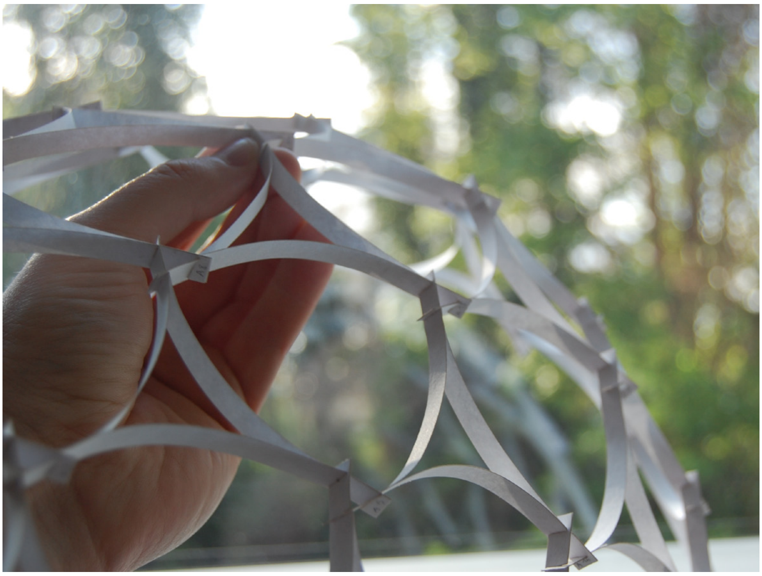


Fig. 42. [Re]Active Prototypes: Bending Strips Prototype, paper model.

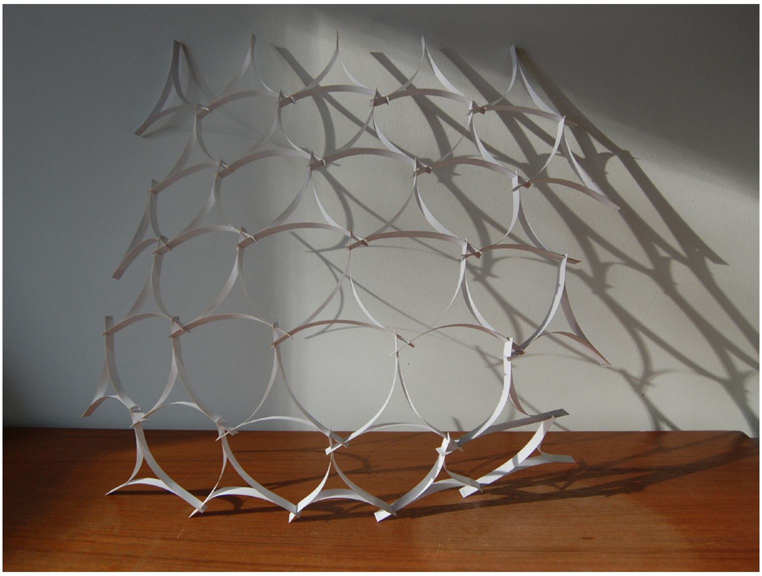


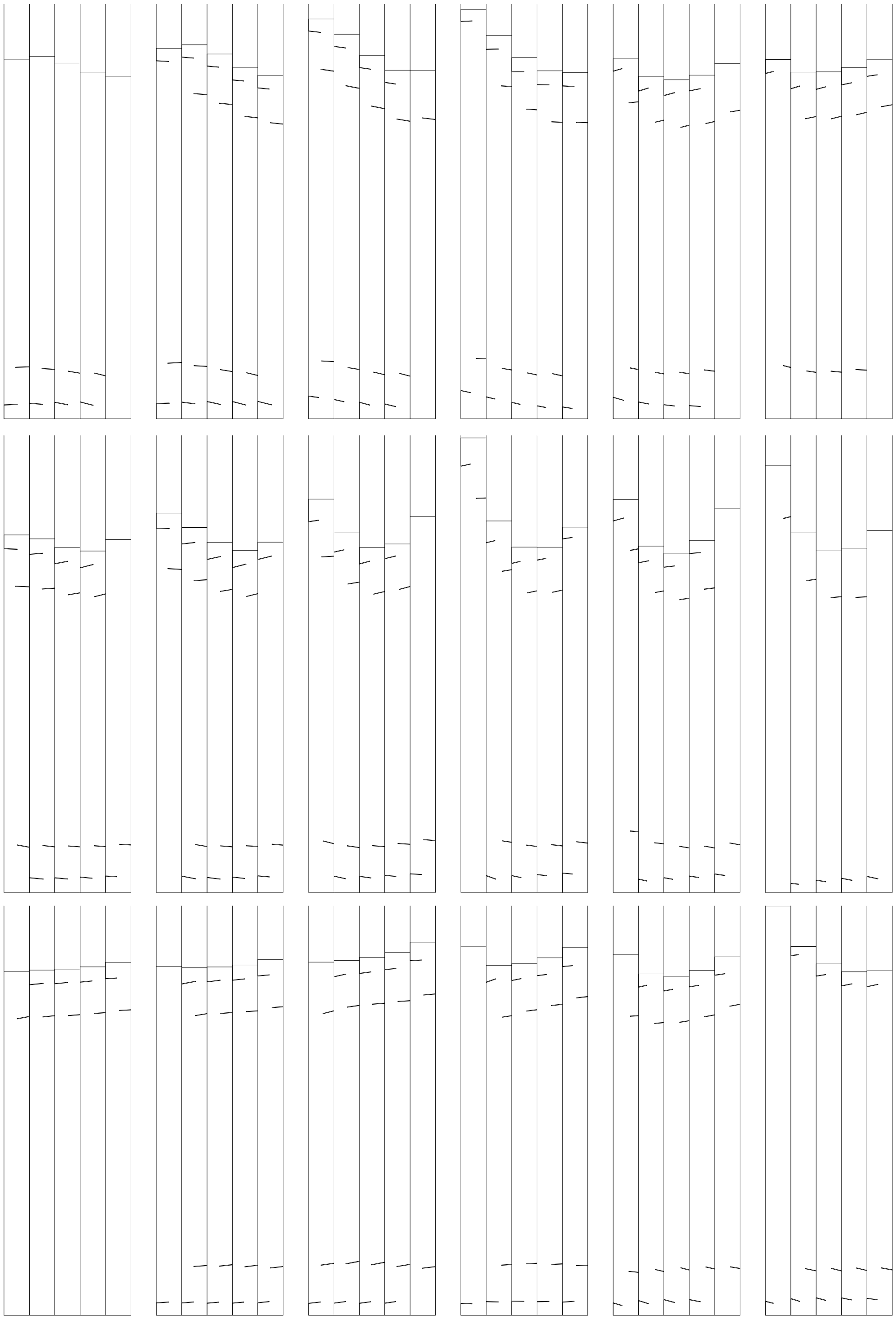
Fig. 43. [Re]Active Prototypes: Bending Strips Prototype, paper model.

started from an active material behaviour, but how and where this behaviour was played out differed; a large part of the work consisted out of manually making prototypes, exploring fabrication constraints and capturing the behaviour into a digital simulation. This resulted in a number of *[re]active prototypes*, each exploring an active material behaviour through an iterative cycle of material and digital design exploration.

Reciprocal Bended Strips (Figs. 39-44) - for this project we collaborated with V.A.C machines, a company specialised in machines for working steel plates. We worked with paper models testing different design strategies that might be translated to steel sheets. After exploring folding and rolling paper, discovering that paper can be formed into single curved surfaces, we worked with bending the paper in order to give it more strength. Anticipating the limits of fabrication, the size of the laser cutter for the steel sheets, and limiting the total amount of material, we decided on working with strips that could be nested on the cutting plane of the laser-cutter.

When bent elastically the strips have the tendency to spring back to their original shape, by clamping three strips in one triangular component, they remain their bent form. Trying a similar component with four strips would make the strips twist and lose their strength. A digital simulation was made using kangaroo, simulating the bended curve, by varying the length of the strips, the clamp length, and the bending forces. Through iterative material and digital prototyping the values for the simulation of paper and metal strips were derived.

Different ways of connecting components were investigated, finally settling on a reciprocal slot connection. In a reciprocal connection three component support each other: each end of the components had two slots, one to support the next component and one to rest on the previous component. With just straight slots this would result in a flat triangular grid of components, but by varying the lengths of the strips and the angles of the slots could be formed into a curved surface. In the final paper prototype the components where projected on curved design surface, and the form of all components was simulated.



After the form of the components had settled, a parametric model was made to subtract the appropriate slots from the components. The unrolled components ready for cutting show a relative efficient material system, a complex surface can be made from simple rectangular strips and all the complexity is encoded in the connecting slots. While in the paper model the components could be slotted together easily, a metal prototype required the last of the three components to be put in place to have a triangular slot.

Fig. 44. [Re]Active Prototypes: Bending Strips Prototype, cutting strips.
(left).

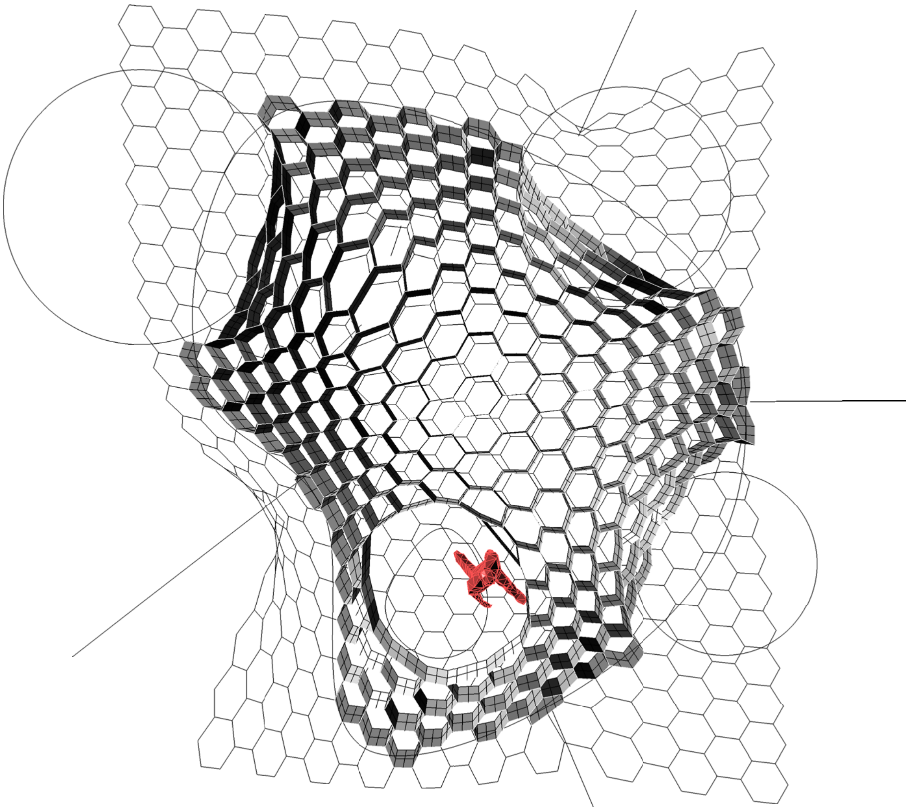
This design experiment shows the combination of digital modelling: the individual component was designed using a form finding simulation, the overall form of the surface was modelled in Rhino, whereas the detailing of the slots was done through an associative model in Grasshopper. What these different models show is how aspects material and fabrication can be encoded into a digital design model: the bending behaviour of the material, the limits of the fabrication machine, and the logic of assembly of the slots.

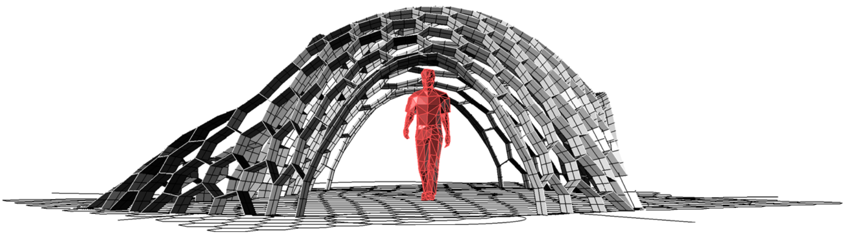
Folded Strips Prototype (Figs. 44-50) - Although the form of the components was derived from a material simulation in the *Bend Strips Prototype*, the overall form was modelled as a surface in Rhino. For the *Folded Strips* design experiment, we explored a physics simulation to derive the overall form of a pavilion. The design simulated a hanging chain model based on hexagonal grid, the grid can be deformed to allow for denser or less dense areas. The grid does not consist of hexagonal cells but is folded from continuous strips.

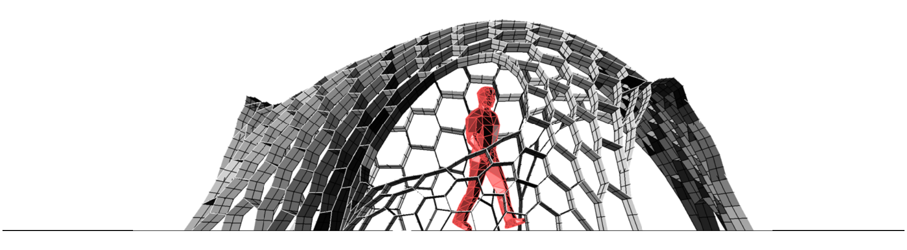
The ground plan of the pavilion is defined by a curve and a number of circles define openings in order to accommodate entrances to the pavilion and an opening in the roof. All cells that are intersecting the curve and not within the circles are anchored to the ground plane in the simulation. The simulation is based on a particle spring-model as discussed before, all the points of the grid are encoded as particles, whereas all the lines are springs, the simulation works applying a gravity force on all the particles. The design can be altered while the simulation is running, by changing the parameters of the simulation, or altering the outer curve, or the circles defining the entrances or the density of the grid.

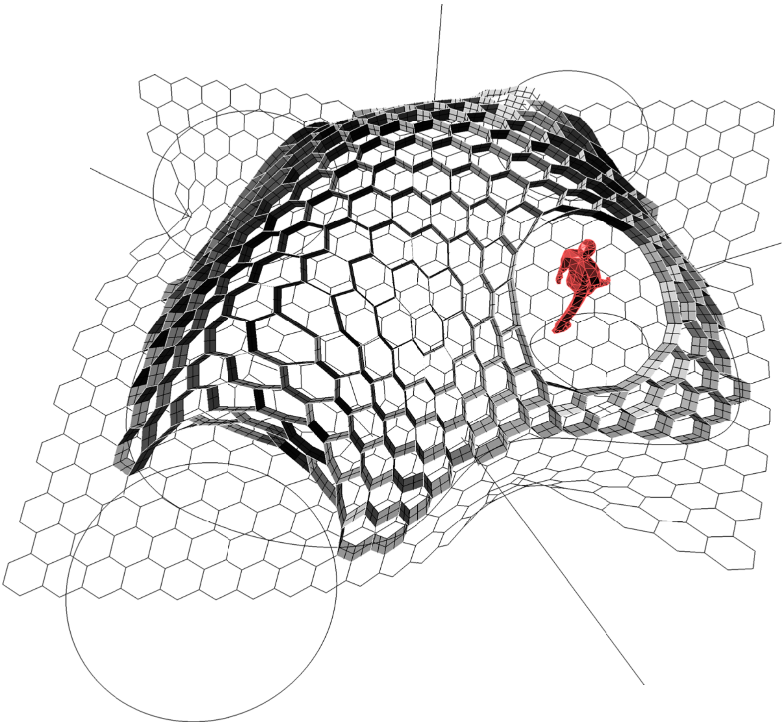
Fig. 45-50. [Re]Active Prototypes: Folded Strips Prototype, digital model, assembly plan.

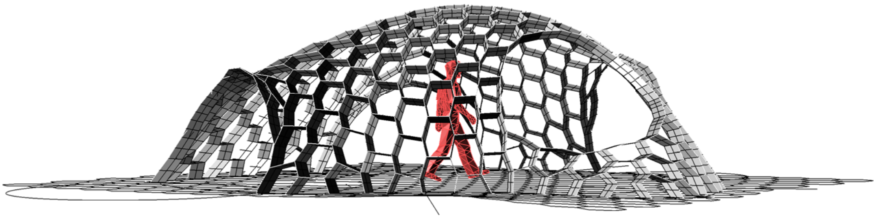
After the final shape is set the grid is giving a thickness, turning

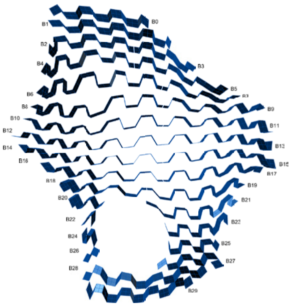








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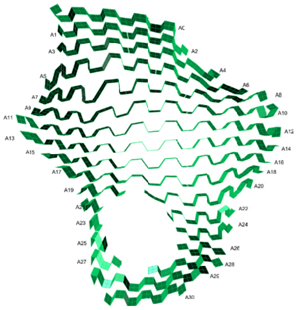
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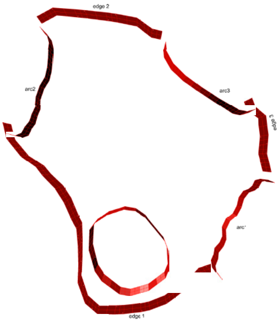
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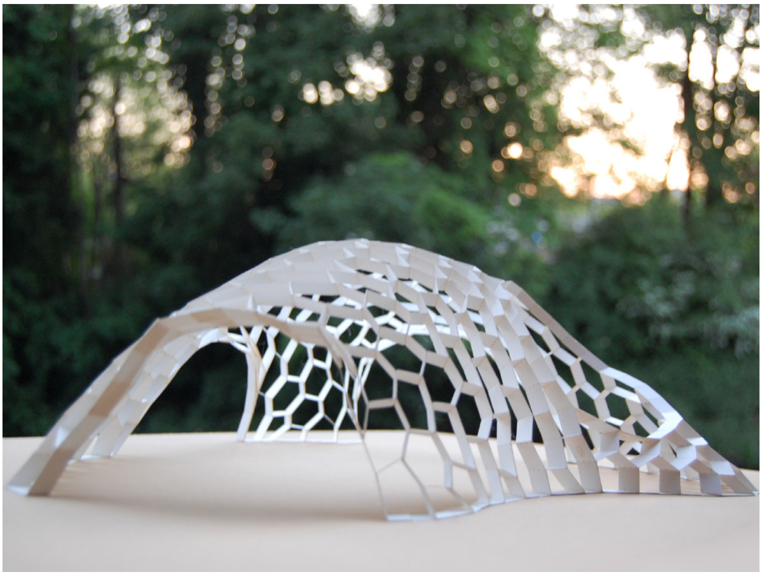


Fig. 51. [Re]Active Prototypes: Folded Strips Prototype, paper model.

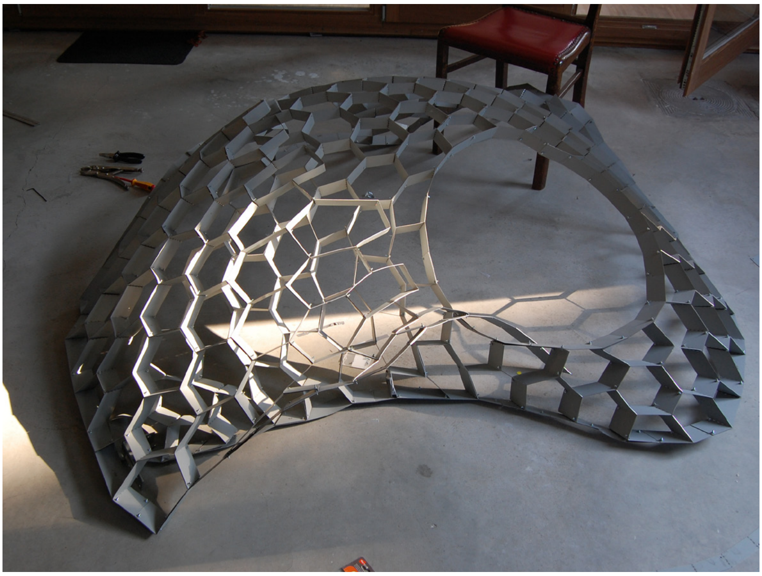


Fig. 52. [Re]Active Prototypes: Folded Strips Prototype, metal model.

the springs into folded strips. In order to make a more lightweight structure, the height of the strips depends on the amount of force they need to support, leading to lighter strips on the top and in the bottom. For the outer shape of the pavilion a series of ground plates are provided that allow for the clamping to the ground plane.

Throughout the design process a number of prototypes have been made testing various ways of connecting and folding strips. Of the final iteration two prototypes were produced, one in paper on scale 1:50, and one in sheet metal on scale 1:5. The scaling up from the paper model to the metal, revealed some difficulties, mainly due to folding by hand of the metal strips.

ADAPTIVE AGGREGATIONS: AIM AND CONTEXT

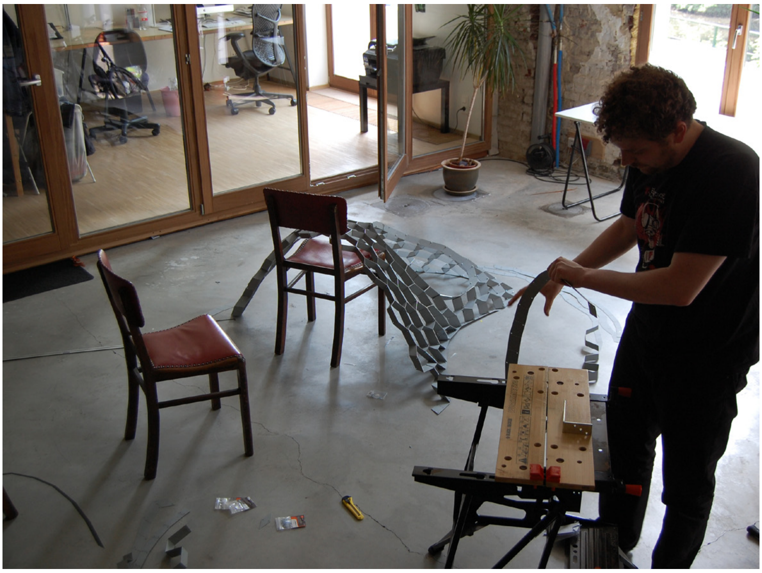
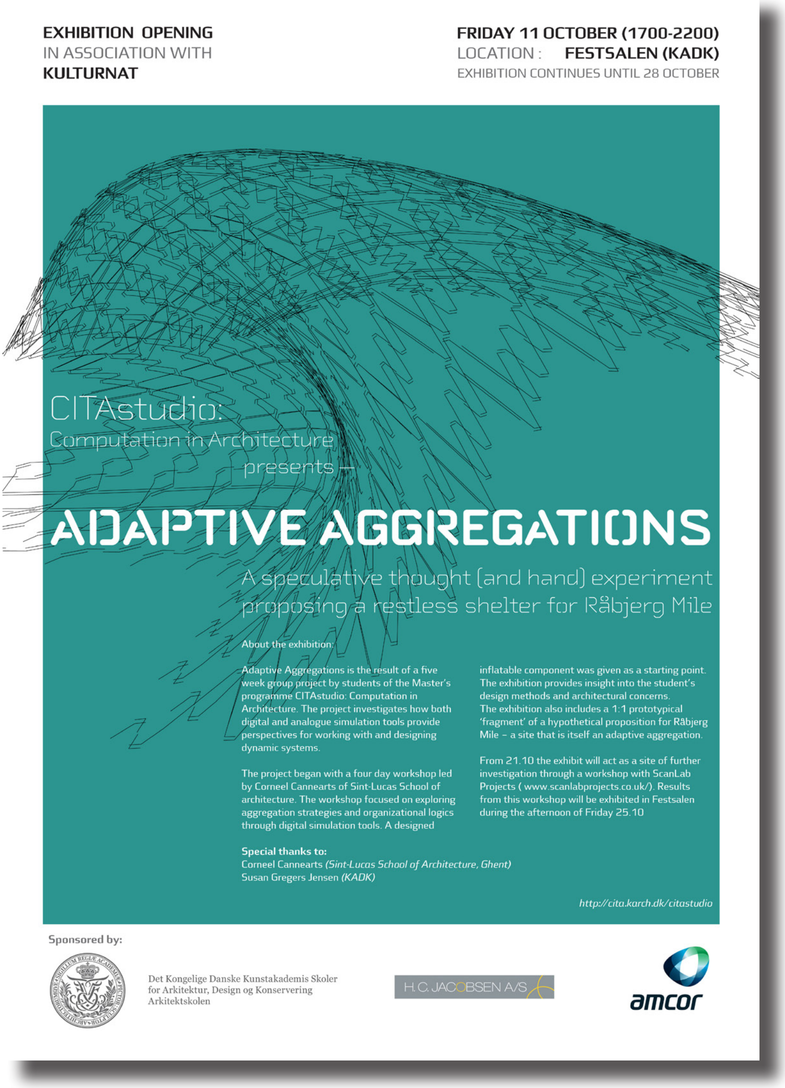


Fig. 53. [Re]Active Prototypes: Folded Strips Prototype, metal model.



EXHIBITION OPENING
IN ASSOCIATION WITH
KULTURNAT

FRIDAY 11 OCTOBER (1700-2200)
LOCATION : **FESTSALEN (KADK)**
EXHIBITION CONTINUES UNTIL 28 OCTOBER

CITAstudio:
Computation in Architecture
presents –

ADAPTIVE AGGREGATIONS

A speculative thought (and hand) experiment proposing a restless shelter for Råbjerg Mile

About the exhibition:

Adaptive Aggregations is the result of a five week group project by students of the Master's programme CITAstudio: Computation in Architecture. The project investigates how both digital and analogue simulation tools provide perspectives for working with and designing dynamic systems.

The project began with a four day workshop led by Corneel Cannearts of Sint-Lucas School of architecture. The workshop focused on exploring aggregation strategies and organizational logics through digital simulation tools. A designed inflatable component was given as a starting point. The exhibition provides insight into the student's design methods and architectural concerns.
The exhibition also includes a 1:1 prototypical 'fragment' of a hypothetical proposition for Råbjerg Mile – a site that is itself an adaptive aggregation.

From 21.10 the exhibit will act as a site of further investigation through a workshop with ScanLab Projects (www.scanlabprojects.co.uk/). Results from this workshop will be exhibited in Festsalen during the afternoon of Friday 25.10

Special thanks to:
Corneel Cannearts *(Sint-Lucas School of Architecture, Ghent)*
Susan Gregers Jensen *(KADK)*

http://cita.karch.dk/citastudio

Sponsored by:

Det Kongelige Danske Kunstakademis Skoler
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Arkitektskolen

H.C. JACOBSEN A/S

amcor

Fig. 54. Adaptive Aggregations, poster.

In the summer of 2013, I was invited by the Centre for Information Technology in Architecture (CITA) at the Royal Academy of Arts in Copenhagen to collaborate on their installation project with Phil Ayres[72] and Hollie Gibbons. The academic year in Denmark starts in September, and the workshop was set-up in the first week as a start of CITA studio and fitted within a larger five-week *installation project*. The aim of the installation project was to take students through a complete design cycle, from sketch design, to a speculative site-specific design, to a built demonstrator on a scale of 1:1. My role in this project was mainly coding design tools, consisting out of three nested simulations. In this section I will not describe the work done by the students, but the work Phil Ayres and Hollie Gibbons and myself in preparation of this workshop, and reflect through my creative contribution to the project.

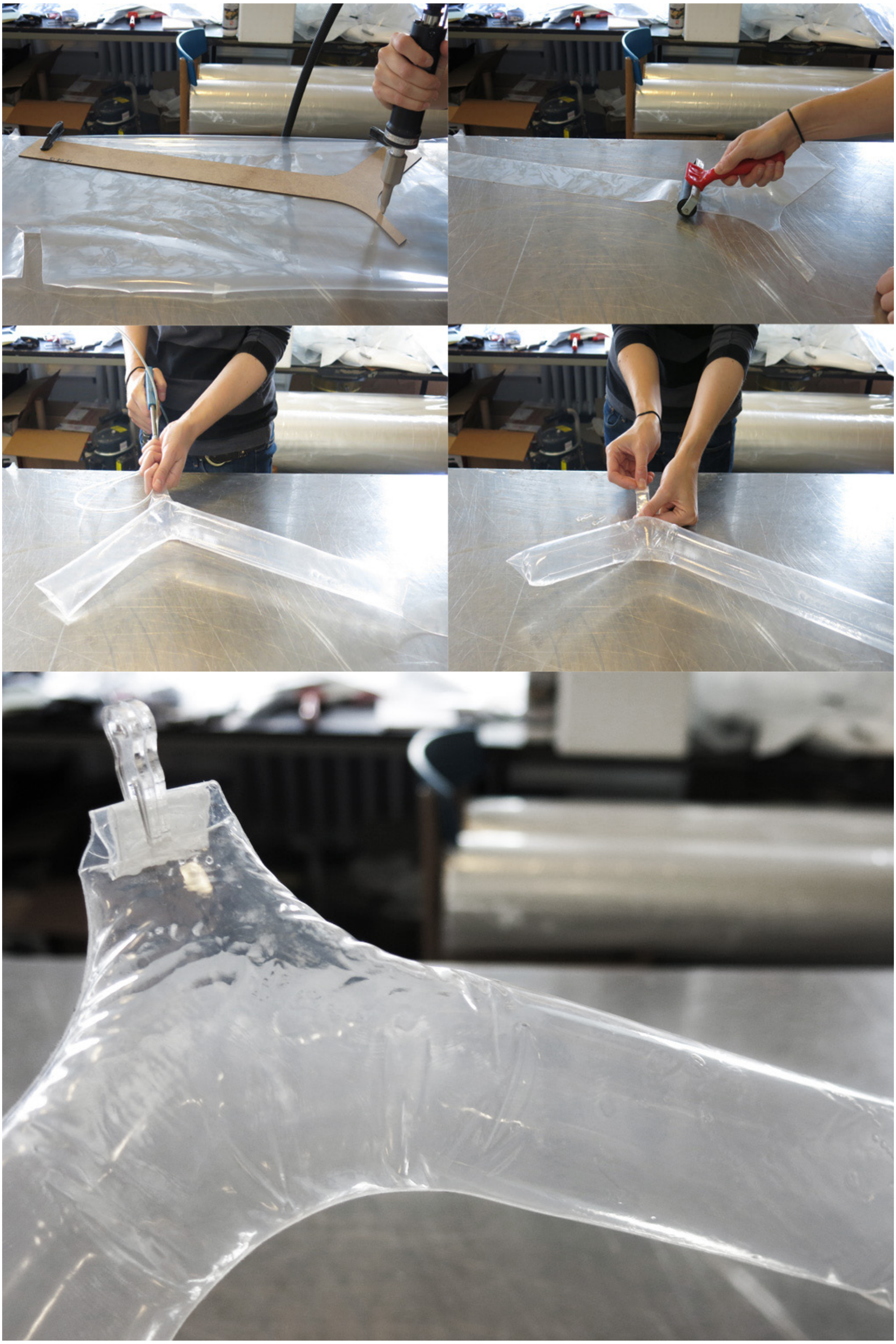
The project built on the work outlined in the *form finding* and *[re] active prototypes*, and on the research done by Phil Ayres on the relationship between material models and digital simulations, under the title *persistent model*.[73].The installation project, called *Adaptive Aggregations*, explored material prototyping, digital modelling and simulation tools as means of developing and analysing different strategies for aggregate structures and how these could adapt to changing environmental forces and conditions. A light weight inflatable component was chosen for ease of handling and fabrication, but also because of the adaptation to site conditions and wind forces. Because of the short amount of time, it was decided the work would be conducted with a limited set of similar components. In the weeks leading up to the workshop, the material, fabrication and connection for the component were developed, and a number of design tools were prepared.

TOOL 1: MATERIAL AND SIMULATED INFLATION

---

[72] I met Phil Ayres as a panellist on the PRS (Practice Research Symposium) in November 2012 and invited him for the final presentations of the reactive prototypes elective. He gave a lecture and demonstrated inflating a steel member with a bicycle pump, a way of making he explored in the persistent modelling series.

[73] See Phil Ayres (ed.), *Persistent Modelling: Extending the Role of Architectural Representation*, (2012). And Phil Ayres, Free-Form Metal Inflation & the Persistent Model in Ruairi Glynn and Bob Sheil, *Fabricate: Making Digital Architecture* (2013). pp.70-73.



The component we developed was deliberately kept simple in terms of geometry and fabrication; it consisted of a linear inflatable tube with a bend. The first tool, prepared by Phil Ayres (Figs. 57-58), could generate the profile for fabrication and simulate the inflation: The two lengths of the legs, the angle of the bend and the planar offset of the profile could be controlled parametrically. In order to simulate the inflation, the surface described by the profile was meshed based on a circle packing algorithm, which automated the tedious process of preparing a mesh. The resulting mesh was mirrored, the seams were welded and turned into a particle spring model and were imported into Kangaroo for inflation.

Fig. 55. Adaptive Aggregations, fabrication sequence of the inflated component.
(left top).

Fig. 56. Adaptive Aggregations, closing the inflated component with an acrylic clip after inflation.
(left bottom).

The material component was fabricated by laser-cutting the profile out of mdf and using a sonic welder to join two layers of foil by tracing the profile (Figs. 55-56). The component was inflated using a small tube, which could be rolled up and closed off by a laser cut acrylic clip. The material research and fabrication process was prepared by Hollie Gibbons, testing a number of materials, ways of inflating and closing the component, which was crucial in keeping the components inflated for the duration of the installation. It was decided to start the workshop with three differently scaled components, labelled *a, b* and *c* in the design tools; but later in the installation project, this could be adapted. The components were connected by aligning two legs of two components and fixing them using tie wraps or rubber bands.

A 3D scan of one of the components was made and compared with the geometry resulting from the simulated inflation. Generally, both geometries matched quite closely, although in the material inflation, the angle of the bend became somewhat more accentuated, and some secondary deformations and wrinkles were absent from the simulated version. This is in line with earlier work by Phil Ayres, in a project called *the persistent model* that looked into feedback between an inflated metal model and a similar digital simulation.[74]

TOOL 2: BRANCHING

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[74] See Phil Ayres, Free-Form Metal Inflation and the Persistent Model, in Ruairi Glynn and Bob Sheil (eds.), *Fabricate: Making Digital Architecture* (2011), pp. 70-73.

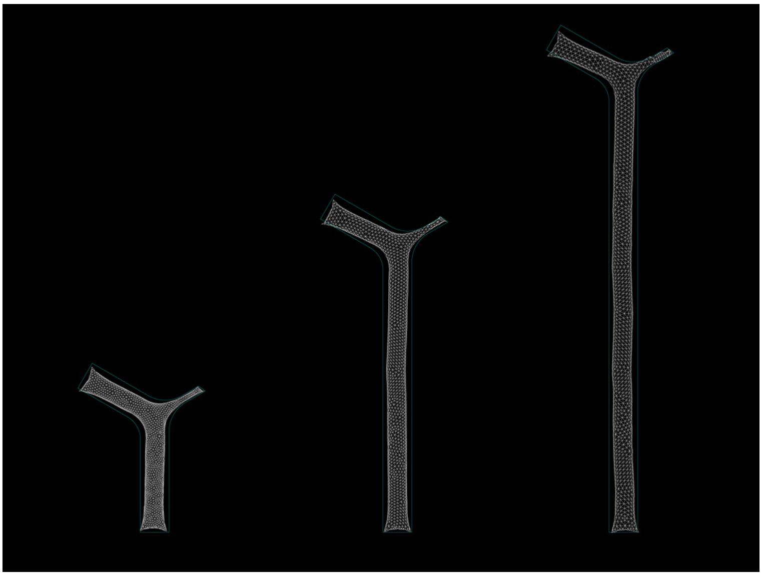

Fig. 57. Adaptive Aggregations, three scales of components.

The second design tool I developed, started from the geometry of the three types of components and the way of connecting them, was encoded in a branching system (Figs. 59-61). The user interface allowed for control over the geometry of each of the three types of components, controlling the length of the two legs and the angle of the bend. For each type of component, you could determine which type it would branch into and how it would be connected: the new component would be parallel to the bent leg of the previous one, but could rotate around and slide along this leg. A maximum of two new components could branch from a previous one, individually controlling the connection parameters and potentially doubling the number of components every iteration. The total number of components could either be limited by controlling the number of iterations or capping the number of components.

The branching algorithm described above can be seen as an implementation of a Lindenmayer System, or L-system, which is a recursive system used to model plant growth.[75] Although the rules of connecting new branches are determined, the recursive nature of the algorithm allows for the modelling of complex structures,

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[75] This system has been widely published; a good description and application of L-systems can be found in Paul Coates, *Programming. Architecture* (2010), p. 73.

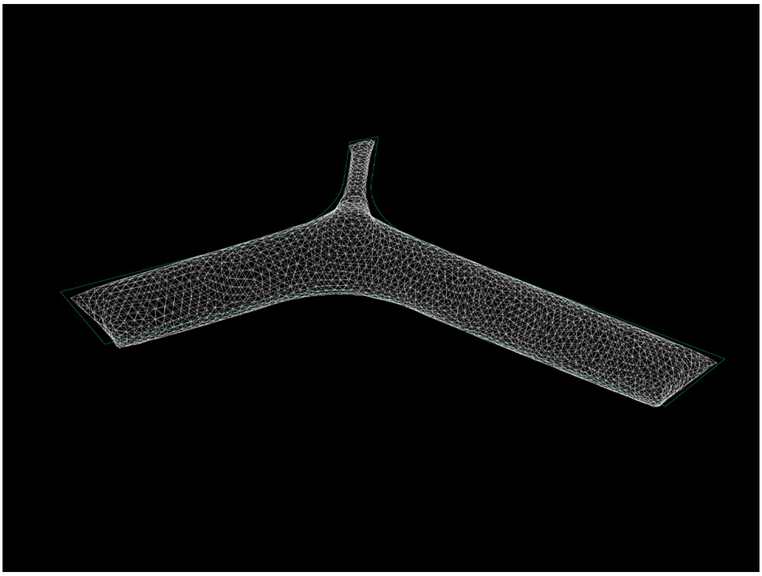
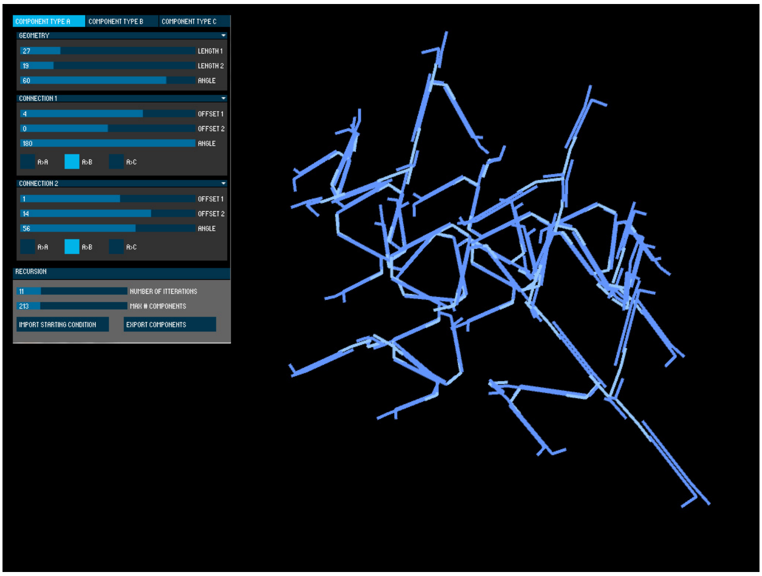


Fig. 58. Adaptive Aggregations, simulated inflation.

varying between the seemingly random and the highly structured. A large variation of forms can be generated from a relatively simple algorithm. Attaching two inflated components with a tie wrap can hardly be expected to result in exact alignment, but the tool allowed for a degree of imprecision in fabrication to be visualised from small deviations from propagation throughout the structure.

When initialised, this branching tool would start from a single component, but an import function which allow drawing starting components in Rhino, import them into the tool and start branching from these. This increased the number of possible configurations; ranging from branching systems populated on free-form curves and surfaces to highly symmetrical and ordered structures. Different rendering modes provided visual feedback on the types of components or the level of iteration for each component. The tool also allowed branching systems to be exported – design became interplay between drawing and simulating, going back and forth between Rhino and Processing.

This branching system can be seen as a simulation, as it takes


COMPONENT TYPE A
COMPONENT TYPE B
COMPONENT TYPE C
GEOMETRY
CONNECTION 1
CONNECTION 2
RECURSION
IMPORT STARTING CONDITION
EXPORT COMPONENTS

GEOMETRY

27 LENGTH 1
19 LENGTH 2
60 ANGLE

CONNECTION 1

4 OFFSET 1
0 OFFSET 2
180 ANGLE
☐ A>A ☑ A>B ☐ A>C

CONNECTION 2

1 OFFSET 1
14 OFFSET 2
56 ANGLE
☐ A>A ☑ A>B ☐ A>C

RECURSION

11 NUMBER OF ITTERATIONS
213 MAX # COMPONENTS

Fig. 59. Adaptive Aggregations, tool 2: branching, interface.

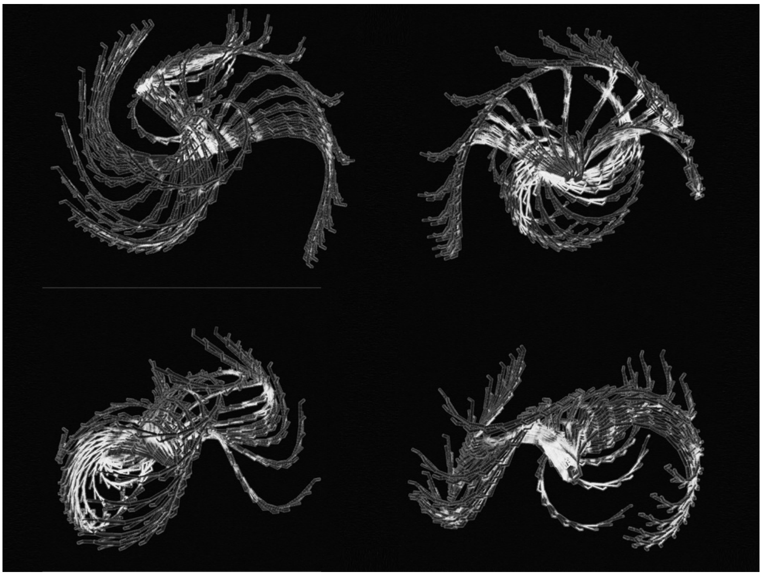


Fig. 60. Adaptive Aggregations, tool 2: branching, example

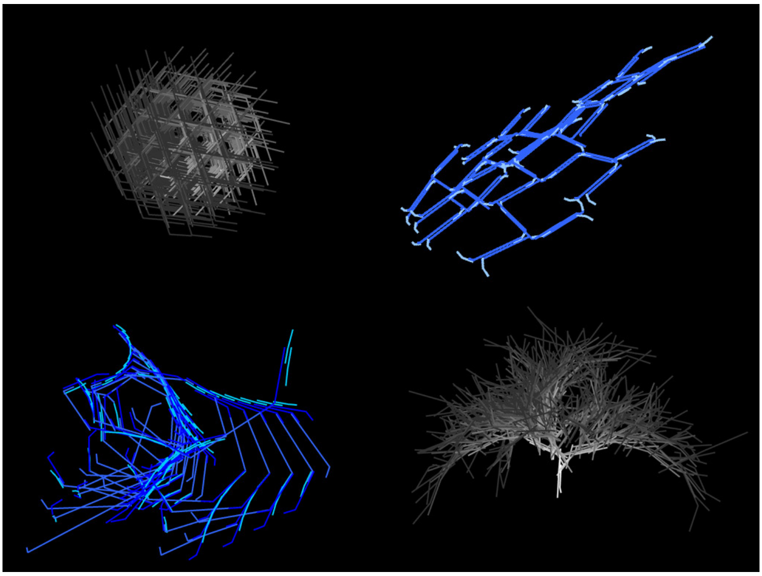


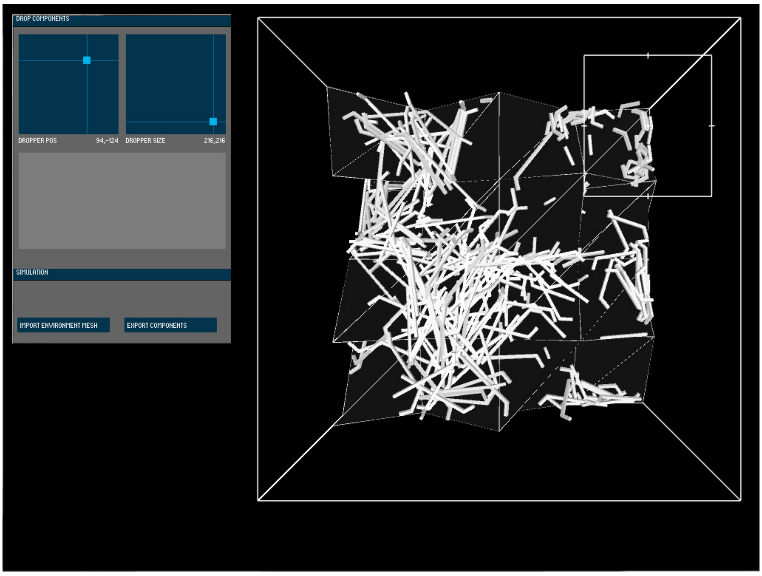
Fig. 61. Adaptive Aggregations, tool 2: branching example

the geometry and the connection system of the components and simulates how a strict application of this system would generate a structure over time. Time here is specifically encoded as the number of iterations the algorithm goes through. As a structural simulation, this algorithm has its limits as it does not take into account gravity and deformation of the components. As a design tool, it allows for an appreciation of how small changes in the geometry or the rules of connection propagate through the whole structure and have large consequences. Designing with this tool becomes an exploration of specific combinations of values of parameters that produce interesting moments, structurally or spatially.

TOOL 3: POURING

The third tool, I developed, was aimed at testing collisions between large amounts of aggregate components and consisted of a rigid body simulation, written in Processing and using the *brigid* library[76] (Figs. 62 - 63). A rigid body simulation allows for forces working on and collisions between objects to be simulated and is often used in animation and game engines. As the name suggests, it considers

[76] bRigid is developed by Daniel Kohler as an interface between processing and jBullet, a java version of Bullet Continuous Collision Detection and Physics Library; see http://www.lab-eds.org/bRigid (consulted on 08/08/2014).


DROP COMPONENTS
SIMULATION
IMPORT ENVIRONMENT MESH
EXPORT COMPONENTS

DROPPER POS 94,-124

DROPPER SIZE 216,216

Fig. 62. Adaptive Aggregations, tool 3: pouring, interface.

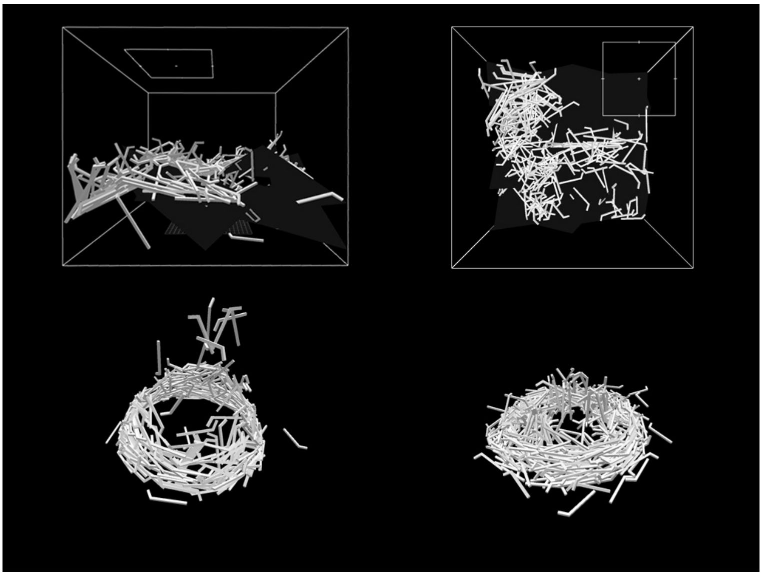


Fig. 63. Adaptive Aggregations, tool 3: pouring, example

objects to be completely rigid and does not take into account the deformation of objects by the forces acting on them. The simulation world consists of a box-shaped environment in which obstacles could be placed, components could be dropped and forces applied.

The library supports a number of standard geometric primitives but also allows for external geometry to be imported, although it only supports convex shapes. In order to import the concave tube with bend geometry, a workaround was found by cutting up the geometry into two convex halves and joining them as a compound shape after importing. In order for the collision to work properly, the parts needed to be modelled with the origin point in the centre of mass of the resulting joined compound component. The task of designing an aggregate spatial enclosure required a substantial number of components to be added to the simulation. In order to keep the simulation feasible, the geometry was approximated by boxes extruded along the axis of the components. The artificial ground condition asked for in the design brief could be simulated by importing a static environment mesh, which was drawn in Rhino, exported as obj[77] file and imported in Processing.

The user interface gave control of the position and size of an area where the components would be dropped, allowing for large and random or targeted and precise drops. There were options to import and delete the environment mesh, export the components as a text file, control the gravity of the simulation and pause or speed up the simulation. During the course of the workshop, I added a number of features: compacting components by shaking them, hiding the environment mesh, reversing gravity and adding wind forces.

IN BETWEEN TOOLS, STRATEGIES AND MEDIA

In order to overcome the limits inherent in design software, we used different computational design tools and strategies to develop a spatial proposition. We chose to operate simultaneously in different software environments and use different computational design techniques: explicit geometric modelling in Rhino, visual parametric

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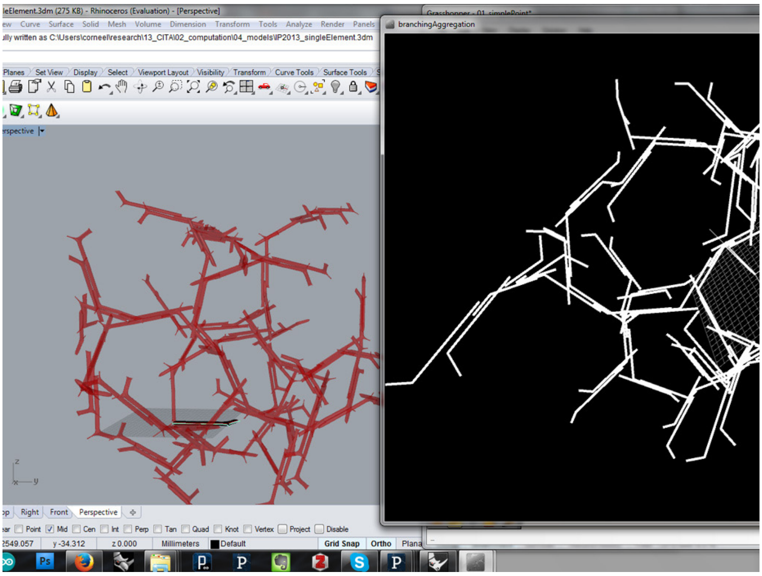
[77] An obj is an open mesh file format, see http://en.wikipedia.org/wiki/Wavefront_.obj_file (consulted on 28/01/2015).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Planes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools
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branchingAggregation
Right Front Perspective
ear Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
2549.057 y -34.312 z 0.000 Millimeters Default Grid Snap Ortho Plana

Fig. 64. Adaptive Aggregations, operating between software.

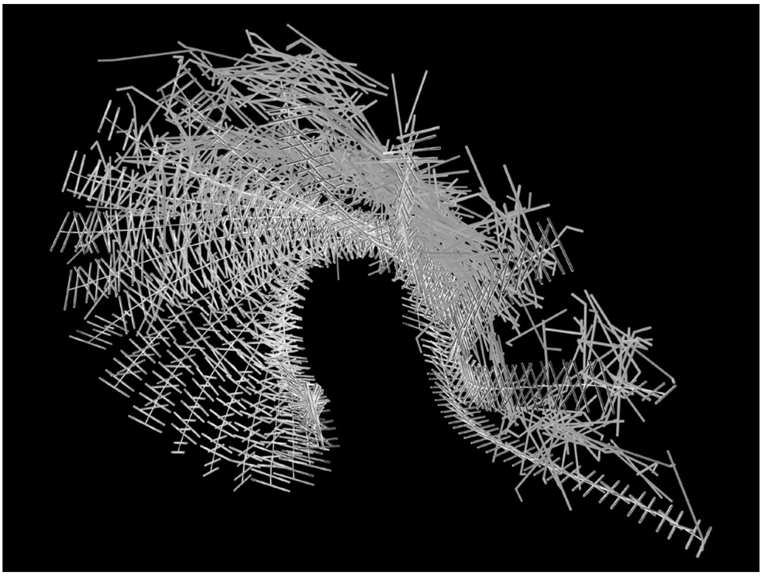

Fig. 65. Adaptive Aggregations, example

modelling in Grasshopper and text-based scripting in Processing. The preparation resulted in three design tools; computational techniques were made available through design tools with graphical interfaces. The three introduced tools are described in more detail above. The position, orientation and geometry of the components could be described by the three coordinates and an offset thickness, and all the tools could export and import text files containing this information. Rhino was central in the work-flow; it was used to collect and compile the multiple explorations, prepare the starting conditions and environment meshes as input for the simulations and assemble the different strategies into a final design proposal (Figs. 64).

REFLECTION

This case shows that extending digital models to include material behaviour can be used as a speculative design medium which extends digital design beyond drawing or modelling form into form finding. The results of the three projects described in this case show a diverse range of materials, strategies and applications. The digital model becomes a contributor to the design process, and the design process advances by setting up conditions, encoding material properties and steering the simulation. The digital model acquires more agency, and the design is a result of negotiation between the designer and the simulation.

In the three projects described in this case, simulations could be found on multiple scales: on the level of the component through simulating its inflation, in the branching tool as a simulation of a connecting logic and in the pouring tool in the simulation of interactions between many components, gravity and environmental conditions. Through nesting different simulations, it becomes clear that each tool comes with its own assumptions and its own requirements and limits in terms of geometry, and all provide a different insight in the design task at hand. All of these simulations have their limitations and capture materiality in discrete encoded elements, from the particles and springs simulating the inflation to the compound shapes assembled out of convex parts in the rigid body simulation. Furthermore, time is encoded as explicit discrete steps: the algorithm that makes up the simulation computes the resulting world one iteration at a time.

The three projects discussed in this case show that the kinds of simulations used do not escape the representational paradigm, as is suggested by David Ross Scheer in *The Death of Drawing: Architecture in the Age of Simulation*. The tendency of simulations to replace reality, to become complete worlds of their own, Scheer identifies is countered by deliberately working with different modes of digital design, switching between different strategies and tools and breaking open the box-like world of simulation. Rather than replacing familiar approaches of drawing and modelling, simulation extends them to also include behaviours that work out in time.

Bob Sheil warns us there is a danger in confusing the simulated design with the actual constructed artefact, and there remains a distinction between the drawn and the made:

" Quite apart from the inevitable selectivity involved, such an approach has the potential to reduce architectural production to a systematic industrial exercise devoid of immeasurable and immaterial qualities that make it more than the sum of its parts.[...] Where it is implied that materials are synthesised as physical and digital matter, it is important to remember that built architecture is not made of points, vectors, splines and algorithms, but of stuff that has the habit of misbehaving unexpectedly". [78]

This is not denying the transitive potential that simulations have, but notwithstanding the possibilities to bridge material and digital simulations provide, there remains a fundamental difference between material artefact and simulation. Acknowledging this difference allows for simulations to be approached for design speculation rather than mere prediction and provides new insights in design rather than confirming the already known.

ACKNOWLEDGEMENTS

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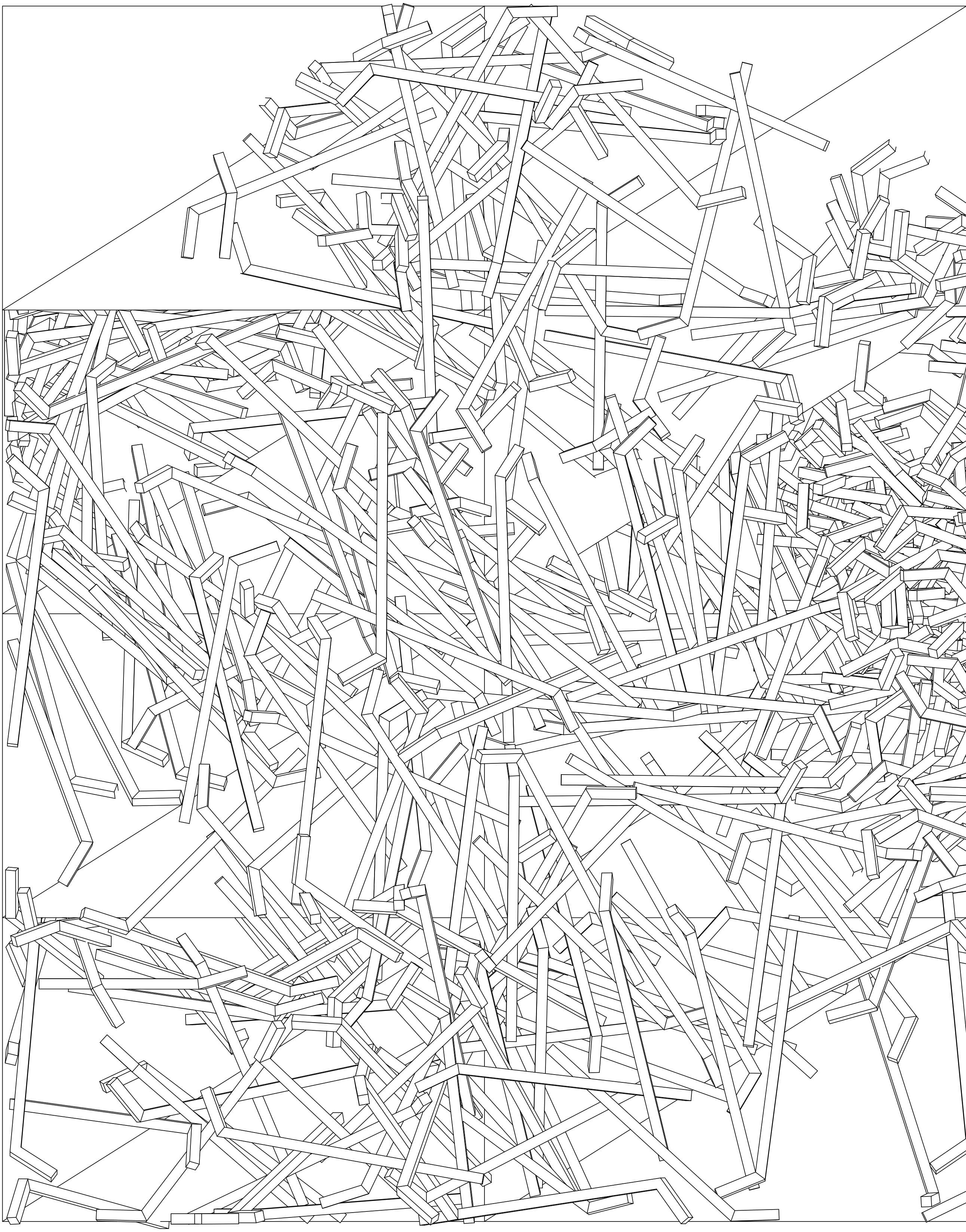
[78] Bob Sheil argues against this equation in his counterpoint to Achim Menges, *Material Computation: Higher Integration in Morphogenetic Design Architectural Design* (2012).

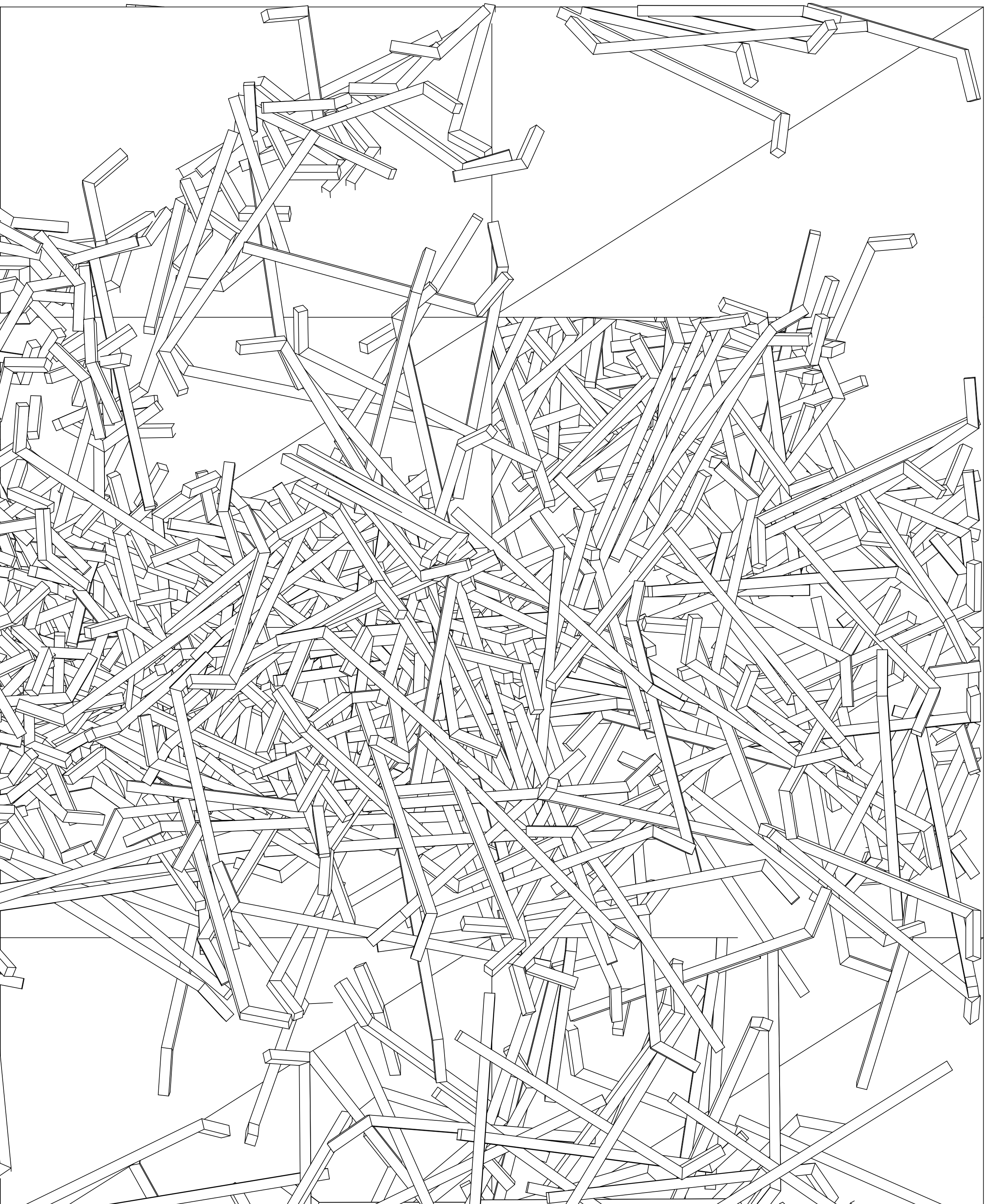
The *Material and Digital Form Finding* project was developed by Corneel Cannaerts

The *[Re]Active Prototypes* project was developed by Corneel Cannaerts in collaboration with Bart Mermans and Jan Van De Velde of VAC machines.

The *Adaptive Aggregates* project was developed by Phil Ayres, Hollie Gibbons and Corneel Cannaerts, CITA Copenhagen.

CONCLUSION: AGENCY IN CODE





“An algorithm is not about perception or interpretation but rather about exploration, codification, and extension of the human mind. Both the algorithmic input and the computer’s output are inseparable within a computational system of complementary sources. In this sense, synergy becomes the keyword as an embodiment of a process obtainable through the logic of mutual contributions: that of the human mind and that of the machine’s extendibility”.[79]

Code is different. After having compared the open-endedness of material design exploration with the relative closedness encountered when using digital modelling and drafting software in the previous chapter, this chapter can be read as the result of a deeper engagement with the digital world. By opening up the black box of software tools and engaging with the underlying algorithms, code was explored as an active medium contributing to the design process and, as such, acquiring agency.

As the quote above outlines, the agency of computation can be found in its otherness, what Kostas Terzidis calls *allo*. Computation extends and is complementary to the mind of the designer; a computational design process can benefit from the synergy between human agency and that of computation. Code is the shared language, the in-between that makes this synergy possible. As a conclusion, I want to highlight the aspects of code uncovered during this chapter that allow us to approach or leverage this otherness.

Code works as a mediator operating between human understanding and the raw computational process. Code is readable and manipulable to humans through interfaces, whether it takes the form of a programming language, a scripting language on top of existing software, a visual parametric modelling environment, point and click manipulations in menus or toolboxes. These interfaces are not neutral; they determine to a large degree what we can understand and how we can manipulate underlying code.

The main idea this chapter revolves around is that taking the step of actively tinkering with and writing code as a designer is just going one layer deeper in understanding computational processes.

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[79] Kostas Terzidis, *Algorithmic Architecture* (2006), p. 27.

It is peeling away a first set of interfaces, and what is revealed is a highly designed and layered digital world. As can be seen in the projects discussed in this chapter, the move of engaging with code is a rewarding one: it affords a deeper understanding of the processes at play in design and allows designers to engage with these processes; it allows the designer to be actively negotiating with technologies rather than merely using them.

Code as tool. As has been discussed in *Tinkering with Code*, I do not subscribe to the distinction between making tools and using tools, nor to their causal relationship – first make the tool then use it. It is the iterative interplay between making and using, remaking and reusing, that makes coding as a designer engaging. Furthermore, taking away the first layer of interfaces of standard modelling and drafting software reveals another set of interfaces and tools designed by others. These afford a different understanding of computational processes and come in the form of programming languages, libraries, code examples, add-ons etc. So rather than promoting or claiming the absolute role of tool maker, it is much more beneficial to define a strategy that acknowledges the highly diverse, designed and authored nature of code and use whatever tool gets the job done and affords you level of engagement needed.

Code as grain. One defining character of code is that it is discrete; code can be understood as the *grain* of the digital world. No matter how complex and vast an algorithm is, it works by evaluating clearly defined instructions in discrete steps. Although we know that raw computational power works on binary operations, we as designers tinkering with code perceive its grain as mathematical entities – vectors, numbers and matrices. When using code as a lens for capturing continuous material and spatial phenomena, it does so at defined intervals at a specific resolution. As the *Sphere Inversion* project showed, as designer you can work with or against this grain and accept the grain as a feature to design with or refine resolutions to an acceptable scale.

When simulating behaviours, whether based on material, spatial phenomena or the purely abstract, the code operates on discrete elements – particles, springs, agents, meshes, bodies and triangles – furthermore, in these simulations time is also encoded in discrete units – ticks, frames and steps. As discussed in the *Adaptive Aggregations, Form Finding* and *[Re]Active Prototypes* projects, the simulation happens fast enough to give the illusion of a continuously adapting model, allowing designers to steer rather than define behaviour. But we are by no means limited to this so-called real time; we can speed-up, slow down or even reverse these simulations.

This discreteness of code is also readable in how information is stored in files and how code interacts with the material world: scanners, screens and prints have resolutions and stepper motors move at speeds calculated in discrete steps. Even a concept that exists as continuous mathematical entities, such as surfaces and curves, can only be brought in the material world through sampling them at discrete intervals.

Code as a medium. How coding works as a design medium is highly dependent on the format, the language, the interface and the experience the designer has with these. In this exploration, I have used multiple language and interfaces, from scripting languages that run on top of a modelling software (Rhinoscript and LISP, to graphical programming languages (Grasshopper and vvvv) to text-based programming (Processing, which is based on Java). What all of these share is that they afford feedback on two levels: the graphical, geometric result of a design you are working on and a textual, visual representation of the code or algorithm that drives these geometries – and most of them allow for design to be altered in both these modes.

Code is cultural. Code is both result and carrier of design culture. As we have seen in the introduction to this chapter, code is both affected by and has an influence on design culture. The plural cultures of code seem to be further fragmented by design blogs and online tutorials. A central issue that emerges out of the cultures of sharing code is the question of authorship. In the case studies, different ways in which authorship is affected by code can be found: from working as an expert collaborator on projects initiated by others, to using code as an enabler and allowing different collaborators of a design team to collaborate better to providing design tools for workshop. The main proposition of this chapter, that code has a particular form of agency in design, also has its repercussions on authorship. I have not discussed authorship explicitly in this chapter; before we can tackle this we need to introduce digital fabrication as a technology that incorporates agencies found in material and in code.

Code and matter. While each of the cases highlights a particular aspect of code as an active medium, in all of them matter and materiality have been instrumental as a means of understanding and engaging with code. The relation between matter and code here can be summarised in two main propositions: code was identified as the matter, the stuff that makes up the digital world, and material behaviour was captured in code through simulation. Notwithstanding this metaphorical and representational use of matter to hint at agencies found in code, code was found to be fundamentally different stuff than matter. In the next chapter, I will introduce digital fabrication as a technology that negotiates that difference.

EXPLORATION III
ALLOGRAPHIC MACHINES

"Make your own tools. Hybridize your tools in order to build unique things. Even simple tools that are your own can yield entirely new avenues of exploration. Remember, tools amplify our capacities, so even a small tool can make a big difference".[1]

INTRODUCTION

After unravelling the affordances and the resistances found in materials as set out in the first chapter, and having explored code as the matter that makes up the digital world and how digital code can be informed by materiality in the second chapter, this final chapter explores digital fabrication: as a set of technologies and machines that operate between the digital and the material world, as a design medium with its specific qualities and challenges. This chapter looks into the agency found in the fabrication technologies and machines themselves and also into how the agencies found in matter and in code, uncovered in previous chapters, play out through these technologies and can be leveraged to further design.

The chapter will start by outlining some notions at play in digital fabrication – allographic and autographic art practices, drawing and making, notation and matter, extensive and intensive material properties, precision and tolerances, control and exploration. While some of these might seem oppositional and dualistic, the intention is not to side digital fabrication with either but to open-up and map-out the layered space in between in which digital fabrication operates. This outline works as a framework for the cases described in this chapter and aims to define the position from which these design explorations began.

The two case studies that make up the core of this chapter explore specific parts of the agencies found in digital fabrication. Each case is centred on one main design project, but also draws from other design projects and references other work: *Fabricating Material Intensities* uses colour, light and translucency to explore the fabrication of intensive material properties and *Digital Traces and Material Thread*s looks into digital fabrication as a process that unfolds in time and how traces of matter, code and machine can be found in fabricated artefacts.

[1] Bruce Mau, *Incomplete Manifesto for Growth*. See http://www.brucemaudesign.com/ (consulted on 20/08/2014).

ALLOGRAPHIC AND AUTOGRAPHIC PRACTICES

The separation between ‘design’ and ‘making’ in architecture has led to different understandings of where authorship can be located in architectural work. As Mario Carpo argues[2], two extreme positions can be taken: You could either argue that the intentions of a designer are captured in the drawing and that the building can only be a lesser version of the design constrained and conflicted by the contingencies of the real. Or you could argue that architecture can only be fully appreciated in the build and see the drawing as a mere instrument to arrive at the construction of the building. The former would locate authorship solely in the drawn, whereas the latter locates it solely in the built.[3]

In practice,[4] both absolute positions are hard to maintain: drawings can never completely capture and anticipate the building, and building is a complex process involving many parties and depending on many factors, which can never be completely authored.[5] What both these positions share is an understanding of drawing practice as purely abstract and disconnected from the realities of the built. As we have argued in the introductory chapter, building on Evans,[6] the relationship between building and drawing is more complex, and authorship in architectural work can’t be located solely in either. Or, as Stan Allen states: “*architectural drawing is in some basic way impure, unclassifiable. Its link to the reality it designates is complex and changeable*”.[7]

In his classification of different art forms, Nelson Goodman makes a distinction between *allographic* and *autographic* art practices.[8] In autographic arts, such as painting and sculpture, the authenticity of the work depends on it being executed by the artist; in other words, it bears the traces of the hand of the artist.[9] In allographic arts, such as music or poetry, the work can be executed without the direct presence of the author. Where autographic arts work directly with the matter at hand, allographic arts work through notation, usually leaving execution to others. The reason for this is that allographic arts tend to be temporal and ephemeral or need coordinated execution by many people, as in a theatre or in an orchestra, for instance.

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[2] Mario Carpo traces the origin of these two positions to Alberti (authorship in the drawn) and Brunelleschi (authorship in the built), respectively. See Mario Carpo, *The Alphabet and the Algorithm, Writing Architecture* (2011). p. 71-79

[3] I use drawing here in the broadest sense and not as a specific design medium and building as any construct regardless of size or function.

[4] For an interesting discussion outlining different contemporary positions, see Riedijk, Michiel, *Architecture as a Craft: Architecture, Drawing, Model and Position* (2010).

[5] See Jeremy Till, *Architecture Depends (2009)*, pp.45-61.

[6] Robin Evans, *Translations from Drawing to Building and Other Essays* (1997). pp. 153-194.

[7] Stan Allen, Mapping the Unmappable, in *Practice: Architecture, Technique + Representation* (2009). p.41

[8] Nelson Goodman, *Languages of Art* (1976). pp. 99-174.

[9] This is obviously a generalization, many examples of sculpture and painting can be found that are partly executed by other hands than that of the artist.

Nelson Goodman considers architecture to be a “curious mixture” of autographic and allographic practices. Like all arts, it started out as the autographic practice of making and building but has acquired allographic elements through the introduction of notation in the form of the drawing. Unlike purely allographic practices, architecture deals with concrete material and is not purely ephemeral, but its building needs the coordinated execution by many people. Architectural drawings cannot be reduced to “pictures” of a future building, according to Goodman; he compares architectural drawing with a musical score, an instruction that combines graphic notations with texts and symbols. Unlike a musical score, the instructions captured in an architectural drawing are not complete and need to be complemented through other documents, and the actual construction still requires many decisions to be made, mostly requiring the architect to visit the site.[10]

INTRODUCING THE MACHINES

Over the last four decades, digital technologies have had an increasing impact on the practices of design and architecture to the extent that almost all design processes are mediated through digital technologies in some way. In general practice, the impact of these technologies has been initially limited to the realm of design representation and did not directly impact the practices of building and making. Software was developed as digital versions of well-established tools of drafting, modelling and rendering. In the aftermath of post-modernism, the more avant-garde architects and designers saw in digital tools a way to break away from the formal and conceptual frameworks. The freedom afforded by digital tools imported from other disciplines led to a design exploration not bound by the formal limitations of traditional tools. Triggered by the desire to construct and materialise this newfound formal complexity afforded by digital tools, architects have adopted digital fabrication, borrowing technologies again from other industries.[11]

In the first projects that adopted digital fabrication, technology was mainly used in a top-down fashion: material solutions were sought to realise a preconceived form that was hard to achieve through

[10] Stan Allen, Mapping the Unmappable, in *Practice: Architecture, Technique + Representation* (2009). pp. 48-49.

[11] See Stephen Kieran and James Timberlake, *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction* (2004) and Neil Leach, David Turnbull and Chris Williams (eds.), *Digital Tectonics* (2004).

traditional building techniques.[12] But digital fabrication technologies have also inspired designers and architects, by offering a feasible way to precisely produce, artefacts not bound by logic of standardisation. Digital fabrication was not merely seen as a technological solution, a means to an end, but as a field for exploration that affords a new theoretical understanding and material sensibility.[13] Whereas these explorations were often heady and philosophical, investments by schools and research institutes led to increased accessibility of the technology and a shift of focus to material exploration.[14]

The adoption of digital fabrication in architecture and design has once again brought materiality and making to the centre of attention in architectural design, both in academia and in practice. Digital fabrication requires us to rethink the relationship between drawing and making, between design and construction, and thus the allocation of authorship within architectural work and whether it has shifted even more to the allographic side or reclaimed some of its autographic aspects. Combined with developments in computer-aided design, parametric modelling and building information modelling, the adoption of digital fabrication technologies has led some authors [15] to speculate on a more central position in making and construction for the architect – a return to the role of the master-builder:

"The new processes of design and production, born out of the pragmatic ramifications of new formal complexities, are providing unprecedented opportunities for architects to regain the authority they once had over the building process, not only in design, but also in construction. The new relationships between the design and the built place more control, and therefore more responsibility and more power into the hands of architects. [...] By reinventing the role of the 'master builder', the currently separate disciplines of architecture, engineering and construction can be integrated into a relatively seamless digital collaborative enterprise, thus bridging the gap between designing and producing that opened up when designers began to make drawings".[16]

Taken at face value, the quote above by Kolarevic suggest a return to a more authoritarian role, shifting architecture back to its *autographic*

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[12] Works of Frank Gehry and Greg Lynn were pioneers in this field. See Jim Glymph, "Evolution of the Digital Design Process", in Branko Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*, (2003). pp.101-120.

[13] The idea of non-standard was explored by practitioners like Bernard Cache, Mark Goulthorpe and Greg Lynn combined both material explorations with theoretical reflection. See Centre Georges Pompidou, *Architectures Non Standard:* Exposition Présentée Au Centre Pompidou, (Paris: Centre Pompidou, 2003).

[14] SIAL, AADRL, ETH and MIT seem to be part of this momentum.

[15] See Stephen Kieran and James Timberlake, *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction* (2004), pp.27-31. and Branko Kolarevic, "Innovation Master Builders" in Branko Kolarevic, *Architecture in the Digital Age: Design and Manufacturing* (2005). pp. 55-62.

[16] See Branko Kolarevic, Information Master-Builders, in *Architecture in the Digital Age: Design and Manufacturing*, (2005).

origins and erasing the need for drawing and representation that has been important in the formation of the profession of the architect. In contrast, Mario Carpo sees the adoption of digital fabrication technologies in architecture as the final emancipation of architecture into a fully *allographic* practice:

> *"Contemporary cad-cam technologies have simply obliterated the notational gap that for centuries kept design and construction apart. Each cad file contains the precise and univocal denotation of the position in space of each geometrical point that composes a building, and a digital notation can be executed anywhere, anytime, regardless of the presence or absence of its author, so long as a machine similar to the one used to make that file is available to read it. [...] With cad-cam technologies, architecture may have finally attained full allographic status".*[17]

These two positions differ in appreciating the impact of digital fabrication on architectural practice and the location of authorship: Kolarevic proposing a return to a more autographic role, Carpo proposing a complete allographic practice. The former stresses the importance of collaboration and shared digital models and places the architect as central in this shared digital environment. The latter gives the architect full authorial control over both the drawing and the building by collapsing the difference between the drawn and the made. In the process, Carpo reinvents the cad file as an absolute and unequivocal form of representation that can be materialised regardless of place and time and, as such, provides "complete determination in advance".[18]

While they differ in nuance, they both propose that the adoption of digital fabrication in architecture offers the potential for an increased authorship for architects and designers – an increased control over materiality and making. In both positions, we can read an assumption that digital modelling and digital fabrication are completely determinate and transparent technologies. It is as if by linking a digital file to a fabrication tool, the agencies we have uncovered in previous chapters are completely absent; gone are the resistance and affordances found in materials and code, not to mention the inherent limits and potentials the fabrication machines add to the process.

[17] Mario Carpo, *The Alphabet and the Algorithm, Writing Architecture* (2011), p. 78.

[18] Robin Evans, *Translations from Drawing to Building and Other Essays* (1997). p. 173.

EXTENDING THE JOURNEY

Digital technology is seen as a force for convergence, whether it is closing the gap between disparate disciplines[19] or collapsing the gap between drawing and making,[20] smoothly and uninterruptedly going from design idea to materialised artefact as it is propagated by the so called *file-to-factory* paradigm. But as Phil Ayres argues, there is a difference between how the impact of the technology is being reported and the experience of its actual use:

"Much of the published work related to digital fabrication in an architectural context, and authored by architects, employs the rhetoric of seamless continuity in which intention flows directly, without interruption or corruption, into physical outcome. However, anyone who has engaged directly with such procedures will be fully aware of the necessary iterations between the digital and the physical that are integral part of the translation from intent to a constructed artefact. Furthermore, CAM procedures almost certainly require supplementary data that is rarely encodable through proprietary architectural CAD packages alone – the implication being that a significant domain of attribute specification, thus authorship, lies beyond the scope of the file".[21]

Designing for or with digital fabrication often requires many iterations, suggesting that the file-to-factory paradigm can only operate if information from fabrication feeds back into the design process. One possible reason for this need for feedback is that the technology is not as transparent and direct as it seems and that the agencies of materials, code and machine need to be negotiated.

Robin Evans warned of architectural representations that promised complete determinacy in advance that closed the gap between design and making. Instead, he proposed a more transitive, more open-ended form of drawing, one that extended the journey between design and making and that has the potential to reach further than initially foreseen.

"There are all those other identically prefixed nouns too: transfiguration, transformation, transition, transmigration, transfer, transmission, transmogrification, transmutation, transposition, transubstantiation,

[19] See Stephen Kieran and James Timberlake, *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction* (2004). p.57.

[20] See Mario Carpo, *The Alphabet and the Algorithm, Writing Architecture* (2011). p. 78.

[21] Phil Ayres, Makers of Architecture, in Bob Sheil and others, *55/02: A Sixteen*(Makers) Project Monograph* (2012), p. 34.

> *transcendence, any of which would sit happily over the blind spot between the drawing and its object, because we can never be quite certain, before the event, how things will travel and what will happen to them on the way. We may, though, try to take advantage of the situation by extending their journey, maintaining sufficient control in transit so that more remote destinations might be reached".*[22]

The case studies that make up the core of this chapter are reports of such a journey. In that sense, in this exploration I will use the term *allographic* in its literal translation from Greek, which reads "other writing", as opposed to *autographic*, which means "own writing", or "handwriting". Rather than using digital fabrication as a technology that allows uninterrupted translation of intent into matter, it is exactly the traces of this otherness, the *allo,*[23] which interested me while undertaking these design projects. Instead of striving for complete control over the fabrication process, the cases allow for the agencies of materials, code and machine to be played out, hopefully reaching a destination further than foreseen in the technology or design intent.

[22] Robin Evans, *Translations from Drawing to Building and Other Essays* (1997). p. 173.

[23] Allo or otherness was already used in the conclusion to the second chapter when describing the agency found in code, see Kostas Terzidis, *Algorithmic Architecture* (2006), p. 27.

CASE 3.1: FABRICATING MATERIAL INTENSITIES

Dazzle Lamp | Design Exploration| MMlab| 2013

“Colours present themselves in a continuous flux, constantly related to changing neighbours and changing conditions”. [24]

Images can be found here

https://www.flickr.com/photos/imaterialise/sets/72157624653006736/

(consulted on 17/10/2014).

Fig. 1. Advertisement for colour 3d printing by i.Materialise.Com.

INTRODUCTION

In architecture and design, digital models operate mostly as representations of material realities that lie outside of themselves; digital models contain information saved in a *file* that describes a material *artefact*. When a material artefact is produced through digital fabrication, the link is made explicit. Instead of relying on a notation based on convention interpreted by a skilled maker, the process of digital fabrication is driven by the information contained in a file.

The *file-to-factory* paradigm suggests a direct, transparent and one-directional translation of design intent into matter, but the reality of working with digital fabrication is not as transparent, linear or direct: Designing for digital fabrication requires digital files made for the specific fabrication process, the resulting material artefacts will always have properties not anticipated in the file and design will often only be successful after iterative prototyping. This case looks closely at the process of translation from digital file into a material artefact. The aim of this design exploration was to look into the experiential material qualities of artefacts produced with a specific printing technology that allows for colour to be added during the printing process.

Files prepared for 3D printing generally describe only the outer geometry of an artefact – in most cases, approximated by a triangular mesh. Colour printing was chosen because it extends the extensive geometric description of an object with colour, which as the quote by Albers above indicates, is an intensive material property. This case explores how this intensive information is stored in a digital file and manifests itself in a material artefact. The case builds on a previous project that worked with changing appearances of objects under different lighting conditions and explores how colour can be used to strengthen those experiential differences.

The design exploration described in this case resulted in the development of the *Dazzle Lamp* series, which consists of a number of prototypes and custom-design software. The series got its name from dazzle camouflage, or razzle dazzle, a technique used to

24 Josef Albers, *Interaction of Color*, (1963, reprint 2006). p.17.

camouflage ships during World War I.[25] Contrary to other forms of camouflage, razzle dazzle makes the object highly visible, but hard to identify its type, speed and orientation by applying contrasting colour patterns that are inconsistent with the shape of the object they are drawn upon.

COLOUR 3D PRINTING

The first 3D printing technology that could print in multiple colours was developed by Z-Corporation in 2000.[26] The printing process works as follows: A print head ejects coloured resin onto a horizontal layer of gypsum-like powder; after hardening, a new layer of powder is added on top. The process is repeated and gradually a 3D artefact is formed. During the printing process the unhardened powder supports the layers above, so overhangs, cavities and objects within objects can be printed. After the printing process, the fragile printed artefact is removed from the powder, excess powder is removed and the model is submerged in glue-like liquid, to strengthen the model, and make its surface less porous.

In terms of software, the technology builds on earlier 3D printing technologies, such as stereo-lithography and laser sintering[27]: it requires a watertight triangulated mesh, which is sliced into horizontal layers; each layer is translated into the movement of the print-head. The colour information is added to the triangulated mesh and can be provided to the 3D printer in different ways: one colour per vertex, where the resulting colour of the face is a gradient of each of these colours; one colour per face or an image can be mapped over the mesh as a 2D texture. In all cases the colour information is limited to the surface of the mesh and has no thickness. This modelling technique is borrowed from animation software and virtual environments that require only the outside of a shape to be rendered as an image on screen.[28]

Colour 3D printing is marketed towards architects with imagery[29] showing scale models of houses, complete with textures, coloured furniture and foliage (Fig. 1). The technology is presented as a final

25 There is some debate as to who invented Dazzle Camouflage, which is attributed to artist Norman Wilkinson (1878-1971) but could be ascribed to zoologist John Graham Kerr (1869-1957). See http://en.wikipedia.org/wiki/Dazzle_camouflage (consulted on 20/10/2014).

26 See http://www.3dsystems.com/press-releases/z-corporation-introduces-the-fir (consulted on 20/10/2014).

27 For an overview of techniques, see Claire Warnier and others, *Printing Things: Visions and Essentials for 3d Printing* (2014). Pp. 9-18.

28 The Z-Corp printer requires a vrml file, a file format stemming from the 90s that was aimed at creating online virtual worlds. See http://nl.wikipedia.org/wiki/VRML
(consulted on 17/10/2014).

29 The images can be consulted on the flikcr account of i.materialise, a printing service I used for this exploration. https://www.flickr.com/photos/imaterialise/sets/72157624653006736/
(consulted on 17/10/2014).

presentation tool to lure in potential clients, as 3D version of a slick presentation rendering. The fragile gypsum powder technique has its limits: the surface is rough and porous, and the minimum wall thickness is about 1mm with a maximum building envelope of 300 x 200 x 200 mm. On the scale of a typical presentation model, the combination of the added realism of colour with the plumpness of its features leaves the uncanny impression of a doll-house like world.

LIGHT INTENSITY AND TRANSLUCENCY

The interest in objects with different experiential states based on varying light intensities builds on a previous design project called *Low-Poly Lamp (*Figs. 2-5). This project combined the capacities and limits of both subtractive and additive digital fabrication in a bespoke design tool, scripted in Processing. The script generated a low-polygon mesh, the faces of which were laser-cut from translucent acrylic sheets and the corner-pieces were 3D printed in black ABS plastic. The script incorporated fabrication parameters and material thickness and tolerances and exported the files for both fabrication processes. The panels and corner-pieces could be joined into a convex lampshade without glue.

After fabricating and assembling the series of prototypes and final lamps, some unanticipated features emerged: On the outside the connecting principle is quite visible, as the tabs stick through the acrylic panels, whereas on the inside the corner-pieces hide the connecting tabs, which shows a much more abstract figure. The irregular low-polygon shape gives the lamp a different contour when viewing it from different angles. When the lamp is not lit, the different angles of the faces give each a different light intensity. When the lamp is lit, the light coming through translucent white acrylic flattens out these different intensities; this reduces the appearance of the lampshade to an irregular white planar polygon contrasting with the black corner pieces (Fig. 4).

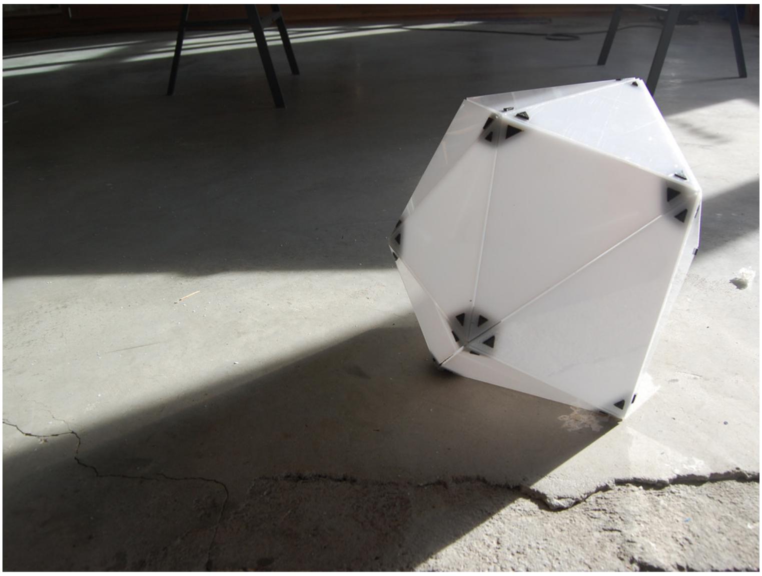

Fig. 2. Lowpoly lamp prototype 1.

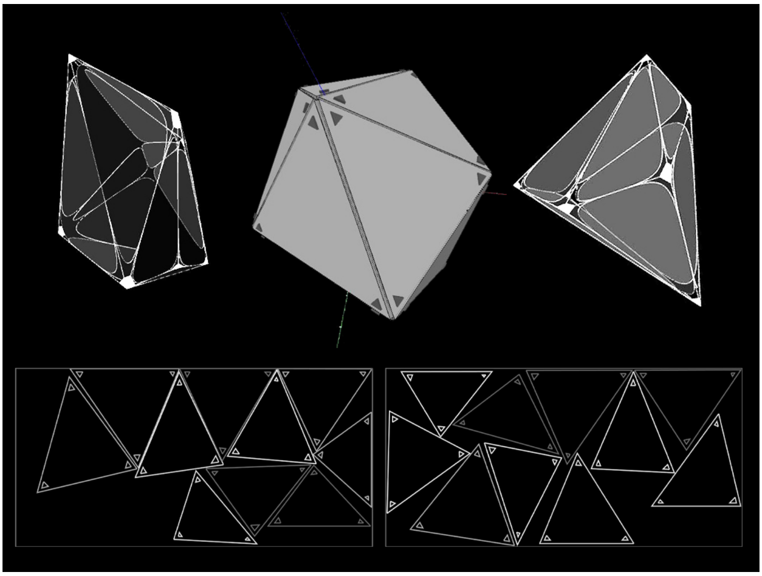

Fig. 3. Lowpoly lamp software.

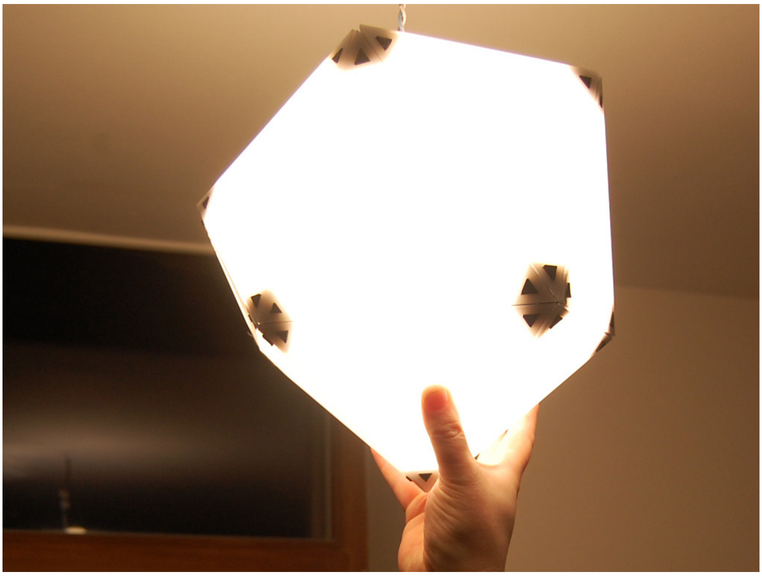

Fig. 4. Lowpoly lamp lit.

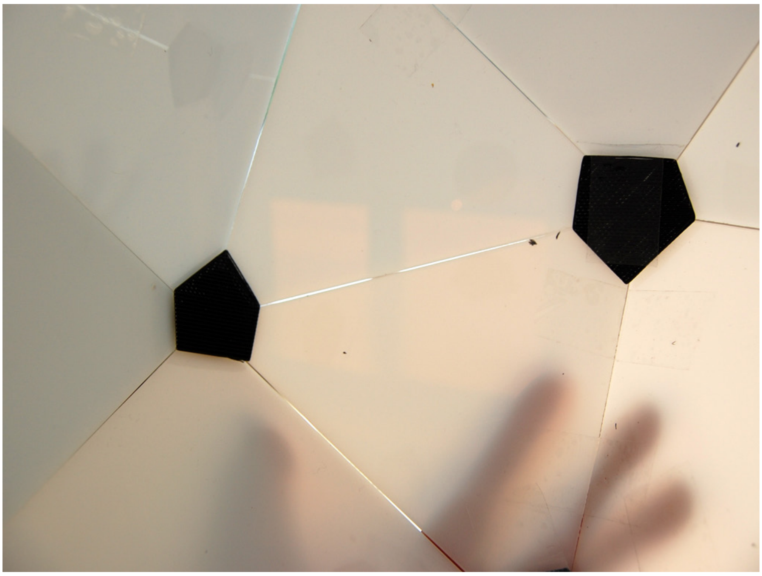

Fig. 5. Lowpoly lamp interior.

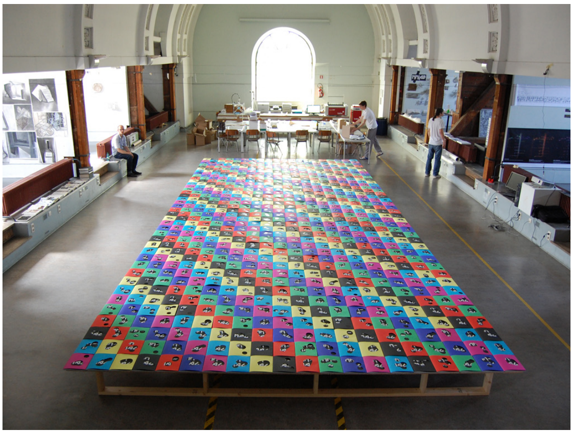

Fig. 6. CrMgYbK installation.

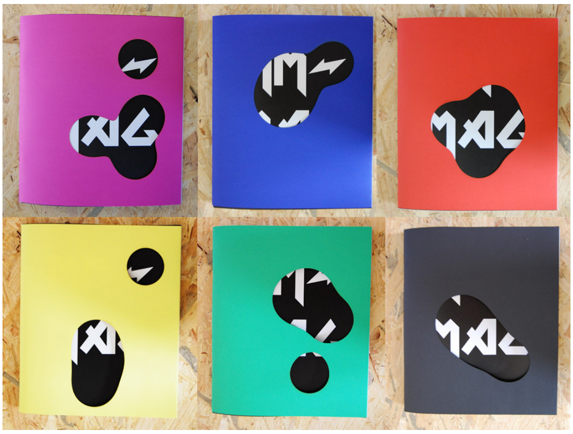

Fig. 7. CrMgYbK unique magazine covers.

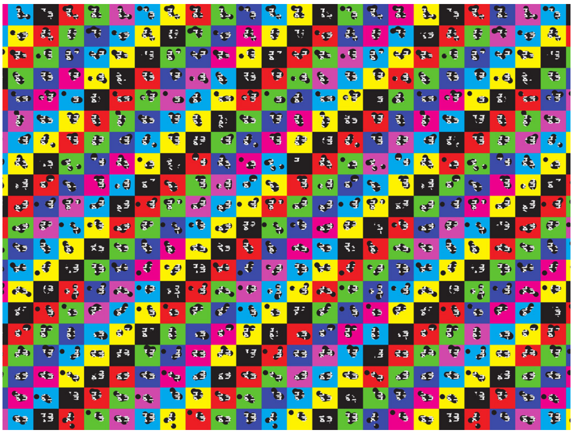

Fig. 8. CrMgYbK seemingly repetitive pattern.

COLOURS FOR SCREEN AND PRINT

Our perception of the colour of an object depends on the material properties of the object as much as on the light conditions and other colours that surround it. Colouring objects through ink and paint works by absorbing certain spectra of light while reflecting others. Mixing colours through paint and ink is known as *subtractive* colour mixing – mixing two paints will adsorb light frequencies absorbed by both and look darker. On the other hand, mixing different coloured light, as in a projector or on a screen, is known as *additive* colour mixing – mixing two coloured light beams will add frequencies of both and look brighter.

This is also reflected in how colour is described and stored digitally: Screen colours are described by their respective red, green and blue values (rgb); mixing all of them leads to white. Colours for print are described by their cyan, magenta, yellow and black values (cmyk); in principle black could be achieved by mixing the first three, but in reality this is hard to achieve due to impurities, and black is added separately.[30] Colour 3D printing uses a file format called vrml, the origins of which lie in on-screen and online virtual worlds, not in the materialised world of 3D printing. Somewhere in the process of sending a file to, and a material artefact emerging from, the 3D printer, a conversion happens from one colour-space to another.

A play on the different ways of representing colours digitally can be found in a previous work called CrMgYbK (Figs. 6-8), which reflects on material manifestations of digital phenomena and combined elementary screen and print colours. For the end of year exhibition of the Sint-Lucas School of Architecture in 2010, we collected the work produced by the mixed media department in a magazine. Each of the eight-hundred magazines had a unique cover through the use of the three elementary screen colours and four print colours combined with a custom cut-out that revealed black and white typography (Fig. 7). The magazines were positioned using a script producing a seemingly repeating pattern, which sometimes skips colours based on the rounding of integer numbers (Fig. 8). The magazines were displayed on a large table, and the cut-outs were used as giant, blob-like confetti during the exhibition opening (Fig. 6).

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[30] See http://graphics.stanford.edu/courses/cs178/applets/colormixing.html (consulted on 17/10/2014).

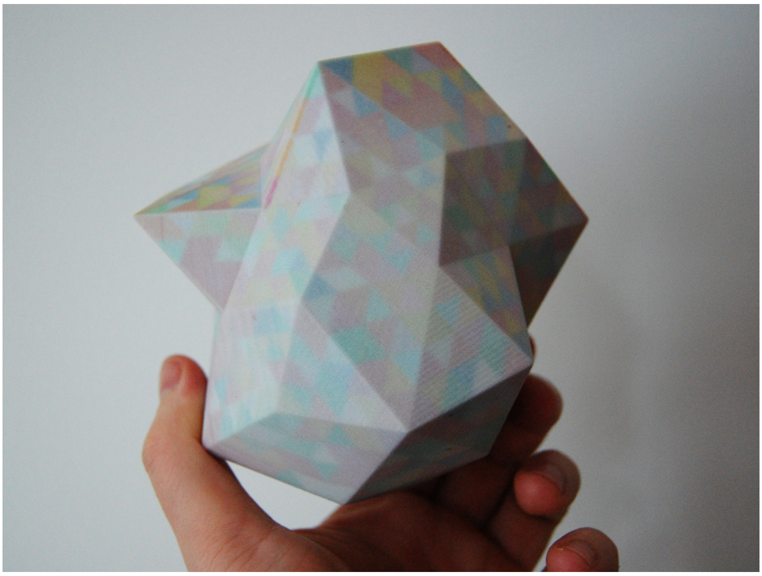


Fig. 9. Dazzle lamp early prototype a1, colour is still bleeding through.

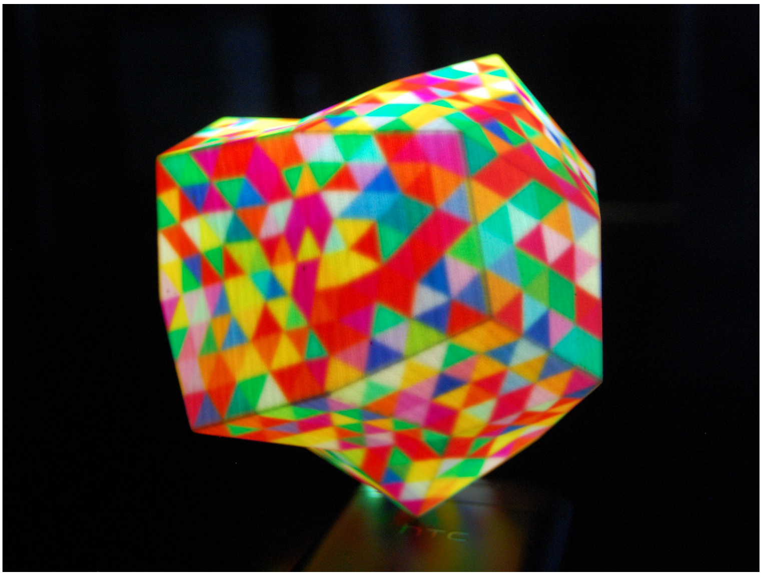


Fig. 10. Dazzle lamp early prototype a1 when lit.

BECOMING MATERIAL

The *Dazzle Lamp* project (Figs. 9-29) started out of an interest in the transformations that occur in the translations from a digital file to a material artefact, and what traces of the file and the fabrication process would be readable in the materiality of the fabricated artefacts. In other words, I was interested in colour 3D printing not as a representational medium, but as means of making in its own right. The technology was not explored as a presentation technique, for which it was designed and marketed, but for its peculiar materiality and for the potential adding colour offered for design.

Building on the previous work – the two projects outlined above – I was particularly interested in what the addition of colour to 3D printing could deliver in terms of intensive material qualities, light, colour and translucency, and in its ability to embed different experiential states into the materiality of an object. I was interested in how the two dimensional, screen-based encoding of the colour information would manifest itself in material print and thus become three dimensional.

Initial prints were made to test the different colouring modes and evaluate the material qualities (Figs. 13-14). The prints showed that the colours were sensitive to light, dust and moisture: the colours on the surface of the objects became pallid quite fast without an extra coating. I decided to apply the colour on the inside of a lampshade, thus protecting the colour from external light and dust. Building on the effect of translucency flattening out the reading of an external form, as discovered in the *Low-Poly Lamp* project, the idea was to design an object which was pristine white when lit from outside becoming colourful when lit from inside (Fig. 10).

A number of iterations had to be printed, testing variations in colour, different sizes and different starting forms and degrees of deformation. The wall thickness proved to be especially tricky: balancing the need to be thin and translucent enough for light to shine through but thick enough for the colours not to bleed through and become visible on the outside. When cutting the shell of a prototype, the ink can be seen bleeding into the material somewhat

Fig. 11. Dazzle lamp early prototype a2 in-between state (next page).

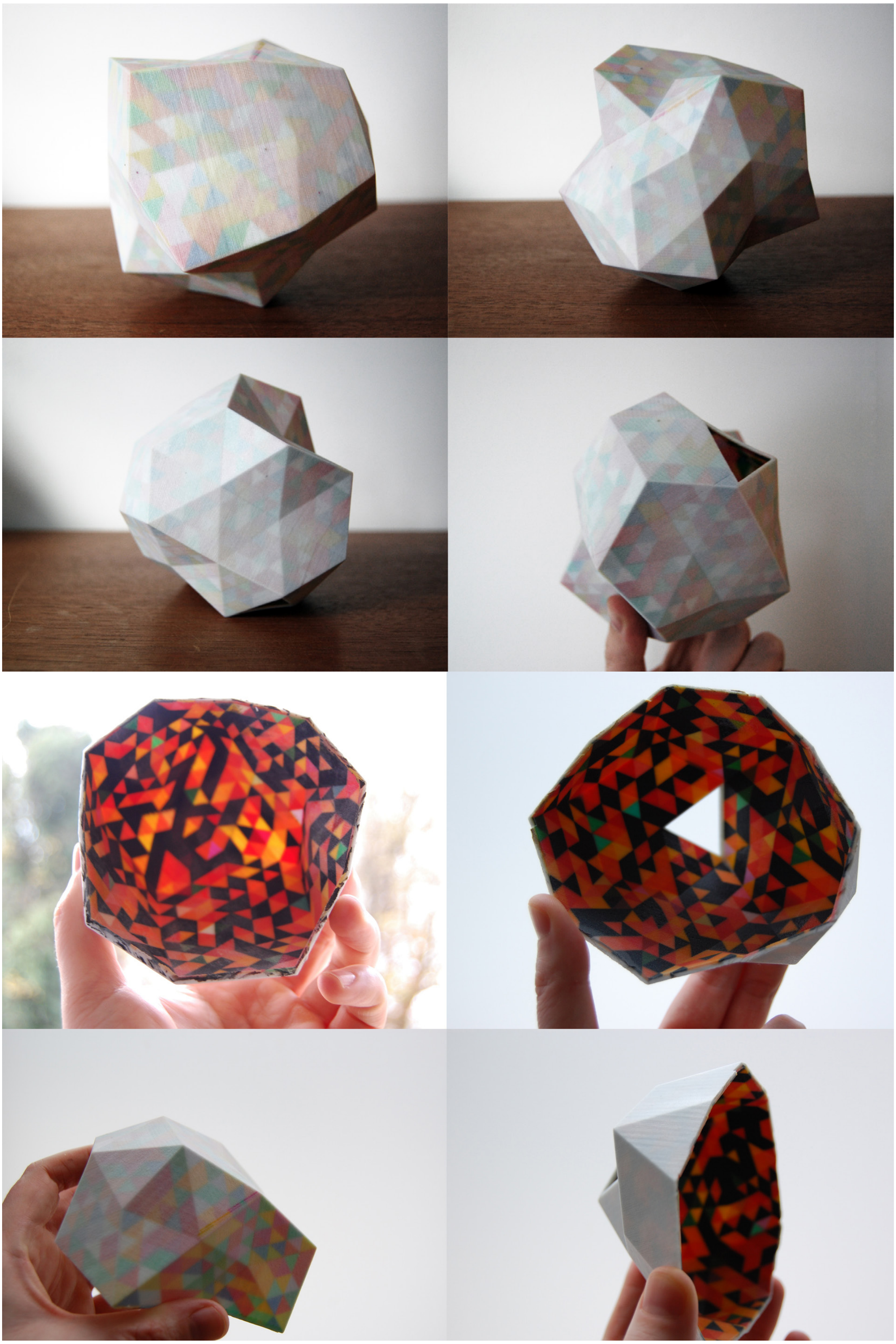


Fig. 12-15. Dazzle lamp early prototype a1 view from different angles.

Fig. 16-19. Dazzle lamp early prototype a2 cut open.

(Opposite page).

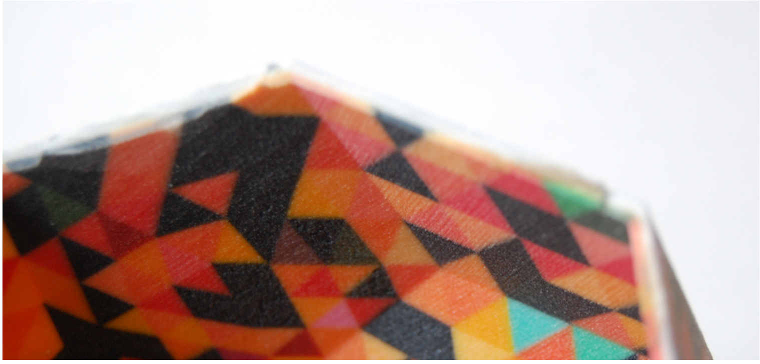


Fig. 20. Dazzle lamp early prototype a2 bleeding ink.

more than a millimetre, although it apparently varies depending on the angle of the respective face with regards to the direction of the layers (Fig. 20).

Using the colour on the inside can be seen as exploiting a discrepancy between the information in the file and the fabrication technology and as a design feature rather than a coincidence or even a problem. By using the colour to design a translucent shell, the light passes through the whole volume of coloured material and is not just reflected on the surface. This volume of coloured material is absent from the information contained in the file, where it is described as a surface without thickness, let alone grain and bleed.

Next to difference in colours, I wanted each lamp to be formally different but clearly belonging to the same design family (Figs. 12-15). The overall form is determined by deforming a basic mesh; I wanted to go beyond the purely convex hull of the *Low-Poly Lamp* and also allow concave deformation. In the end, I decided on starting from a geodesic dome deformed by scaling each vertex towards the centre of the dome, resulting in straight planes cutting through the deformed mesh. The deformations happen in such a way that the centre of mass remains under the triangular hole used for hanging or standing. The inside of the mesh is subdivided into smaller triangles, and each of the smaller triangles is given a different colour. So, turning on the light will provide a colourful image, which distorts the perception of the external shape.

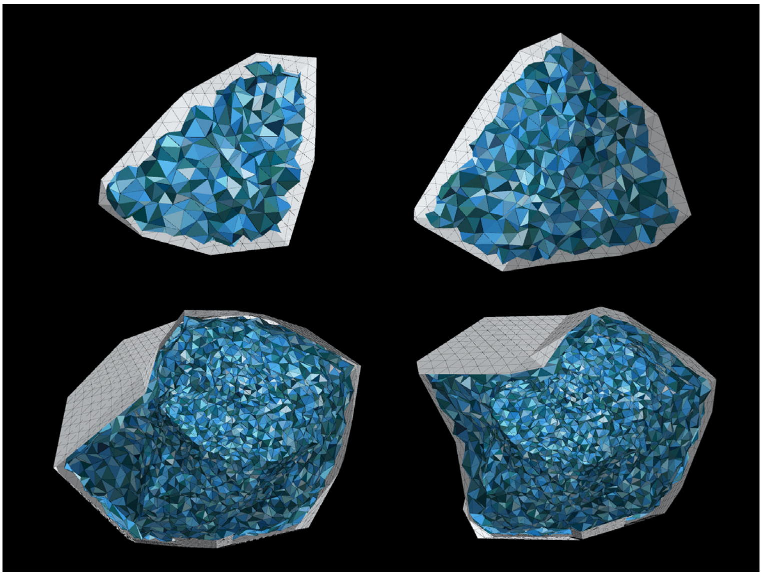
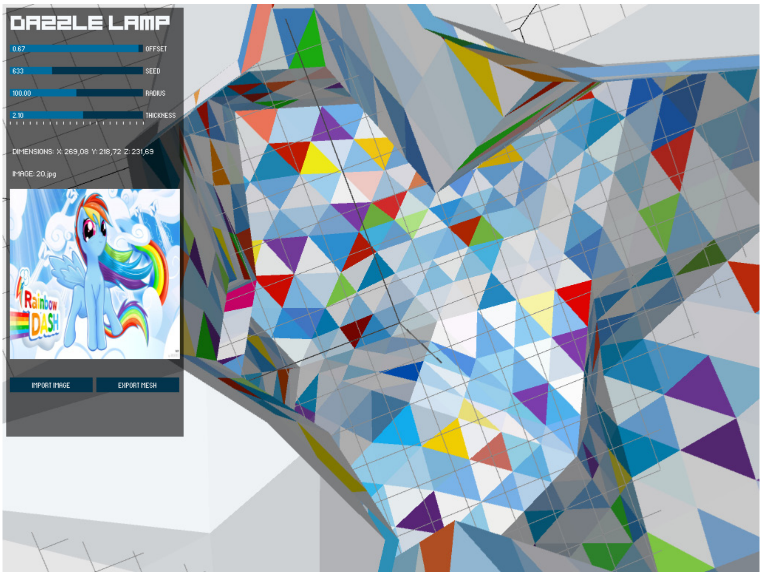


Fig. 21 Dazzle lamp, sketch software.


DAZZLE LAMP

0.67 OFFSET
633 SEED
100.00 RADIUS
2.10 THICKNESS

DIMENSIONS: X: 269,08 Y: 218,72 Z: 231,69

IMAGE: 20.jpg

Rainbow
DASH
IMPORT IMAGE
EXPORT MESH

Fig. 22. Dazzle lamp design tool.

FROM PROTOTYPING TO DESIGN TOOL

Several software sketches (Figs. 21-22) were made during the development of the design of the *Dazzle Lamp* series, overcoming technical difficulties, testing a formal language and pushing material properties. I ended up coding a custom exporter for the *vrml* file directly from Processing. This resulted in a design tool that anticipates fabrication, incorporates limits of the technology and materiality and takes into account use either as a hanging or standing lampshade. The final software can be seen as an encoded understanding of a specific fabrication technology, similar to the design tool developed for the *Encoded Matter* project, described later in this chapter.

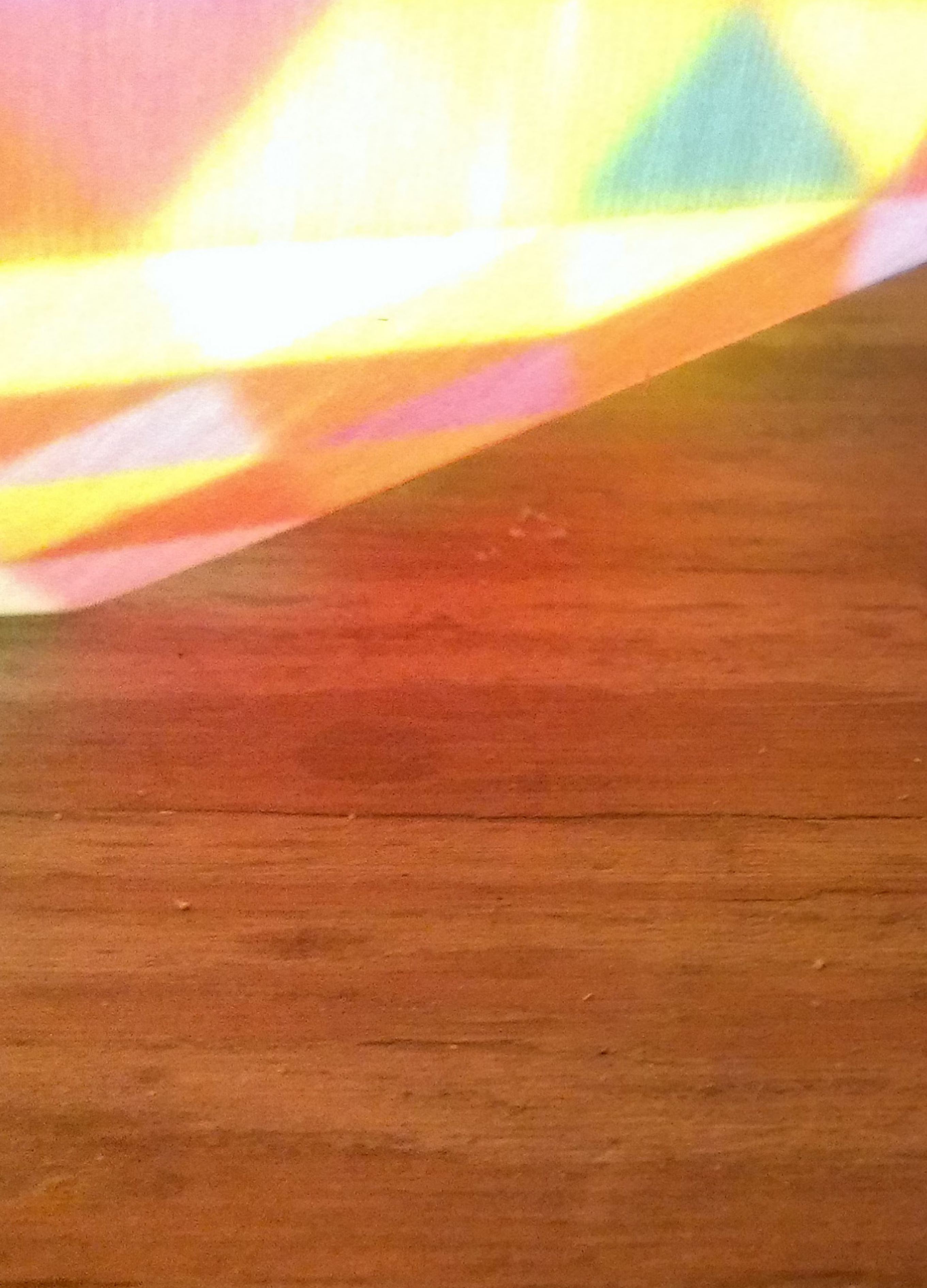
The technology used for this design exploration is closed and propitiatory in terms of its software, internal workings and exact material composition. As I had no access to an actual machine, the process of prototyping went through different online services. The time between uploading a file and the print arriving would be around ten working days – that is, if the file passed all the algorithmic and human checks in between. With a print that pushes the material limits of the technology, I would often get a message that files were not printable; only after taking upon myself the risk of a failed print would they be printed.[31]

With the *Dazzle Lamp* I wanted to take the development of the prototyping tool a step further and open it up for other people to design their own custom versions of the lamp. Through a graphical user interface, a number of parameters can be controlled: the deformation of the overall shape, its size and the colours. The colours are picked from an image which can be opened or dragged into the application. The application also generates an armature for a standing and a pendant light fixture. At the moment of writing, an online version is being released where custom versions can be designed and ordered.[32]

Fig. 23. Dazzle lamp prototype b1 intensive colours (next page).

[31] I used both shapeways.com and i.materialise.com; shapeways has since strengthened its policies on minimum wall thicknesses, so the first prototypes, painfully tweaked for their machines, can no longer be printed.

[32] This will happen in collaboration with Limemakers; see limemakers.com.



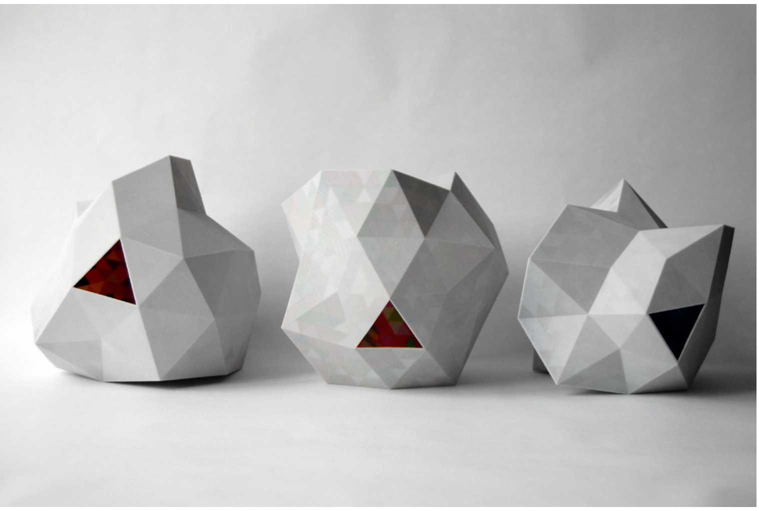


Fig. 24. Dazzle lamp prototypes b1-3, outside.

REFLECTION

The transformation from a digital file into a material artefact, like one of the *Dazzle Lamp* prototypes, is far from as a smooth and direct process as the technology that is being promoted to architects and designers. The distance and closed nature of the fabrication technology, which was both subject and means of exploration, considerably slowed down the iterative and prototypical design process.

Looking closely at the printed prototypes, it is clear that they contain traces of the file types – the triangulation of the meshes, the colours defined per face – the materials, – the grain and rough surface of the gypsum print – and the process of fabrication – visible layers. In other words, the digital model, the material and the fabrication process have an influence on the design outcome; to design with digital fabrication, we need to understand *file, matter* and *factory* as having agency.

Looking back on one of the *Dazzle Lamp* prototypes, which has found a place on a cupboard in my living room, as an object it belongs to both the digital world of meshes, surfaces, pixels and rgb values as it does to the material world of gypsum and its grain, bleeding ink,

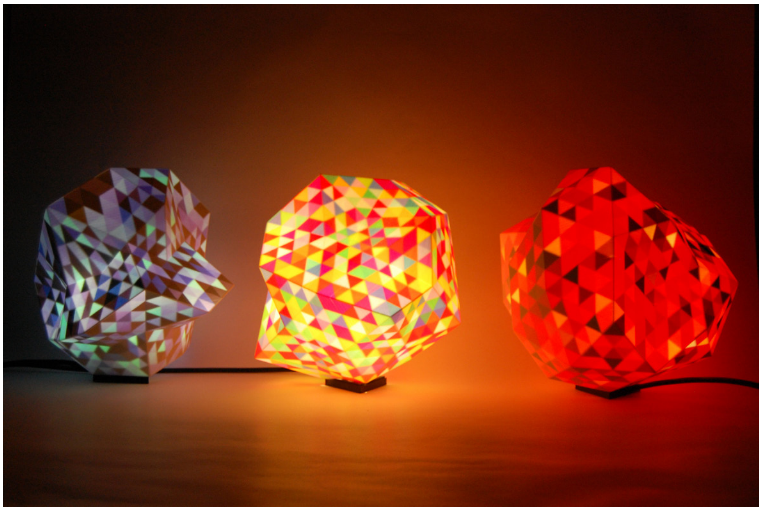


Fig. 25. Dazzle lamp prototypes b1-3, lit.

dust and moisture. When lit, the dazzling triangulated pattern makes it hard to make out its exact form: the two dimensional drawing on the shape confirms some external triangles while it hides others. Although it does not use the exact same strategy as the dazzle camouflage that inspired it, the lampshade also hinders the reading of an object in plain sight by applying two-dimensional patterns over its form (Figs. 24-25).

However, the design is governed by a number of oppositions – light on or off, coloured or white, interior or exterior experience – and was designed with these two extreme states in mind: either pristine white or full of colour. Because of the intensive nature of the light and colour, an infinite amount of moments exist between these two extremes, where colour start to shine through in certain parts while still being hidden in others. While I anticipated this, and colour 3D printing was selected exactly for this reason, the material artefacts display qualities that could not be displayed on screen and were not fully anticipated in the files used for fabrication. Through iterative prototyping it was exactly the material properties lacking from the file – thickness, bleed of colour – that were pushed in the design process to achieve this.

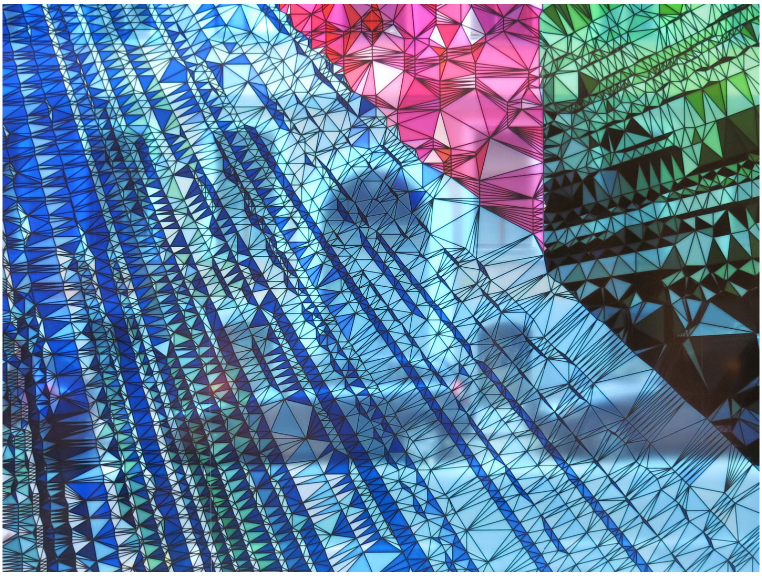


Fig. 26. Spectra view from inside, through window.

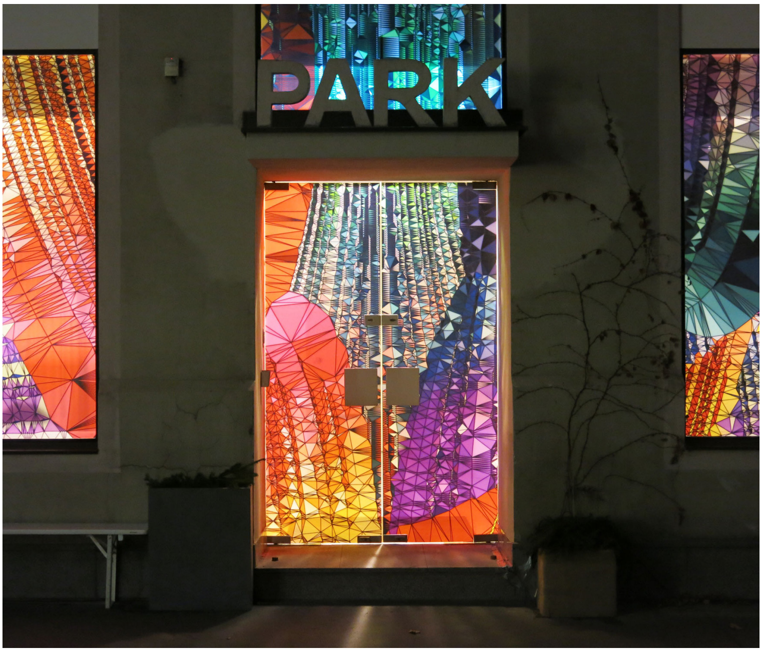


Fig. 27. Spectra exterior view at night.

EPILOGUE: SCALING UP

In both the *Low-Poly Lamp* and *Dazzle Lamp* series, there is a clear difference between the interior and exterior appearance based on changing light intensities. Although both these series of lamps are limited in scale, the idea of using light and colour to articulate different experiential qualities in time is an architectural theme that has a substantial history in architecture and design.[33] This is not tied to a specific fabrication method and can be applied on larger scales.

An opportunity to test this proposition on a larger scale presented itself when I was invited to collaborate on an installation project for the Park gallery in Vienna (Figs. 26-27). The project was developed for Pelican Avenue, a design collective from Antwerp mainly working in the field of fashion, but their creative output extends into installations and video. They were invited to exhibit their work in Park gallery and got the opportunity to develop an installation for the event.

Since they use a lot prints on textile in their work, it was decided early on to work with printed film on the façade, showing patterns based on the designs by Pelican Avenue. My role in this consisted of coding a custom design tool that transformed images into triangulated patterns. The tool allowed for different patterns to be tested and files to be exported for printing and was then used by Pelican Avenue to finalise the design. Although the fabrication technique is different, the *Spectra* installation shows similar experiential qualities as the ones explored in the development of the *Dazzle Lamp* series.

[33] Glass windows of Gothic churches being the most obvious examples, but also Joseph Albers' glass assemblages at Bauhaus and Le Corbusier's use of coloured glass in Ronchamp come to mind.

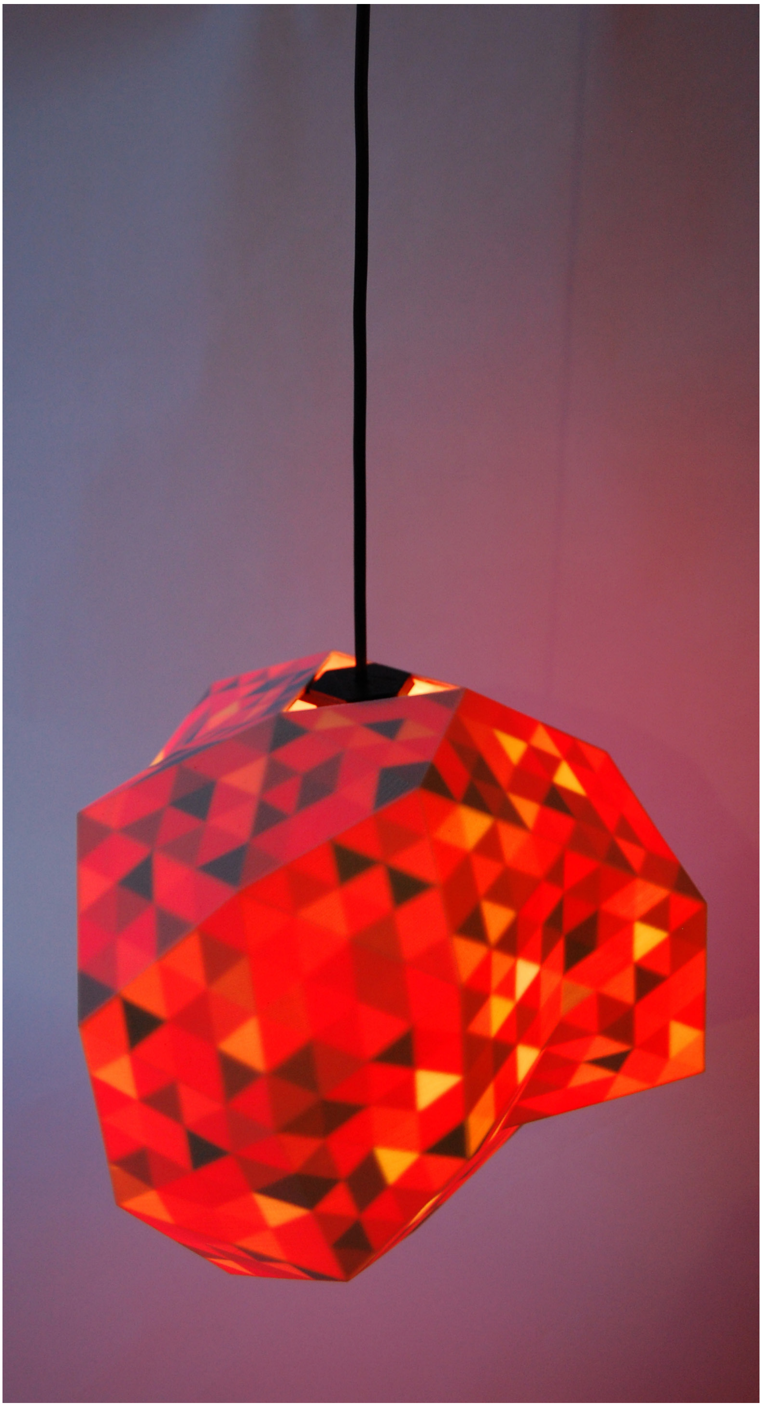


Fig. 28. Dazzle lamp prototypes b2, hanging, lit.

ACKNOWLEDGEMENTS

The prototypes of the Dazzle Lamp were exhibited in London and Paris, were published in several magazines and received some coverage in the blogosphere.[34] An online version is being developed at the moment in collaboration with limemakers, a start-up in Berlin.

The *Dazzle Lamp* series was inspired by works of Matthew Plummer-Fernadez, whose 3D scanned and deformed Mickey Mouse series raised questions on copyrights and sampling in 3D print design. We shared code and thoughts by e-mail during the project.

The magazine[35] for *CrMgYbK* collected works of students and colleagues in the mixed media department; redaction was done by Carl Bourgeois, Pieterjan Ginckels and myself and the layout of the magazine and the installation was designed by Pieterjan Ginckels and myself.

The *Spectra* installation was designed by Pelican Avenue, which consists of Carolien Lerch and Michiel Helbig, and the photography was taken by Michael Strasser and Pelican Avenue.

Fig. 29. Dazzle lamp prototypes b1-3, lit (next page).

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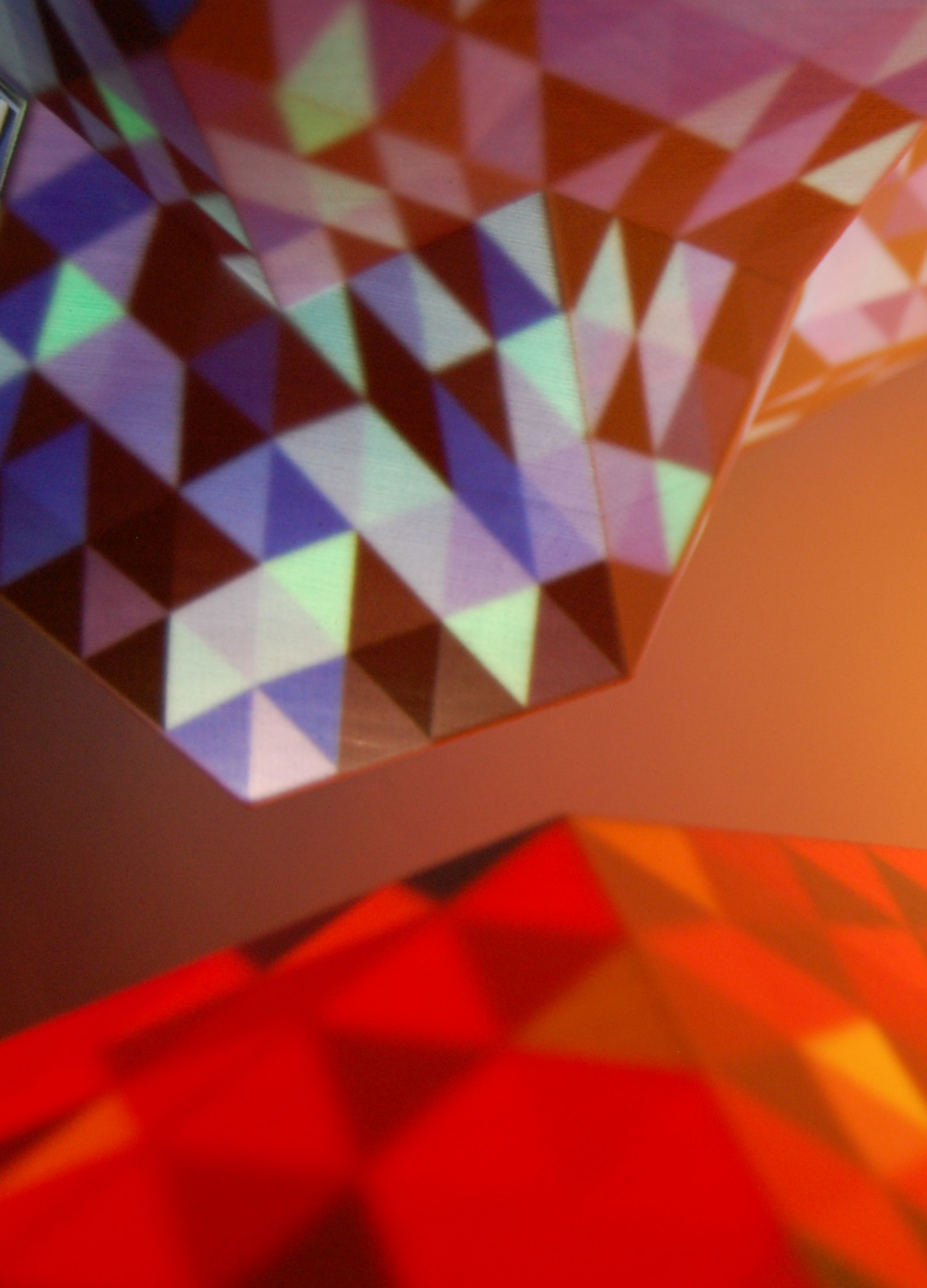
[34] See, amongst many others, http://www.dezeen.com/2014/02/09/3d-printed-dazzle-lamps-corneel-cannaerts/ (consulted on 05/07/2014),

[35] Carl Bourgeois, Corneel Cannaerts and Pieterjan Ginkels (eds.). *MMMAG* (2010).



CASE 3.2: DIGITAL TRACES and MATERIAL THREADS

Encoded Matter | Design Exploration| MMlab | 2012-2013

“Threads may be transformed into traces, and traces into threads. It is in through the transformation of threads into traces, I argue, that surfaces are brought into being. And conversely, it is through the transformation of traces into threads that surfaces are dissolved”.[36]

TRACES AND THREADS

Materials go through a number of transformations before they are applied in architecture and design: Materials are formed through processes of growth, sedimentation and synthesising; they are mined, harvested, gathered and refined; they are sawn, cut, bent, moulded, etc. Transformations continue during the making process of architecture and design, and beyond construction through use, ageing and weathering, repair, etc. These processes of transformation leave traces in the material and in the materiality of the artefacts made from them. Working with these traces of material formation, working materials, construction and assembly and anticipating traces of use and wear has a long lineage of precedents in architecture and design.[37]

The traces found in materials are often as much the result of their growth or sedimentation as they are of disciplining material through industrial processes, into sheets, beams and building blocks for construction. The conception of architecture as being essentially built up from geometric blocks, like a giant jigsaw puzzle, is dominant in architecture today.[38] Geometry plays a crucial role in describing and preparing materials for construction, and this conception is strengthened by the adoption of CAD software, which tends to describe construction elements as geometric blocks, only referring to their materiality through notation such as hatches and text.

Tim Ingold states that this understanding of architecture as being assembled from blocks of material is relatively recent and argues that the origins of making and construction can be found in weaving, basket making, carpeting and other crafts. In these practices of making, form is not predefined as a kit of parts, but emerges from a gradual weaving and building up of threads. Also, in stone cutting or woodworking, there is an understanding of the intensive material make up, and overall form unfolds in time through that understanding.[39]

Digital fabrication can be seen in the light of the ideas outlined above: materials used in digital fabrication tend to be highly standardised – sheet and block materials for cutting and milling,

[36] Tim Ingold, *Lines: A Brief History*(2007). p.52.

[37] While many examples could be given of architects and designers with a particular attention for these traces, I refer here to the books by Jonathan Hill, *Actions of Architecture: Architects and Creative Users* (2003) and *Immaterial Architecture* (2006).

[38] This is called *hylomorphism*; see the introduction to the first chapter. See Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (2013), pp. 20-25.

[39] Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (2013).). pp. 47-48.

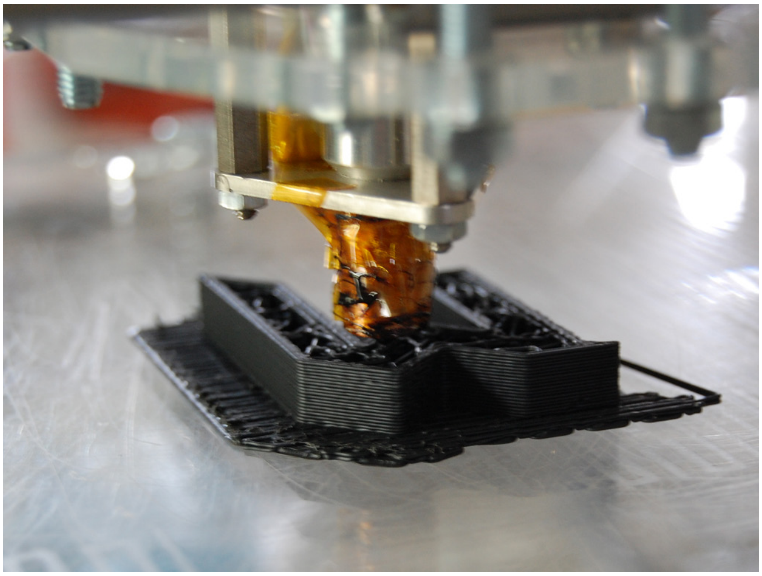


Fig. 30. First reprap machine built at MMlab

MMLAB
EXTENDED

Fig. 31. MMlab extended workshop.

filament or powder for additive manufacturing – but fabricated artefacts tend to be highly specific, non-standard and unique. This has typically led to an even more complex kit of parts, where every component that makes up a structure is unique and can be described geometrically and exactly fabricated.

Digital fabrication processes leave traces of their own – the trace followed by a cutting mill, the burned edges of a laser cut sheet or the layered build-up of additive manufacturing. Instead of using digital fabrication for precision and exactly replicating digital models, an alternative use of digital fabrication can be found in exploring these traces. Crucial to such an approach is understanding digital fabrication as a process that unfolds in time.

This case discusses *Encoded Matter;* it is a series of design explorations that looks into the specific material qualities of d.i.y., open-source, digital fabrication technologies. The openness of this technology allows for an extension of the control from controlling external form to controlling the fabrication process as it unfolds in time and the material traces this process leaves in the fabricated artefact.

OPEN TECHNOLOGY

The current interest in digital fabrication is a result from the opening up, democratisation and increased accessibility of these technologies, which have been developed just after the Second World War. Two projects in particular have been influential for my own use and understanding of this technology: The FabLab Project initiated at MIT by Neil Gershenfeld[40] aimed at opening up fabrication technologies to students, designers and the general public, encouraging sharing, and resulting in a global network of FabLabs and the RepRap project, initiated by Adrian Boyer of the University of Bath in 2005, which stands for *replicating rapid prototyper,* an open-source 3D printer able to produce most of its own parts.[41] It has since spawned a large number of open-source, d.i.y. and cheap 3D printers.

[40] Neil A. Gershenfeld, *Fab: The Coming Revolution on Your Desktop--from Personal Computers to Personal Fabrication* (2007).

[41] See http://reprap.org/ (consulted on 20/09/2014).

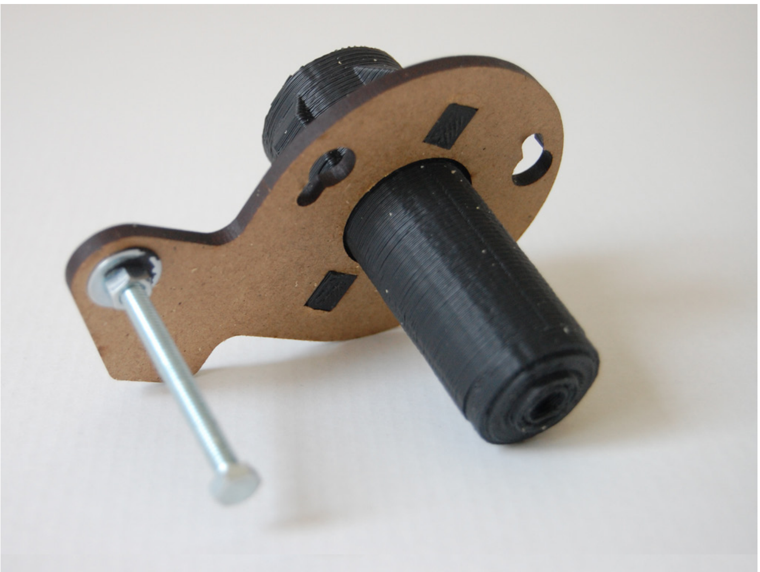


Fig. 32. Fabmod project, modified toolheads for the reprap.

The MMlab was established in the spirit of the FabLab project, aimed at opening up digital fabrication technologies to the students and faculty of Sint-Lucas School of Architecture. Within this context, I built my first RepRap machine in 2009 (Fig. 30), which gave me a good understanding of some of the difficulties and potentials of the technology. The *Encoded Matter* project has benefited from the accessibility, openness and low cost of the technology. Having a machine on my desktop while printing, experiencing the process in real time and not being afraid of breaking things when messing with the machine was liberating compared to the closed technology used in the *Dazzle Lamp* series.

The printer uses a process called *fused filament fabrication*[42]: a thermoplastic filament is fed to an extruder tool-head in which the plastic is melted. The tool-head moves in an x and y direction, depositing material and forming one layer; then, the platform is lowered in the z direction and the next layer is deposited. The prints are built up thread by thread, layer by layer, which results in the typically layered materiality. The technology has some limits and difficulties. Each layer needs to be partially supported by the previous

[42] The technology is also named *fused deposition modelling*, but that term is trademarked by Stratatsys, who first developed this technology. It is only since the original patents on the FDM technology expired that there has been an increase in 3D printing. See http://reprap.org/wiki/Fused_filament_fabrication (consulted on 24/10/2014).

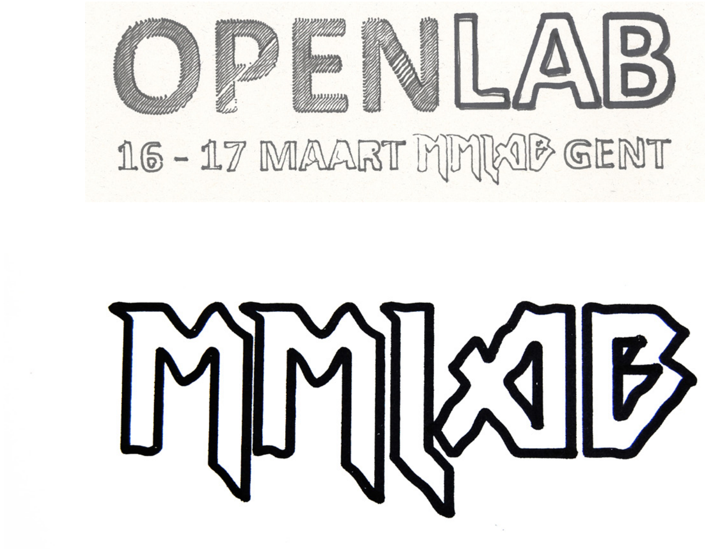


Fig. 33. Fabmod project, poster drawn by hacked reprap.

one although overhangs up to about 45° are possible. There is a temperature difference between the already deposited layers and the one being printed, since the material shrinks while it cools down, this can result in warping the print. When the toolhead moves over a gap in the print, the extrusion is stopped, but some material will still drip out of the nozzle, resulting in strings being formed on the side of the print. The process of going from a digital file to a material print follows these steps: Model or generate a digital 3D model, process this model through an external software and send the resulting file to the machine and print.

A previous project undertaken with this machine was called *Fabmod* (Figs. 30-33), where I hacked our RepRap 3D printer and replaced the extruder with different tool-heads to turn it into a drawing and milling machine. Since the RepRap technology is open-source hardware and software, hacking the machine was quite straightforward but required me to script software to provide for the movements required by the new tool-heads, which would inspire the *Encoded Matter* project described in this case.

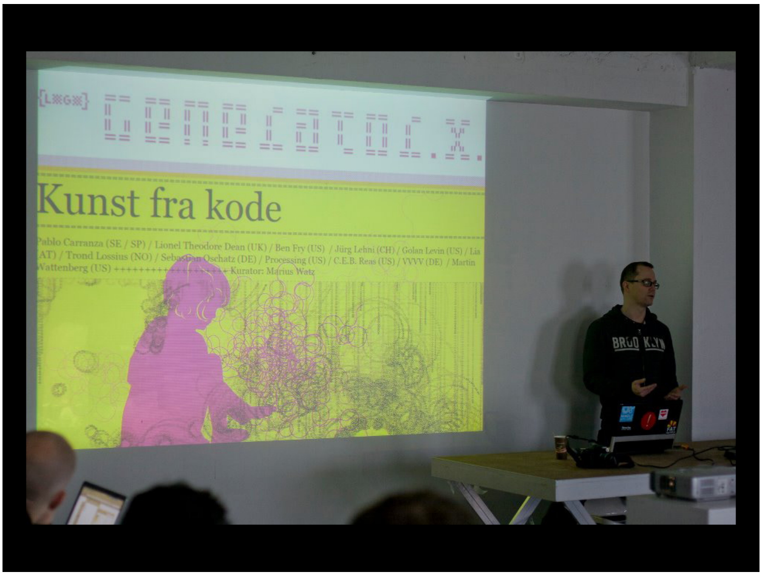

Generator.X.
Kunst fra kode
Pablo Carranza (SE / SP) / Lionel Theodore Dean (UK) / Ben Fry (US) / Jürg Lehni (CH) / Golan Levin (US) / Lia
AT) / Trond Lossius (NO) / Sebastian Oschatz (DE) / Processing (US) / C.E.B. Reas (US) / VVVV (DE) / Martin
Wattenberg (US) ++++++++++++++++++ Kurator: Marius Watz
BROOKLYN

Fig. 34. Generator.X, introduction by Marius Watz.

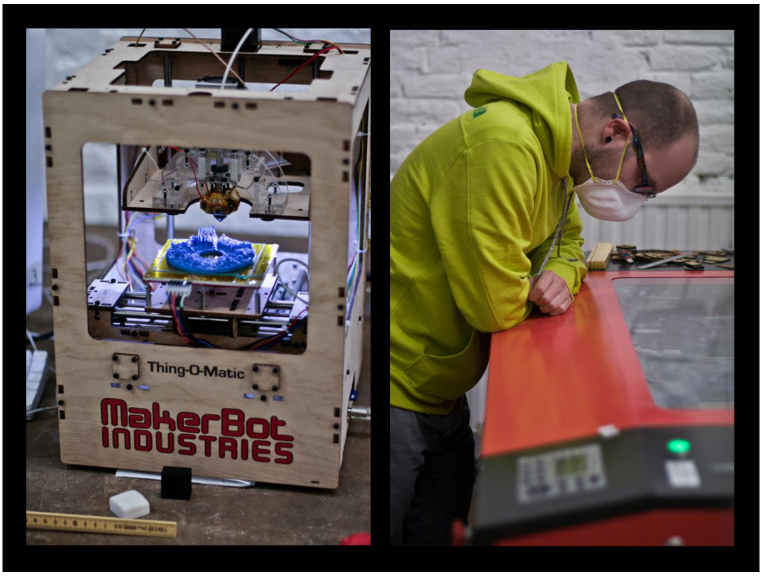

Thing-O-Matic
MakerBot
INDUSTRIES

Fig. 35. Generator.X, machines used.

ENCODED MATTER, PROJECT CONTEXT AND AIM

The first iteration of the *Encoded Matter* project (Figs. 36-60) was developed when in the context of *Generator.X: From Code to Atoms,*[43] master class with Marius Watz held at iMal in February 2012 (Figs. 34-35), in which I participated. This week-long intensive workshop brought together artists, designers and architects with diverse backgrounds to work with digital fabrication machines. What all these practitioners had in common was that they write code in one form or another as an integral part of their creative practice. The practitioners were selected based on previous work and a proposal for a project to be worked out during the master class. The event worked as a platform where all practitioners worked on their own proposed projects, the work presented in this case is the project I have initiated during this event and was further developed later.

As the tag-line – from code to atoms – suggests, the aim of the workshop was to explore the link between writing code and materiality through digital fabrication. The week started with introductory workshops in both computational design tools – Processing and the external libraries ModelBuilder[44] and HE_Mesh[45] – and digital fabrication machines – a laser-cutter, two MakerBot 3D printers and a 3-axis CNC milling machine. These machines were to become part of the FabLab at iMal, which was kick-started by this workshop. During the week, participants worked on their own projects, sharing knowledge and collaborating when necessary, and all documentation was collected on a wiki.[46] The week ended with a presentation of the produced works and the opening of an exhibition showcasing the work.

The master class was interesting not only for the discussed content, shared knowledge and produced work, but also for maintaining and establishing a network and extending a community of practice. Among the participants were Frederik Vanhoutte, developer of the HE_Mesh library and contributor to Processing Ghent and Share&&Tell;[47] Jan Vantomme and Bert Balcaen, co-founders of Processing Ghent;[48] and Frederik De Bleser and Lieven Menschaert, developers of NodeBox;[49] Mathew Plummer-Fernandez and Julien

Fig. 36. Encoded matter project, close up (next page).

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[43] For documentation of the workshop, see http://www.generatorx.no/20120301/generator-x-3-0-documentation-and-aftermath/ and http://www.imal.org/nl/activity/generatorx3 (consulted on 01/09/2014).

[44] See http://workshop.evolution-zone.com/ (consulted on 01/09/2014).

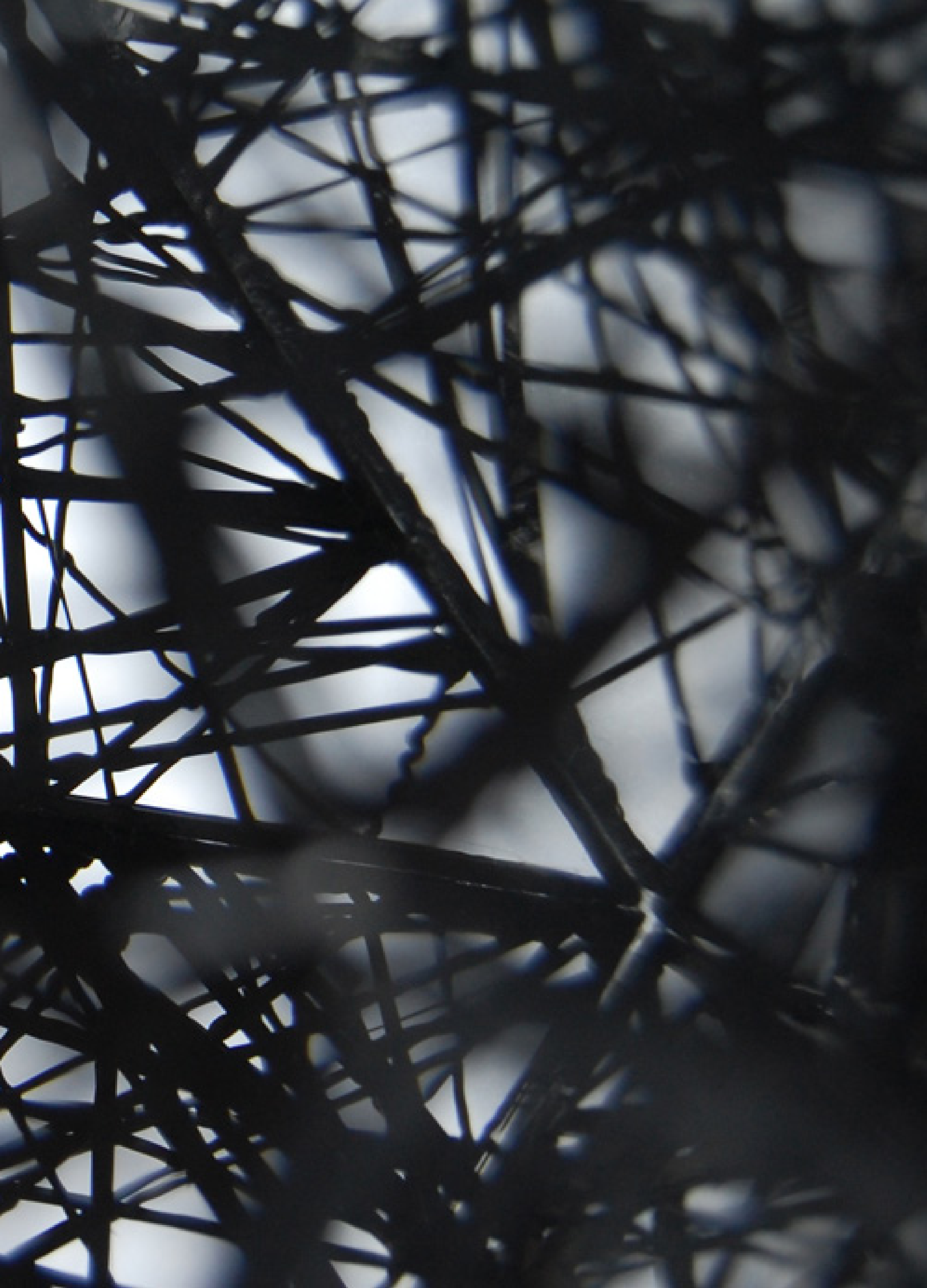
[45] See http://hemesh.wblut.com/ (consulted on 01/09/2014).

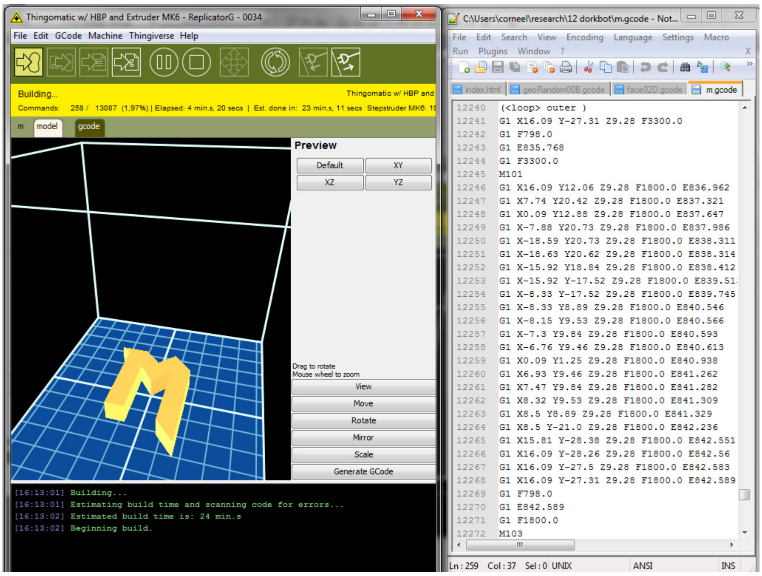
[46] See http://wiki.imal.org/ (consulted on 01/09/2014).

[47] Share && Tell was a series of lectures and workshops where practitioners writing code would be asked to give an informal talk on their work and share a piece of source code.

[48] Processing Ghent is a community of creative coders based in Ghent and is part of a global network of similar communities called Processing Cities; see: http://processingghent.org/ and http://www.processingcities.org/ (consulted on 20/09/2014).

[49] See http://nodebox.net/ (consulted on 20/08/2014).




Thingomatic w/ HBP and Extruder MK6 - ReplicatorG - 0034
File Edit GCode Machine Thingiverse Help
m
model
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Drag to rotate
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Move
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C:\Users\corneel\research\12 dorkbot\m.gcode - Not...
File Edit Search View Encoding Language Settings Macro
Run Plugins Window ?
index.html
geoRandom00B.gcode
face02D.gcode
m.gcode
Ln : 259 Col : 37 Sel : 0 UNIX ANSI INS

```
Building...                                                                          Thingomatic w/ HBP and
Commands:   258 /   13087  (1,97%) | Elapsed: 4 min.s, 20 secs  |  Est. done in:  23 min.s, 11 secs  Stepstruder MK6: 19
```

```
[16:13:01] Building...
[16:13:01] Estimating build time and scanning code for errors...
[16:13:02] Estimated build time is: 24 min.s
[16:13:02] Beginning build.
```

```
(<loop> outer )
G1 X16.09 Y-27.31 Z9.28 F3300.0
G1 F798.0
G1 E835.768
G1 F3300.0
M101
G1 X16.09 Y12.06 Z9.28 F1800.0 E836.962
G1 X7.74 Y20.42 Z9.28 F1800.0 E837.321
G1 X0.09 Y12.88 Z9.28 F1800.0 E837.647
G1 X-7.88 Y20.73 Z9.28 F1800.0 E837.986
G1 X-18.59 Y20.73 Z9.28 F1800.0 E838.311
G1 X-18.63 Y20.62 Z9.28 F1800.0 E838.314
G1 X-15.92 Y18.84 Z9.28 F1800.0 E838.412
G1 X-15.92 Y-17.52 Z9.28 F1800.0 E839.51
G1 X-8.33 Y-17.52 Z9.28 F1800.0 E839.745
G1 X-8.33 Y8.89 Z9.28 F1800.0 E840.546
G1 X-8.15 Y9.53 Z9.28 F1800.0 E840.566
G1 X-7.3 Y9.84 Z9.28 F1800.0 E840.593
G1 X-6.76 Y9.46 Z9.28 F1800.0 E840.613
G1 X0.09 Y1.25 Z9.28 F1800.0 E840.938
G1 X6.93 Y9.46 Z9.28 F1800.0 E841.262
G1 X7.47 Y9.84 Z9.28 F1800.0 E841.282
G1 X8.32 Y9.53 Z9.28 F1800.0 E841.309
G1 X8.5 Y8.89 Z9.28 F1800.0 E841.329
G1 X8.5 Y-21.0 Z9.28 F1800.0 E842.236
G1 X15.81 Y-28.38 Z9.28 F1800.0 E842.551
G1 X16.09 Y-28.26 Z9.28 F1800.0 E842.56
G1 X16.09 Y-27.5 Z9.28 F1800.0 E842.583
G1 X16.09 Y-27.31 Z9.28 F1800.0 E842.589
G1 F798.0
G1 E842.589
G1 F1800.0
M103
```

Fig. 37. Slicing a mesh into g-code, using replicator g.

Deswaef. Most of them I already knew and had collaborated with before; some I met during the workshop and were influential for later projects.

Starting from previous experiences of hacking a similar machine in the *Fabmod* project, the aim of the proposal I submitted was to explore the software side of this printing technology and the affordances and resistances encountered as a trigger for design. In other words, it was an exploration of what can be gained by not accepting the specific 3D printing technology as a given passive medium, but seeing it as an active area for design exploration. Compared to the *Dazzle Lamp* series described in the previous case, this technology was open and accessible, both in terms of hardware and the software operating the machine.

FABRICATION IN SPACE AND TIME

The workshop built on writing code as a creative practice, which is an inherently reversible, dynamic medium. In order for the output to be materialised, the dynamic process of the generative software needed

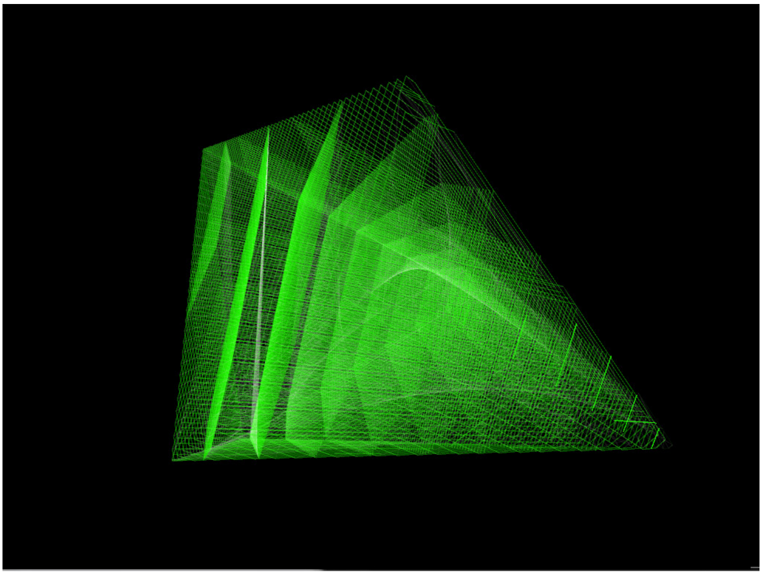


Fig. 38. Screenshot from processing sketch, generating g-code directly from processing.

to be stopped and static files needed to be exported, converted and sent to the machine for fabrication. Artefacts designed through writing generative software and produced using digital fabrication machinery are as much the result of the discrete and reversible time of code, the irreversible and discontinuous time of static files and the continuous but irreversible time of materialising and making.

The *Encoded Matter* project started from an interest in this freezing of time and the transformations between the dynamic processes of generative code, the process of materialising and the resulting static material artefact. A close reading of this process reveals a design environment with different layers of continuous feedback, where design progresses through a number of discrete irreversible steps. Designs are generated through code and evaluated as on-screen images. The resulting design can be either indirectly influenced by manipulating parameters, or directly manipulated by stopping the software altering the algorithm and rerunning the software. Once this reaches a moment or variation that seems interesting, a static file is exported. This mesh file is then taken through external software that slices it and prepares a g-code file to be sent to the

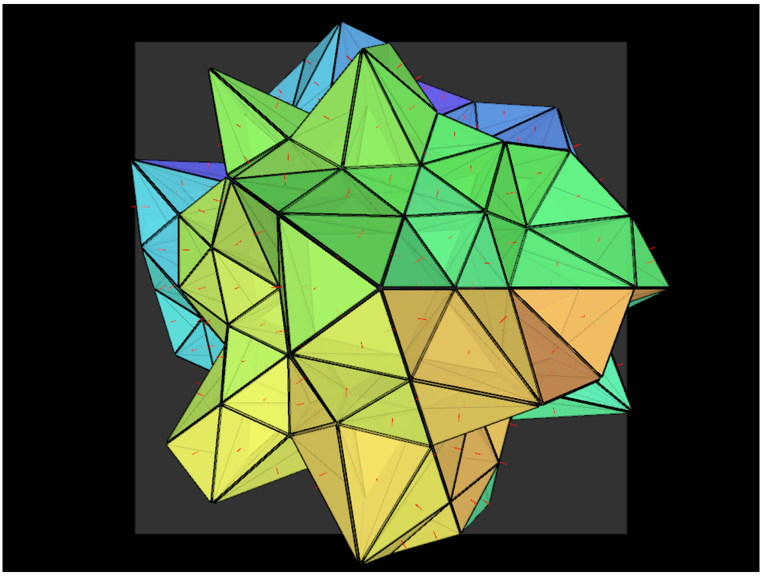


Fig. 39. Design software, mesh.

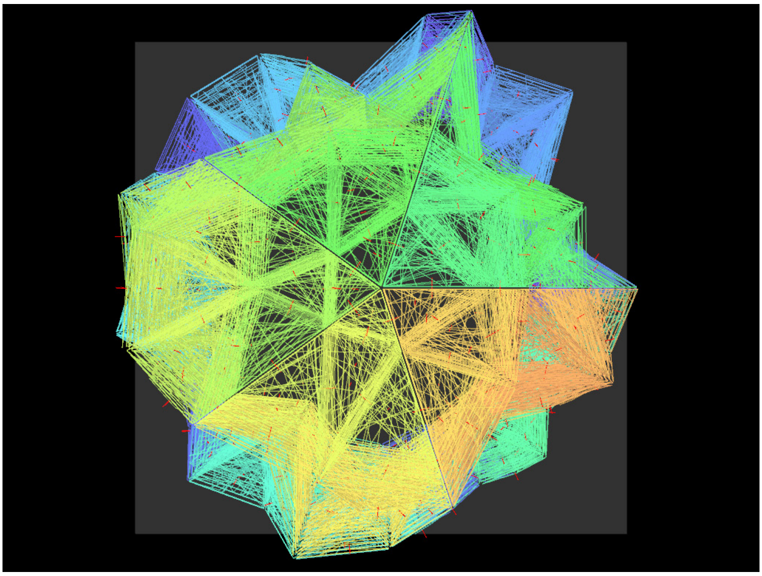


Fig. 40. Design software, toolpaths.

printer (Fig. 39). While the images on-screen provide a certain feedback, it is often only through actual fabrication that the results can be evaluated.

Both the mesh and the g-code files are static and irreversible stages in the process of making a 3D print, but they allow for a different control over the fabrication process and how it unfolds in time. Whereas the mesh merely captures the outside form of the artefact as a triangulated approximation, the g-code file actually encodes the process of its making in time. A g-code file contains different types of commands: M-codes which are machine-specific, setting for instance the temperature of the heated bed and extruder; g-codes which control the position of the extruder; F-codes which control the speed and E-codes which control the amount of material that is being extruded. Combined, they provide control over the amount of material deposited in space and time.[50]

G-code is a direct inheritance from the World War Two effort to develop a numerically controlled positioning system, which was used after the war for controlling fabrication machines. Although over the years many versions have been developed, the basis has remained unchanged. A g-code file is highly readable to someone with a basic understanding of code, but even for a simple 3D print can contain over ten-thousand lines of code. Although it is possible to just write it up from scratch, as was custom with early CNC milling, it is hardly convenient for artefacts beyond a certain complexity.

For this project, I decided to skip the in-between of the mesh and generate the g-code directly from within a custom design tool, which was written in Processing using the Code-Thread external library[51]. During the design exploration, a number of series of artefacts were designed and fabricated, and a specific design tool for each of these series was developed. After a series of tests providing proof of concept and grasping and tuning the different parameters at play, a number of material experiments was conducted in the order described below (Fig. 41).

[50] For a thorough explanation of g-code, see http://reprap.org/wiki/G-code (consulted on 26/09/2014).

[51] See http://blog.diatom.cc/category/codethread (consulted on 01/09/2014).

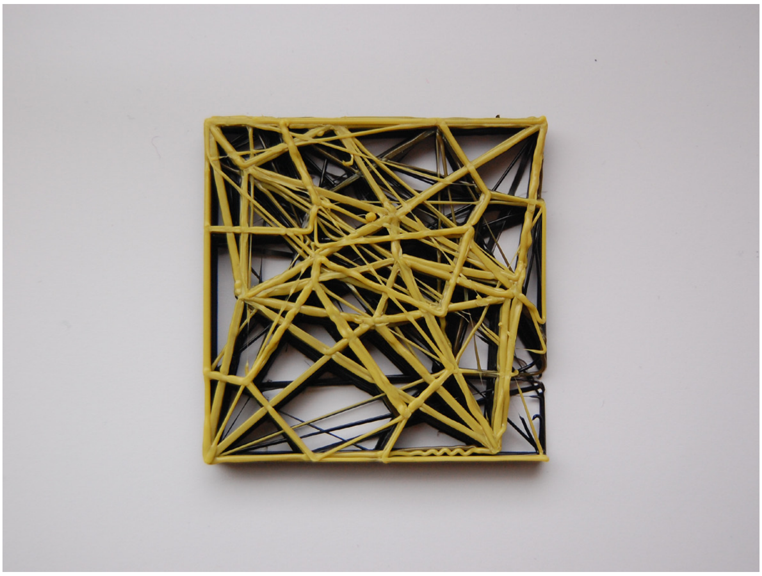


Fig. 41. Encoded Matter, first proof of concept, test print.

SERIES 1: OBJECTS WITHOUT SKINS

For the first series (Figs. 42-43), I wanted the objects to express the idea of skipping the mesh as an in-between step and format and show the inner material build-up of the artefact, so I decided to print a number of objects without skins. The inner structure was designed as a rectangular grid which could be rotated in two directions. Although not explicitly defined in the g-code file itself, the outer volume of the objects had been sliced by different angled planes so they would intersect the rotated grids at various angles, giving each face of the artefact a different texture and material expression. The grid structure of the first series was controlled by an algorithm; its structure was similar to standard "fill" structures found in slicing software. Different rotations and distances in the grid were tested, so although they had no outside skin, the grid had the same density throughout each of the resulting artefacts.

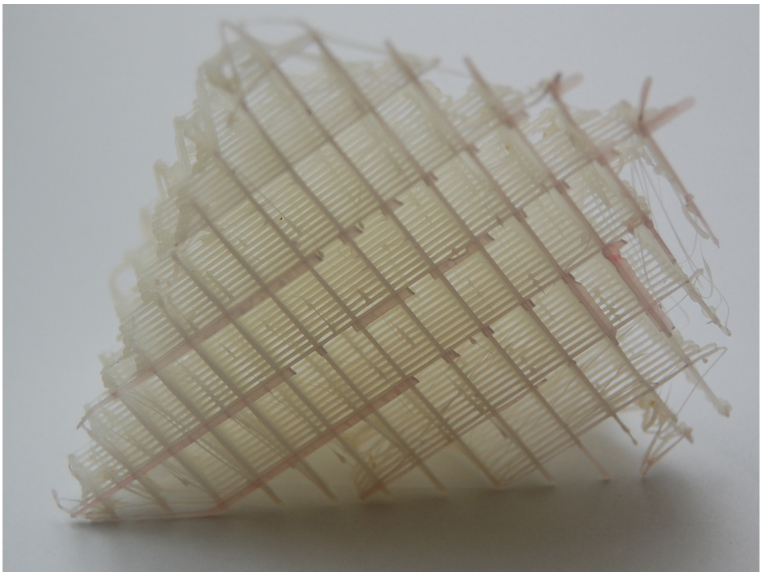


Fig. 42. Encoded matter, series 1: objects without skins.

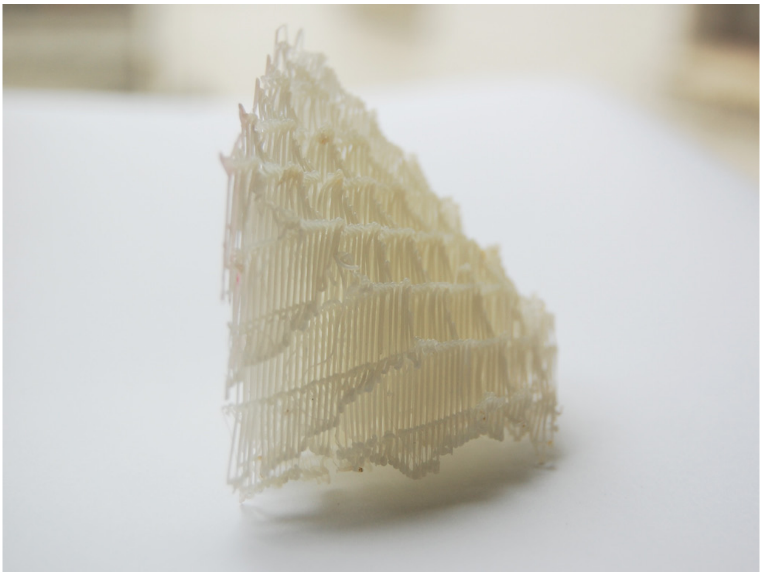


Fig. 43. Encoded matter, series 1: objects without skins.

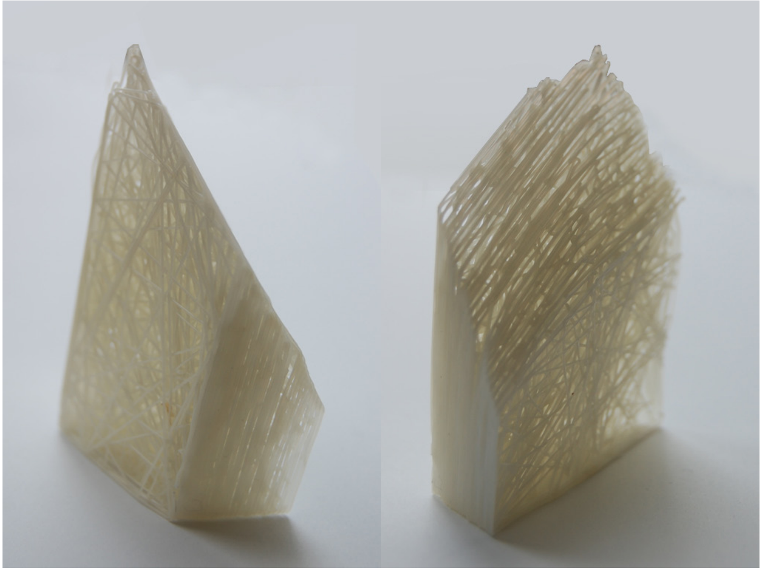


Fig. 44. Encoded matter, series 2: steering density and transparency.

SERIES 2: STEERING DENSITY AND TRANSPARENCY

In the first series (Figs. 44-45), there were no collisions between threads because they were parallel and alternating in direction every other layer. In the second series, every layer would have a number of lines randomly crossing the section of the layer; this resulted in a radically different materiality, where density would be variable per layer. Because the lines were random, they would occasionally intersect, causing a local build-up of surplus in material.

While this resulted in some intricate pieces, the randomness in the system did not allow enough control over the materiality of the result. The series was refined by weighting the randomisation by using a coloured gradient mapped over the surface of the mesh – the

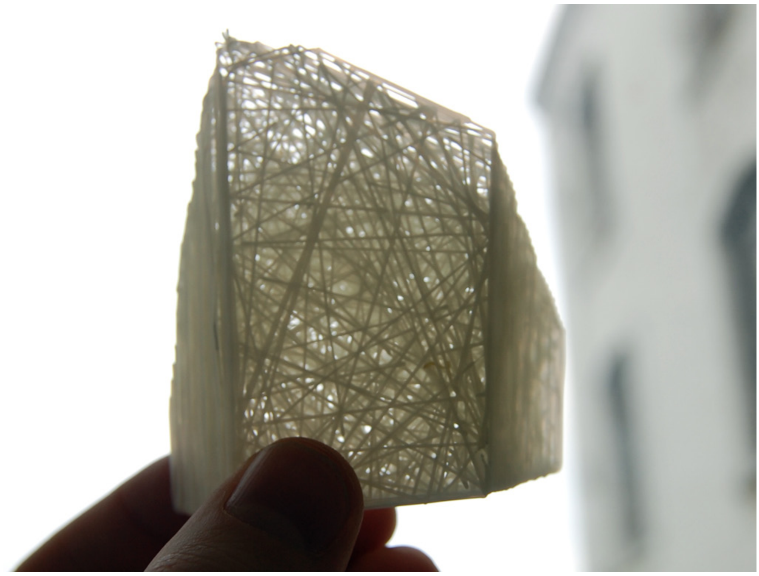


Fig. 45. Encoded matter, series 2: steering density and transparency.

darker its colour, the more chance of a thread starting there. The algorithm also incorporated the material build-up in the layers below. While not completely determining the transparency, it allowed for the density of material and transparency to be “steered” towards a certain density.

Representing the material density and transparency on screen proved problematic. The high density of traces would blend together on the screen as one colourful patch. The thickness of the line could be manipulated to more or less represent the speed of the extrusion and thus the amount of material build up. The only way of really testing the material qualities of the result was by actually fabricating it.

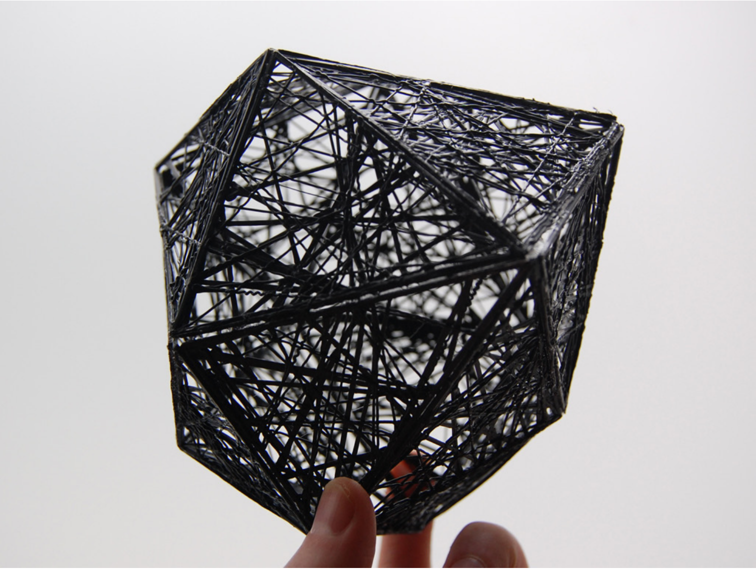


Fig. 46. Encoded matter, series 3: steering density and pushing material and machine limits.

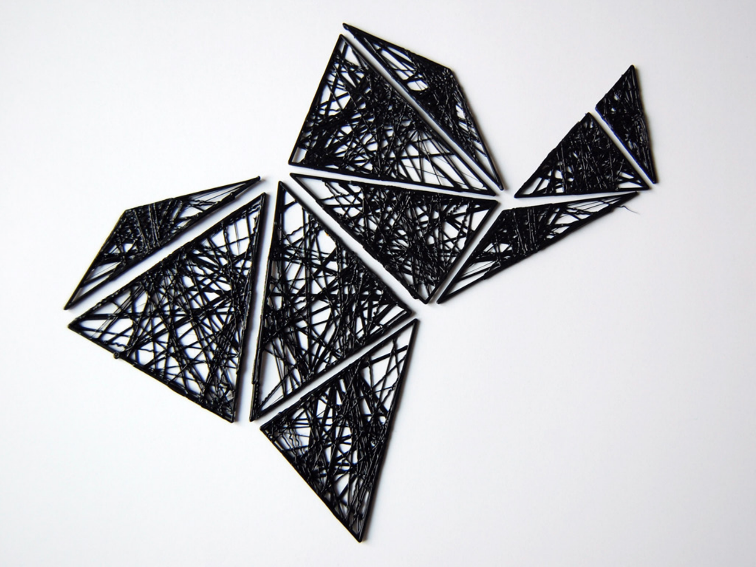


Fig. 47. Encoded matter, series 3: steering density and pushing material and machine limits.

SERIES 3: PUSHING MATERIAL AND MACHINE LIMITS

Like all digital fabrication machines the MakerBot used during the workshop had limitations – the size of the print was limited to about 100 mm x 100 mm x 100 mm, shapes with overhangs can't be printed, it has a relative slow speed and there is material that can be used. The resulting prints clearly show material traces of the printing process – the flat bottom due to the heated bed, the visible layers and threading where unsupported overhangs occur in the model. In the third series of objects (Figs. 46-49), I tried to overcome some of these limitations and use specific traits of the machine as an advantage.

Instead of printing finished objects, I decided to print panels that could be assembled into larger objects afterwards: the digital model would be scaled until the largest panel could still fit the build platform. The panels were kept rather flat, so printing times were greatly reduced. Because of the heated bed, the panels had a flat side and a more articulated side. While assembling, both of those sides could be used as an outside of the object, resulting in radically different artefacts with a materiality and scale that went beyond what normally can be produced with these machines.

The algorithms used for filling the panels were the same ones tested for the objects without skins and the ones with variable density. The first one led to a hatching of different panels, and the second one led to controlled density over the artefacts.

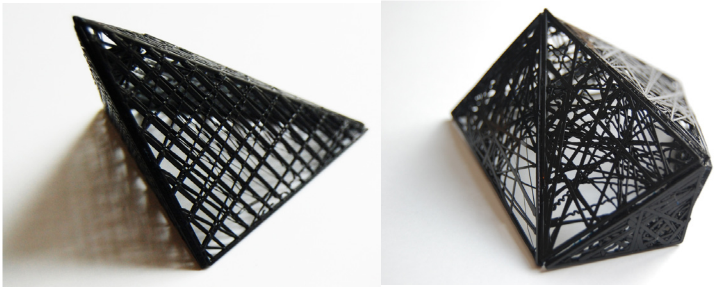


Fig. 48-49. Encoded matter, series 3: steering density and pushing material and machine limits.

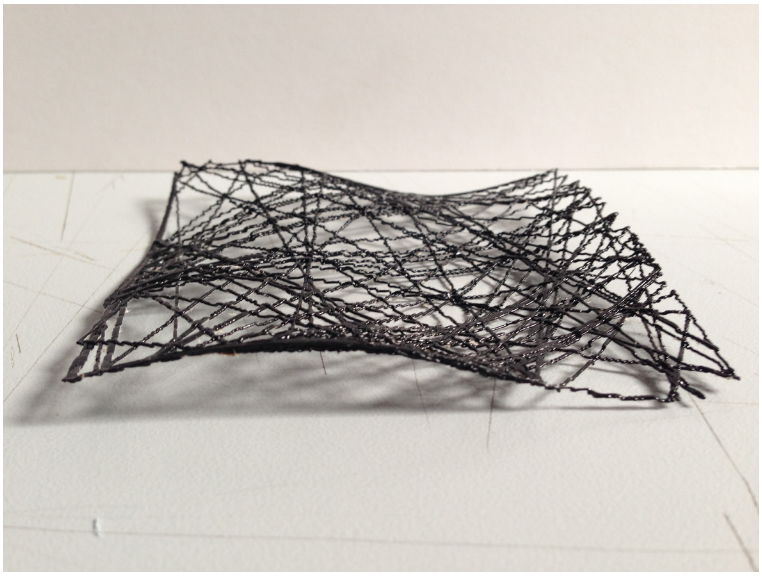


Fig. 50. Encoded matter, series 4: half a dimension extra, sample printed on cardboard.

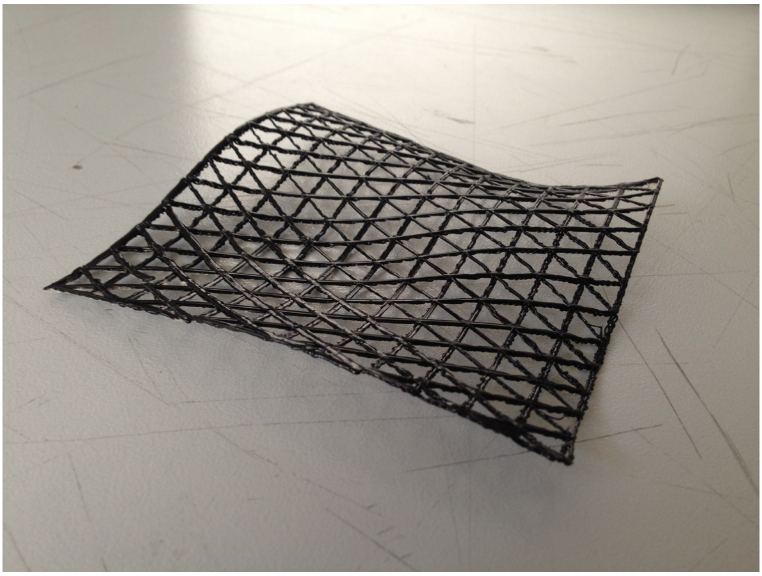


Fig. 51. Encoded matter, series 4: half a dimension extra, triangular grid sample.

SERIES 4: A HALF DIMENSION EXTRA

At the basis of most CNC machines is a Cartesian positioning system; in case of the MakerBot used for this design experiment the movement is constrained to 3 axes. An extra constraint stems from avoiding collision with the already deposited material. The movement of the head could actually be described as 2.5D: the machine deposits material per layer by moving in x and y direction and only moves in the z direction after a layer is finished. The result of this process is visible in the layered structure of the finally printed artefact.

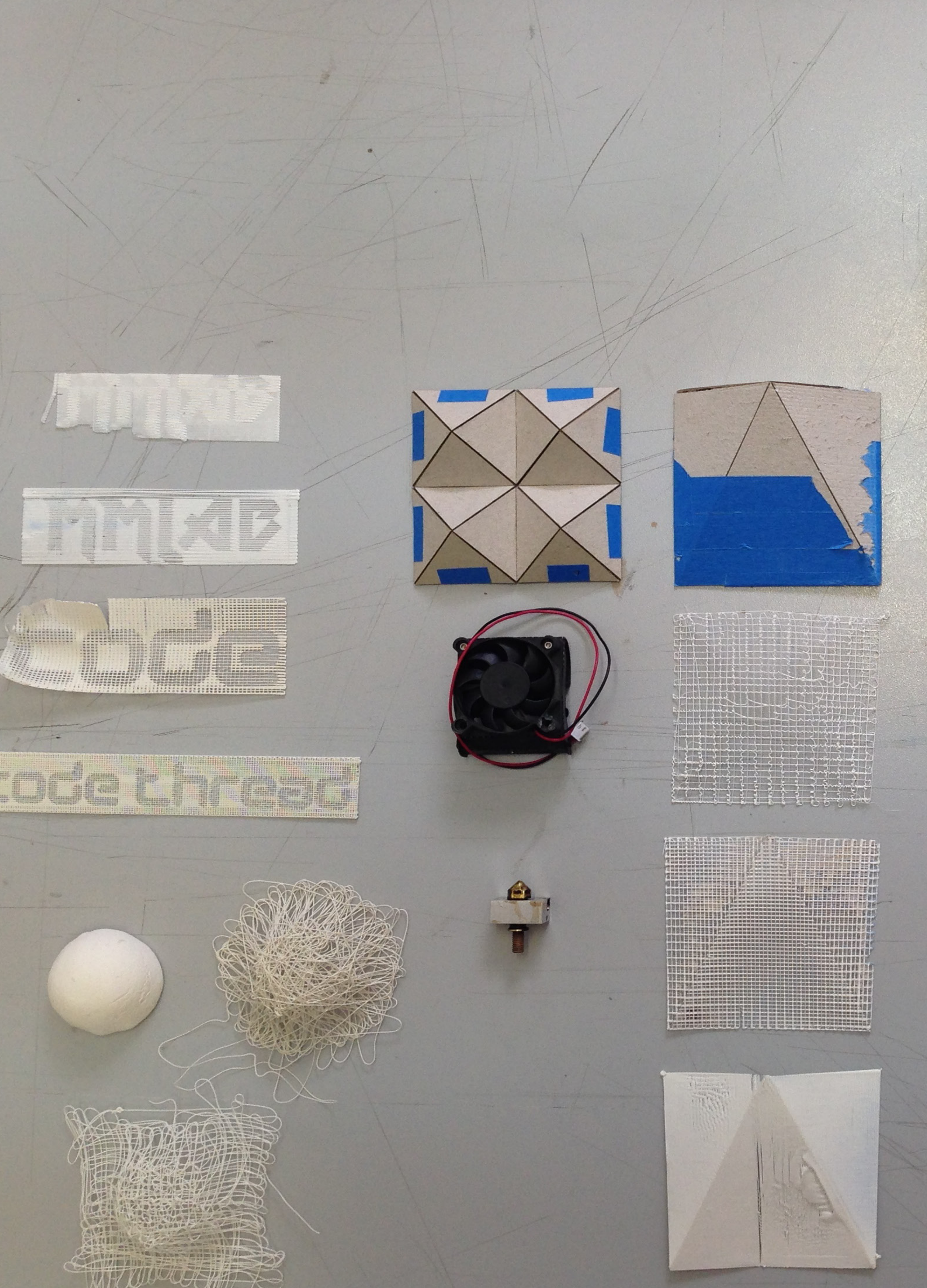
A last series (Figs. 50-54) of artefacts tried to overcome this limitation by moving the tool-head in the z direction *during* the printing process and not only between layers. The printing bed, the actual surface on which the first layer is printed, in a normal printing process has to be completely flat, levelled and neutral so the print can easily be removed and leave no traces. Because of the gained movement in the z direction, we could then print onto more articulated surfaces. But with this new freedom came some complexities: alignment of this non-neutral surface and collision between this surface, the deposited material and the tool-head.

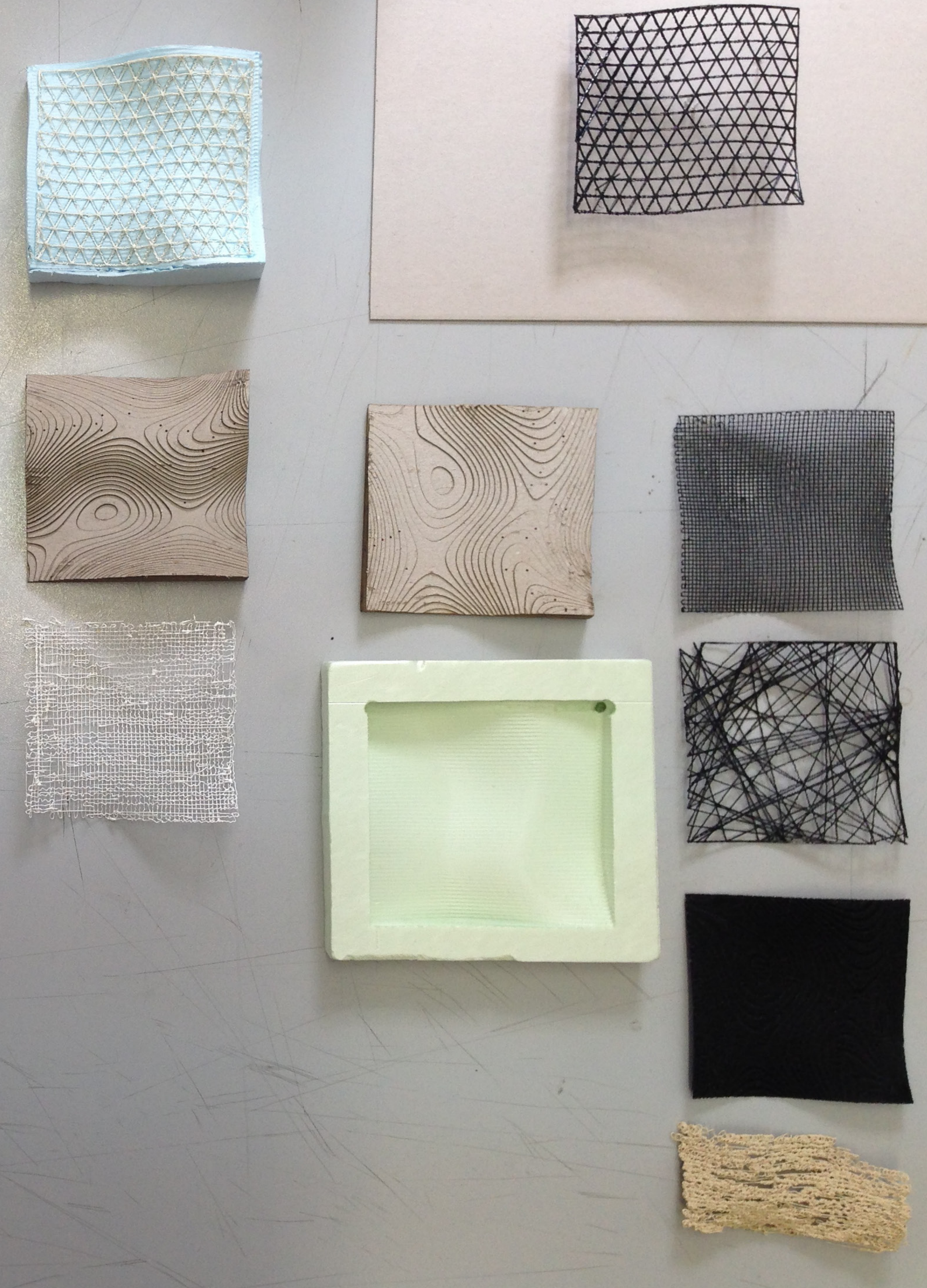
During the experiment, different surfaces were printed upon and fabricated by slicing cardboard and milling foam. The fabrication of the moulds would also result in specific lines and traces: horizontal topographical lines in the case of stacked cardboard and traces of the milling head in the case of the milled foam. The heated plastic of the printer would adapt to these articulated surfaces, effectively resulting in a materiality that bears both the traces of the mould and the plastic threads drawn on top. An interesting illustration of this printing on a non-neutral surface happened when printing on Pu foam: The plastic of the print would melt the foam, effectively leaving a trace in the mould while forming the print.

CODE AS MATERIAL UNDERSTANDING

Next to the material artefacts, each of these design experiments resulted in a bespoke design software, written in Processing and external libraries and later translated to Grasshopper and Rhino.

Fig. 52. Encoded matter, series 4: half a dimension extra, overview (next page).


MMLAB
code
codethread



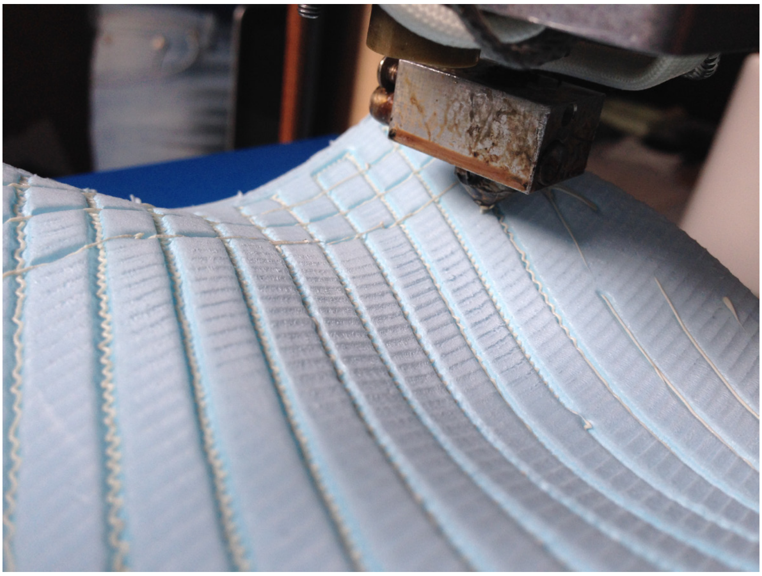


Fig. 53. Encoded matter, series 4: half a dimension extra, sample printed on milled foam.

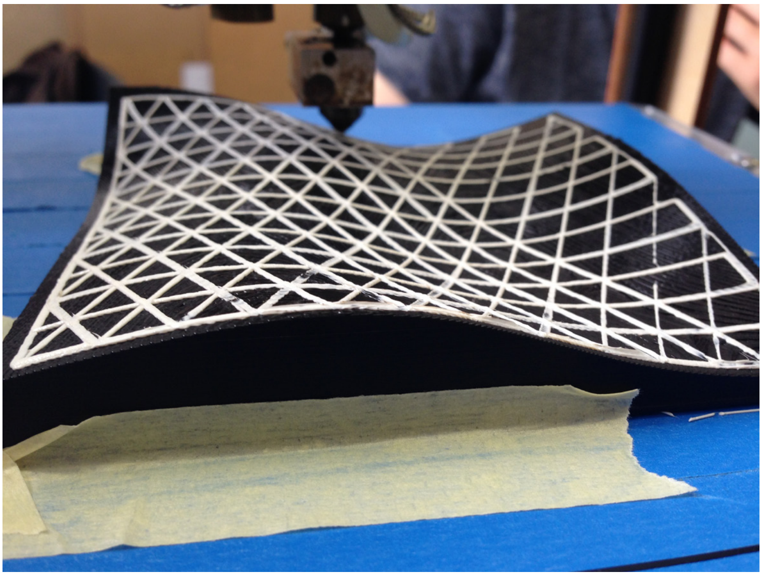


Fig. 54. Encoded matter, series 4: half a dimension extra, triangular grid sample.

The software allowed for algorithmic exploration of formal, and fabrication parameters provided visual feedback to assess the outcome and had features for importing and exporting files. These design tools were developed while the designs were being made and the artefacts were being fabricated. Through the design of these series and accompanying algorithms, an understanding gradually developed of the affordances and resistances on different levels: a computational understanding of the codes and files and an understanding of fabrication constraints and material possibilities.

The different ways of interacting with code, machine and material and the different kinds of feedback between these and me as a designer show a much more layered and non-linear design process than is being suggested by the *file-to-factory* paradigm. Although the understanding was gradually developed, the process is not continuous: manipulations of the underlying algorithm require stopping, altering and re-running the code, exploring the changes through testing different parameters and steering the digital model – evaluated by an on-screen image. When this reached a state that seemed promising, the process was frozen, an image was saved, a file was exported, the code in the file was inspected in a text editor before finally being sent to the printer – watching the printing process, intervening and nudging if possible and, after evaluating the result, the process could start all over again.

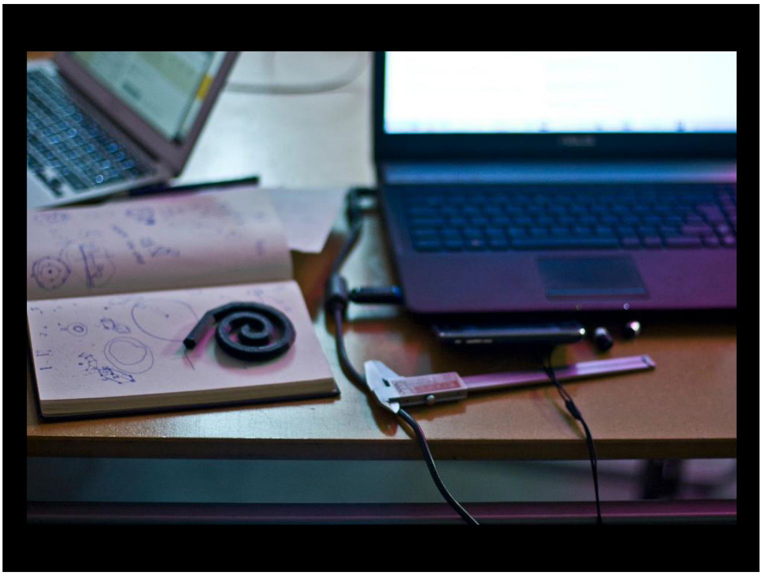


Fig. 55. Working environment, sketching, coding, printing.

ACKNOWLEDGEMENTS

The first iteration of *Encoded Matter* was developed during *Generator.X: From Code to Atoms,*[54] a master class with Marius Watz held at iMal in February 2012. The software was written in Processing using the HE_mesh and CodeThread external libraries.

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[54] For documentation of the workshop, see http://www.generatorx.no/20120301/generator-x-3-0-documentation-and-aftermath/ and http://www.imal.org/nl/activity/generatorx3 (consulted on 01/09/2014).

REFLECTION

The *Encoded Matter* project described in this case closely examined the different steps involved in getting from a digital model to a material artefact using a specific digital fabrication technology. Proponents of these technologies will stress the transparency and directness of this translation from an idea captured in a digital model to a material artefact, as described by the file-to-factory paradigm. The reality of working with these technologies is different, and all of these steps have their own specific affordances and resistances which need to be negotiated in order to obtain a specific end result. The digital model requires a volume described as a watertight mesh. The slicing process is specific for each machine and allows for many parameters to be tweaked. The printing itself is not hassle–free, as can be seen by the many plastic droolings collected during the design experiments.

We can make a distinction in the kind of traces we can read in *any* print made with this technology: (1) traces of the algorithms used for modelling, (2) traces of the software used for slicing the model, (3) traces of the fabrication process and (4) traces of material properties and limits. In a normal use of this technology, a designer typically only defines the input of these.

The standard printing process gives control over only the external form of an artefact and allows the designer to control only its extensive properties. Through a better reading of the fabrication process and taking control over its inner workings, we also gain control over the intensive material properties of the printed artefact.

Mitchell's terms might be useful here: *design world*, describing the tokens in which design ideas can be represented and the possible transformations of these tokens, and *construction world,* the material world in which these ideas are materialised. The case study can be described as: (1) extending the tokens of the design world in such a way that they are more attuned to the construction world – that is, going from a mesh to a g-code file and (2) understanding and developing manipulations in this design world that explore and push the limitations of the construction world.

Fig. 56. Encoded Matter, Generator.x Exhibition view (next page).

EPILOGUE: BACK TO DRAWING

During the period of this exploration, a curious machine arrived at the MMlab – a Mutoh 501 pen and pencil plotter bought by Robin Schaeverbeke[52] for his research into *Extended Drawing*. After several unsuccessful attempts to get it running by hooking it up to old computers running even older versions of AutoCad and testing various drivers and cables, it landed on my desk. After a close inspection, it turned out that the *hpgl* dialect the machine understands is similar to g-code as it is a combination of coordinates and commands to select and lift pens. The commands are encoded as plain text and can be sent to the machine over a serial port.

In need of coordinates to feed the machine, I used the same algorithms used for the design experiments described in this case. The algorithms were extended so they would simultaneously export files for making and files for drawing (Figs. 57-58). The different output format from the same algorithms allowed me to overcome the limits in size and complexity resulting from the maximum volume of the 3D printer. It also allowed for speculation on the relationship between these drawings, the algorithms that produced them and the artefacts that could simultaneously be fabricated.

Since the algorithms are highly attuned to the fabrication and material nature of the 3D printed artefacts, their 2D counterparts can be seen as representational – they represent a material reality outside themselves, but the way they refer to this materiality is not symbolic, but rather an enactment of the same movements that can be made by a different machine to produce material artefacts. When drawing an architectural section, line-weights and hatches are used as a symbolic notation of materiality: the thicker the line, the denser the material. The hatches in these drawings might be reminiscent of hatches in architectural drawings, but they operate in a non-symbolic manner. As such, these drawings also acquire an experiential quality, and become non-representational. As Mette Ramsgard Thomson[53] suggested, the nature of the drawing is altered through digital fabrication: The drawing loses it projective connotations and becomes an unfolded trace for cutting or adding material.

[52] Robin Schaeverbeke is colleague, who is also active in the MMlab.

[53] Mette Ramsgaard Thomsen, *Computing the Real: Time, Scale and Material* (2011). p. 27.

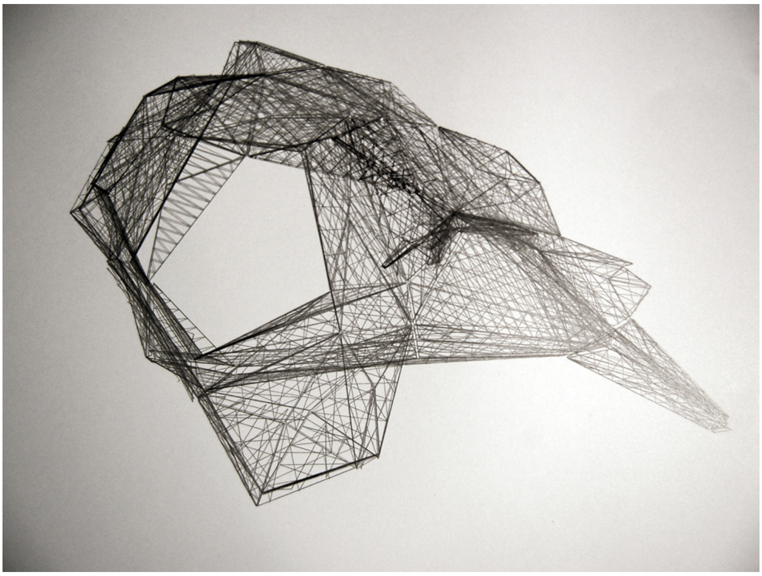


Fig. 57. Encoded matter, drawing.

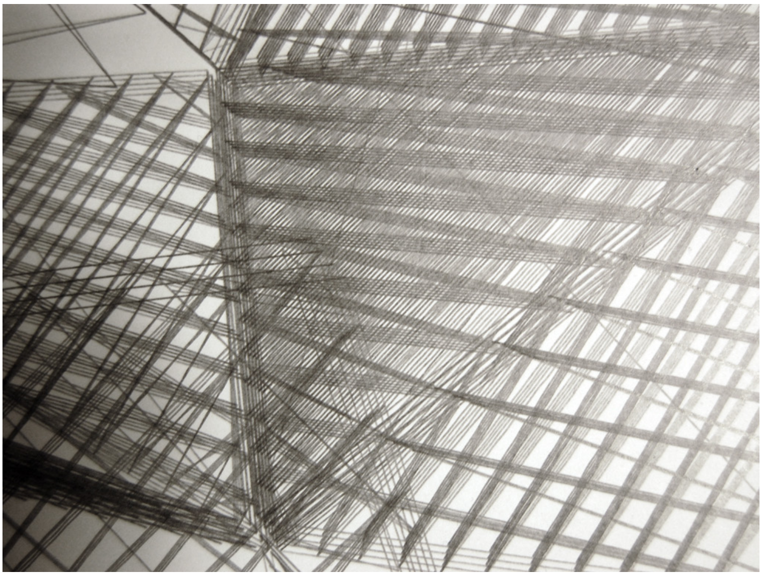
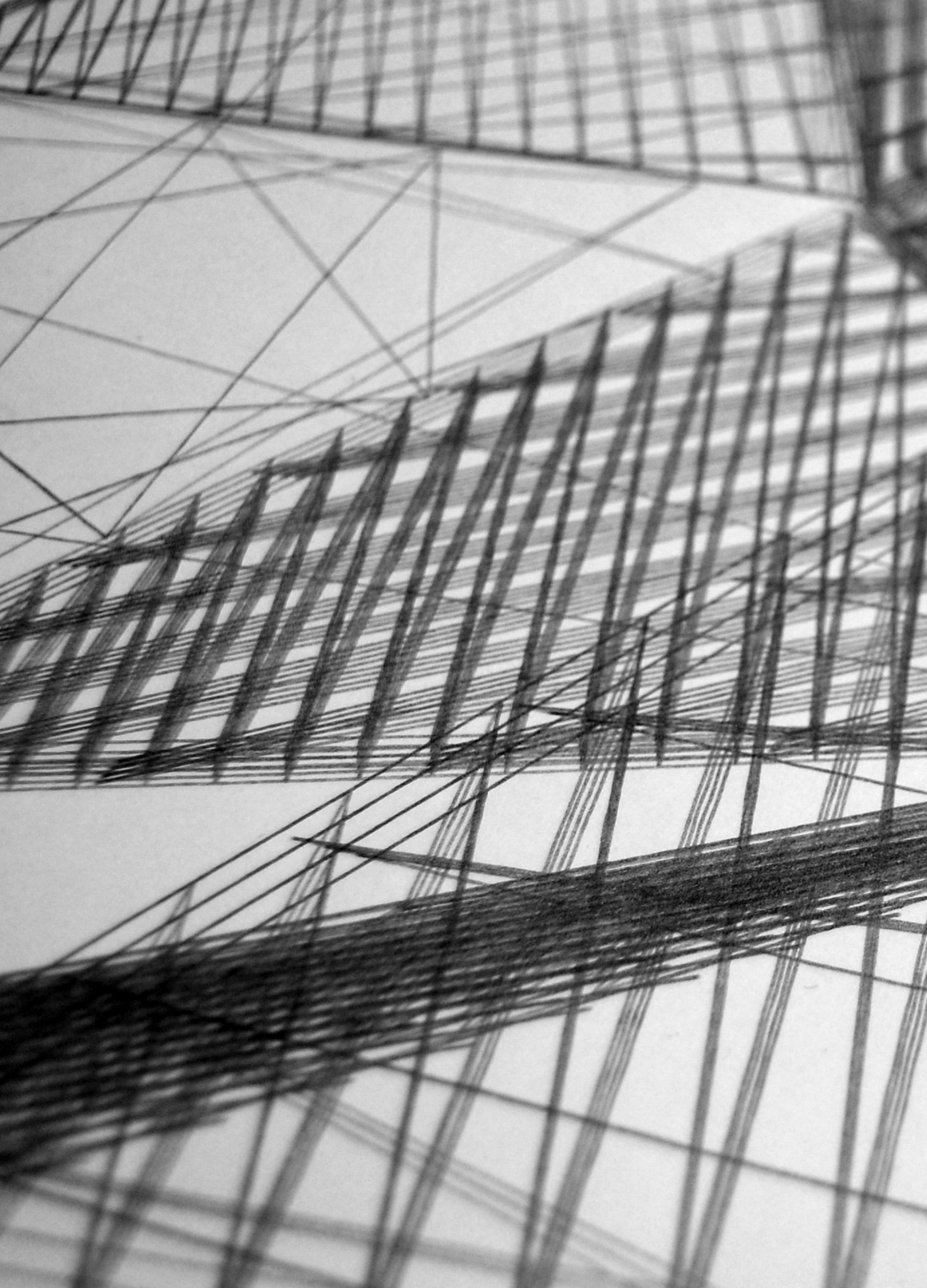
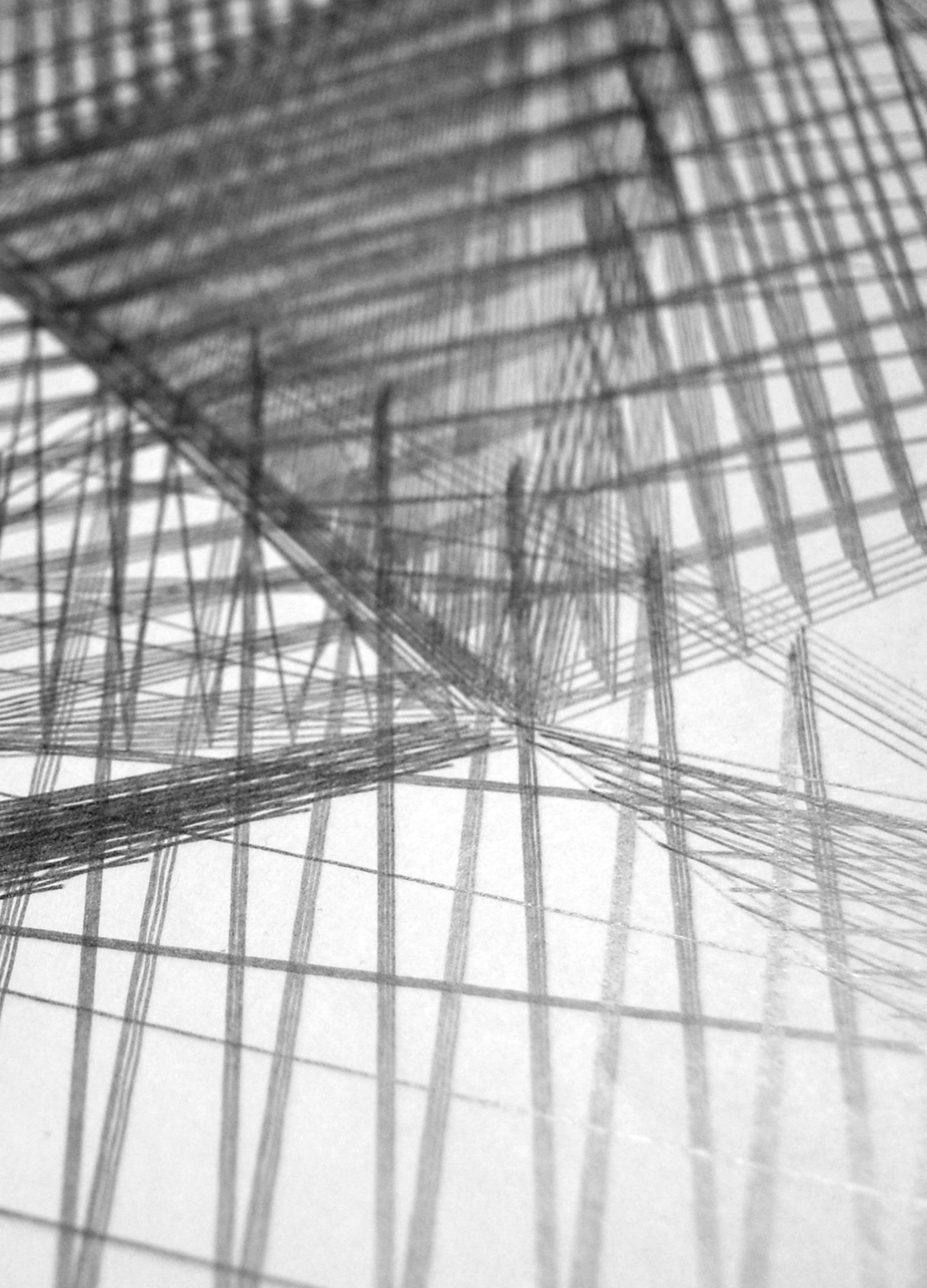


Fig. 58. Encoded matter, drawing, close up.





CONCLUSION: AGENCY IN THE MANGLE

Both cases discussed in this chapter started from an interest in digital fabrication as a specific mode of making, which operates in between the digital and the material. The material artefacts produced during these explorations demonstrate that computation and fabrication are not neutral or transparent technologies, but will have an influence on what can be designed and made. The agencies uncovered in matter and code in previous chapters are both at play in the process of making through digital fabrication, and are furthermore complemented by agencies found in the fabrication machines. As a conclusion to this exploration I will describe my understanding the agencies of matter, code and machines play in the mangle of my post-digital practice[55], mediated through computation and digital fabrication.

The starting **material** used in the digital fabrication processes, described in the two cases, is highly standardised and industrially produced; this disciplining of material is further strengthened by the processes in digital fabrication. Both cases show that the agencies ascribed to materiality uncovered in the first chapter are still at play. Making a material artefact, albeit through a highly controlled mechanical process of digital fabrication, will to some degree remain unpredictable. In the two design experiments, I encountered many occasions of material behaviour that was not completely anticipated in the files or by the fabrication process – the bleeding of the ink in the colour prints of the *Dazzle Lamp,* the warping and drooling of melted plastic in the *Encoded Matter* project.

An understanding of **code** has helped in both cases to interface and tinker with these technologies. On the one hand, digital technologies themselves are highly designed and cultural artefacts, which tend to develop incrementally, gradually building on previous code. In both technologies used for the cases in this chapter, traces of this incremental process can be found: the origins of g-code lie in the post-war servo control labs of the '50s, while colour 3D printing is based on the vrml file type, finding its origins in early online worlds of the '90s. On the other hand, the pace at which digital technology

[55] I refer here to the work of Andrew Pickering who describes practice in general as a 'dance of agency' which he calls the 'mangle of practice', in the concluding chapter I will provide argumentation why I align my understanding of agency with that of Pickering. See Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (1995). pp. 21-26.

is evolving seems to be ever increasing. We only need to look at how the RepRap project has developed both in quality and in number since its inception in 2005 – the first half working version I built in 2009 – and where we are now: the number of printers, services and companies based on RepRap is hard to keep track of. When looking for agencies in these technologies, part of them is located in this incrementally, collectively developed code that drives these technologies.

The technology used in both cases differs in distance to the design process, openness and accessibility. The *Encoded Matter* project uses open technology, both in software and in hardware, was assembled and operated by me. The project shows that openness allows for an extended control over the materiality of the fabricated artefact. Whereas the technology for the Dazzle Lamp was much more closed, and accessed through an online platform. While this clearly makes a case for open technologies and a minimum understanding of code by designers and architects, it is not a plea for a complete mastery of a technology. I am aware that the step of going from the description of an artefact as a mesh to the description as a g-code file is just peeling away the first layer of a technology and that there are more layers below. But it is an important step as it reveals that the code used to describe the designed artefact in the digital world adds grain to the artefact, whether it is the triangle in a mesh or the toolpath in a g-code file.

The fabrication **machines** used in these design projects, and the fabrication processes they afford, leave their own marks in the fabricated artefacts: the visible layered structure, and limits in size, in both printing technologies; the accidental shifts between layers and the grainy textures in the Dazzle Lamp prints; and the flat bottom of the prints due to the heated bed, the impossibility of printing overhangs and the visible material threads in the *Encoded Matter* series. The machines, being material contraptions driven by code, inherit aspects and qualities from both material they work with and the code that runs them. Moreover, taking digital code as an input and generating material objects as an output makes traces of the code apparent in the material world. Instead of seeing the grain, the resolution and visible traces of the technology as a problem, something to be resolved through a better, newer version of the technology, we can design for and with these qualities, it is these qualities I describe as being *allographic*.

This chapter started out with a discussion on whether the introduction of digital design technologies leads to a shift toward an allographic design practice, or allows a more autographic role to be reclaimed. While the scale, scope and nature of these projects leave many questions unanswered, from a distance these projects look very similar to an autographic, crafts-like endeavour; but that fails to notice the allographic qualities that drive this work. The design projects described in this chapter started from wonder for and an interest in making material things, and the pleasure I find in unravelling and understanding the inner workings of both code and machines. The source of this wonder and pleasure lie in the allographic qualities found in material, code and machine. I do consider myself the author of these works, but their specific qualities could only emerge in the mangle[56] of a design process that operates between the material and digital world, and negotiates with agencies external to those of the designer.

[56] Ibid. pp. 21-26.

CONCLUSION

CONCLUSION

My research investigates the influence of computation and digital fabrication on designers and architect and their engagement with materiality and making during design processes. The central proposition, concluded from this project lead investigation, is that computation and digital fabrication influence the outcome of design processes, and the materiality of fabricated artefacts. In other words agency can be ascribed to computation and digital fabrication. Based on the cases presented in the this exegesis I argue that negotiating with the agencies found in computation and digital fabrication, is beneficial for a design process and can lead to innovative design outcomes.

In this concluding chapter I summarise my argument and findings of this project-based investigation and reflect on my understanding of agency within design developed through this research. I will describe the implications of this research and the contribution it makes to design practice, discuss alternative positions and outline potential areas for further research.

SUMMARISING THE ARGUMENT

The exegesis has been organised in three chapters, that each explore a recurrent field of interest within my work: materiality and making, computation, and digital fabrication. In these explorations I have looked at how matter, code and digital fabrication machines influence design processes and outcomes. The fields explored in this three chapters groups cases and projects *thematically*, but they are also partially ordered *chronological*, the first exploration describes the earliest projects, the later ones later projects. Most importantly they are ordered *hierarchical*, the last exploration builds on work, reflections and gaps identified in earlier ones, and most clearly demonstrates the argument. Furthermore, as the exegesis progresses, the fields of exploration becomes narrower defined, and the project work and position taken becomes more focussed and outspoken.

EXPLORATIONS

The first exploration, **Design and Making**, encapsulated my motivation for undertaking my research and describes setting up the MMlab as the environment for my research. Motivated by my experience of the distance between the act of designing and the act of making, both in architectural and artistic practice, this chapter describes two cases which investigate alternatives to this observed distance. Both cases integrate making as an important part of a design process. *Digital and Material Design Worlds*, looks into digital and material model making, as models *for* design, that trigger design ideas rather than just capturing them, and proposes a design approach that incorporates both digital and material modes of design. *Engaging Material,* discusses the tension between designing with material as a medium and unmediated material making, full scale and on site. Whereas the exploration started from a number of oppositions – design and making, digital and material, mediated and unmediated - what it uncovers is the negotiation between these oppositions: design through making, combining digital and material modelling, altering between mediated and direct making. Throughout this exploration matter is described as an active contributor to design and ascribed agency, whether it is through scale-less material experimentation, model making or building full scale mock-ups.

The second chapter, **Code and Matter**, explores engaging with code as a design medium within creative practice, going beyond the interfaces of standard design software. This reveals a hierarchical, collectively and incrementally designed world of code, that is both affecting and being affected by design culture. *Tinkering with Code,* gives an account of how I understand code a design medium, through a number of projects that highlight aspects of coding as creative practice. In this case I identify code, as an exact, technical, and unforgiving design medium, but also as a structuring, discursive and conceptual support, geared towards repetition and variation. In the *Sphere Inversion* project, code is described as a lens for capturing and encoding material and spatial qualities as discrete numerical entities. Code is conceived as the matter that makes up the digital world and gives it grain. The idea of code as means of capturing matter is extended in *Nested Simulations,* to also encode material behaviours that unfold in time. The physics simulations used in this case describe material properties and capture material behaviour as an interaction between discrete elements, or agents. In a simulation code gains a degree of autonomy, instead of directly defining a design solution as designer, design emerges out of the interplay between discrete encoded elements. The role of the designer becomes setting up conditions, letting a simulation run, negotiating and steering when necessary, and deciding when an appropriate solution is reached.

The third chapter, **Allographic Machines**, explores design processes and projects, designed with a number of specific digital fabrication machines. Not only as precise and detailed ways of making, but for the qualities they introduce into fabricated artefacts, which I have called allographic. *Fabricating Material Intensities* investigates how colour, as an intensive material quality, is encoded in file and emerges out of a digital fabrication machine. The *Dazzle Lamp* project shows how the properties gained in the process can be used as a quality and design asset. *Digital Traces and Material Threads*, explores how digital fabrication processes unfold in time, how taking control of this process can be used to design material qualities that go beyond defining the external form of the fabricated artefacts. Both cases demonstrate how the geometric entities captured in code become material, a surface without depth becomes a thin volume of colour; a digital trace becomes a material thread. The design process can be described as a negotiation, with the agencies of code, matter and machine, taking control over certain aspects of the process while allowing others. In the *Encoded Matter* project, I take control over the code that runs the machine, but use that to allow material behaviour like dripping and stringing. The technologies used of these two cases differ in open-ness and distance to the design process. The first was distant, closed, proprietary, and accessed only through an online platform, the second was nearby, open-source, built and maintained by myself. This difference influences the nature of this negotiation, but both cases resulted in material artefacts that demonstrate allographic qualities.

UNCOVERING AGENCY

Through conducting design projects I have explored the agencies at play within each of these fields on interest, in this section I will outline the agencies I have uncovered.

The first exploration, **Design and Making,** deals mainly with the agencies that can be ascribed to matter, and how it informs a design process, either through material experimentation, model making or full-scale prototypes. These agencies are located in the open-ness of material design worlds, and in engaging tacit knowledge and ineffable spatial and material qualities.

The second exploration, **Code and Matter**, deals mainly with the agencies that can be ascribed to code, using matter as metaphor for engaging with code: code as matter that makes up a digital design medium, and code as a means of capturing material behaviours. The agencies of code can be partly found with the people that programmed it, code is part of design culture. The agencies of code can also be found in its role as mediator between human thought and computational process, as a design medium rather than a tool. Through simulations it was found that code can be given a degree of autonomy, directly encoding agency in a discrete autonomous element, or agent.

In the last exploration, **Allographic Machines**, we can say that the agencies found in matter and codes are extended with those encapsulated in the machines. Digital fabrication machines, being material contraptions operated by code, demonstrate the agencies ascribed to code and matter. Digital fabrication machines produce artefacts, with material qualities which depend on the code that runs them, on how the machine is built and operated, and on the material it processes. I have described these qualities as *allographic*.

Uncovering and acknowledging these external agencies within design practice mediated through computation and digital fabrication makes these agencies negotiable. In my experience of designing with these technologies, design progresses through an iterative process of testing and refining design ideas within a medium, in other words design becomes a negotiation between the agency of the designer and those found matter, code and machines. This is illustrated by the series of design experiments in the *Fabricating Material Intensities* project, where discovering a certain quality afforded by the technology, the bleeding of colour into the material that inspires design.

In digital fabrication technology all agencies uncovered in matter, code and machine are present; furthermore, through the operation of the machine they mutually influence each other. Negotiating agency can be seen as this mutual negotiation and as the negotiation of the designer with these technologies. Acknowledging agencies within a design process does not mean that as designer you have to accept them. Through this research I have come to understand agency in design as negotiable, it's a push and pull of resistance and affordance. For example, the digital fabrication technology used in *Digital Traces and Material Threads*, results in the typical layered materiality in the fabricated artefact, but by taking control over the code that runs it, other material expressions were reached, all within the constraints of the machine.

CONTRIBUTION

The work this PhD is based on is diverse in nature, application, scale, duration, context and my role within these projects. A first contribution of the work itself has to be situated within the specificity of the projects, the code produced, and the material outcomes and experiences it generated. Conducting this research has fuelled my practice and given me a better understanding of its motivations.

The contribution that my research makes to new knowledge can be located within the specificity of the explorations: The main contribution of this research is uncovering the agencies at play in a technologically mediated design practice, making explicit agencies uncovered through the explorations; secondly, recognizing with these agencies to be negotiable; and thirdly, developing design projects through negotiating these agencies. Fourthly, next to these specific contributions, a more general modus operandi has been developed for negotiating external agencies as a designer: an agile, prototypical approach for giving value and meaning to rapidly changing technologies in design.

With negotiating agency I propose a modus operandi for evaluating and using technology within design practice. Although the findings are based on design projects with specific computation and digital fabrication technologies, the way technology is approached can be extended to other computation and digital fabrication technologies, other technologies. Instead of seeing technology as means to an end, a mere tool, through this I see technology as a design medium having agency.

UNDERSTANDING AGENCY

Attributing agency[1], the capacity to act or the condition of acting and influence design outcomes, to designers and architects requires no argumentation, but granting agency to matter, code and machines requires some more explanation. I think it is useful to look at how agency has been ascribed to human and non-human agents in related fields of inquiry. I do this not to theorise or justify my findings within an external field of inquiry, which would constitute a 'topological error,'[2] but to reflect on my understanding of agency developed through this inquiry within my design practice.

THE MANGLE OF PRACTICE

"The process of bringing an architectural idea to expression in material reality could usefully be seen in terms of the philosopher Andrew Pickering's concept of the 'mangle'. Pickering has described the process of devising and testing a scientific hypothesis through the construction of increasingly sophisticated technological devices as a kind of collision and interaction between human goals and material resistance. He calls this process the 'dance of agency' – an ongoing, open-ended and temporally structured operation involving a dialectic of resistance and accommodation out of which scientific knowledge ultimately emerges."[3]

Although in his book *The Mangle of Practice, Time, Agency & Science*, philosopher Andrew Pickering is primarily concerned with the practice of science, I find Pickering's 'dance of agency' an appropriate description for a post-digital design practice and the role of computation and digital fabrication in an iterative and mediated design process, as Jonathan Hale argues:

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[1] Miriam Webster Dictionary defines Agency as: *The capacity, condition, or state of acting or of exerting power; action or activity; operation.* See http://www.merriam-webster.com/dictionary/agency, (consulted on 20/12/2014).

[2] Richard Blythe, "Topological Errors in Creative Practice Research: Understanding the Reflective Hinge and the Reflective Gap" in Dag Boutsen (ed.), *Good Practices, Best Practices, Highlighting the Compound Idea of Education, Creativity,Research and Practice,* (2012), pp. 51-52.

[3] Jonathan Hale, "Architecture, Technology and the Body: From the Prehuman to the Posthuman"in *The Sage Handbook of Architectural Theory* (2012), p. 520

> *"This notion could also be applied to the architectural design process itself and the way in which concepts are gradually 'worked out' in the material forms of models and drawings. The visual media of architectural representation also possess their own refractory qualities, and thus new formal and spatial opportunities appear unexpectedly through the exploratory process of graphical presentation, simulation and testing."*[4]

Central in this notion of the mangle of practice is material agency, and more specifically how material agency is captured by machines. Not surprisingly in order to demonstrate the usefulness of his theory outside of the philosophy of science, Pickering dedicates a whole chapter to CNC machinery[5] and how it captures material agency, and affords operators control over production processes. While Pickering ascribes agency to humans, matter and machines, he does not see them as equal or symmetrical[6], matter and machines have agency only, and lack intent.

AFFORDANCES AND RESISTANCES

A notion I have used throughout this exegesis to describe the relationship between designer and external mediators in a design process are James J. Gibson's notion of affordance and resistance[7]. In the case of this research, matter, code and machines afford certain actions, while resisting others. For example the corrugated cardboard used in the *Digital Design and Fabrication* workshop affords tearing, while it resist double curved bending. Affordance can be ascribed to things in nature as well as designed artefacts, some affordances are explicitly designed - a knob affords twisting, some are not - a chair can also be used to stand on.

In design practice, affordances reside as much with the external mediators such as matter or technology as it does with the perception, understanding and skill of the designer.[8] Whereas I might be inspired by the specific materiality of certain fabrication error, somebody else might just be annoyed by its imprecision. Affordances are relational; they describe a potential action that depends on both designer and the external environment or object. This makes affordance a suitable notion for describing agency in design, defined as the capacity for acting in the world.

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[4] Ibid, p.520

[5] Andrew Pickering, "Technology: Numerically Controlled Machine Tools" in *The Mangle of Practice: Time, Agency, and Science* (1995), pp. 157-178.

[6] Unlike other theories trying to describe both human and non-human agency, such as Bruno Latour's actor network theory, which sees human and non-human actors as equivalent and interchangeable within the network. See Jonathan Hale, "Architecture, Technology and the Body: From the Prehuman to the Posthuman"in *The Sage Handbook of Architectural Theory* (2012), p. 520 See also Knappett, Carl, and Malafouris, Lambros (eds.), *Material Agency: Towards a Non-Anthropocentric Approach* (2008). p. ix

[7] See also: Gibson, JJ 1977, 'The theory of affordances', in R Shaw & J Bransford (eds), *Perceiving, acting, and knowing*.

[8] Don Norman builds on the work of Gibson but makes a distinction between objective and perceived affordance, see Norman, D. A. *The design of everyday things* (1990), Revised and edited edition (2013). p.10

My understanding of agency in a post-digital design process, mediated through technologies of computation and digital fabrication, developed through this research, is similar to the 'dance of agency' described by Pickering. What I learn from Pickering and Gibson, is an understanding of this relationship, as an iterative cycle of engagement with affordances and resistances. In this research I am interested in specific relationships, between myself as designer and the external mediators of matter, code and machine. Through this research I came to understand agency as the capacity of elements in design practice to influence design outcomes and processes, although intentionality remains with the designer, design results emerge out of the negotiation between the designer and external agencies.

DISCUSSION AND FURTHER RESEARCH

Within the overlap between materiality, computation and digital fabrication, obviously different positions, alternative research routes are possible. In this section I want to discuss some of those alternative routes and how they relate to the position and argument developed in this exegesis. The aim of this is to identify loose ends and gaps within the work, clarify why certain routes were not taken and point towards potential future areas of research.

DESIGNING MATTER

A question that runs through my exegesis is to what degree, scale and resolution do designers want to design and control matter and materiality? In the last exploration, **Allographic Machines**, the focus was on which material qualities and properties emerging from the fabrication processes, and how through manipulating the code that runs these machines, different materialities can be drawn out of these processes. The two design cases that make up this exploration, *Fabricating Intensities* and *Material Threads Digital Traces* were concerned with colour, mass, density, translucency, next to geometry, form, assembly as material qualities. The crucial step taken in these cases was looking at the computational and material processes under the hood of the fabrication machines, and actively manipulating these to achieve material qualities that I have described as being allographic.

While in these experiments matter was designed and controlled at a resolution beyond the intended use of the technology, the kinds of qualities achieved in these prototypes, dealt with experience and perception. In the previous explorations, matter formed a trigger for direct design manipulation, or informed digital simulations to iterate design ideas. The criteria and qualities in these first two explorations, more specifically in the *Engaging Material, Nested Simulation* cases, had to do with constructability, tectonics, and logistics of assembly, site conditions, and ineffable experiential spatial qualities.

In my explorations matter was considered as a starting point, a trigger for design, to be manipulated and worked. This manipulation was informed by code and digital models, but the material itself was not designed. In the intersection between the fields of material sciences, computational design and digital fabrication, I have identified a field of research that takes a more direct approach to combining code and matter. This field explores actively designing matter, in the form of micro structures or composites, and activating matter by use of smart materials and programming matter for certain behaviours.

The work by Paul Nicholas, compiled in the book *Designing Material, Materialising Design*[9], showcases the reciprocity between material and design and how they influence each other across multiple scales[10]. Interesting work is also being done by Skylar Tibbits and the Self Assembly Lab at MIT[11],   Manual Kretzer and the Materiability Network at ETH[12], and some of the work by Achim Menges and the ICD/ITK[13]. While this work is highly speculative, I think the proposition of this research, negotiating agency, could be useful in this field. During the course of my PhD I have not pursued this field in depth partly because it was not the focus of my design projects at the time, partly because it is only through conducting this research that I have become more profoundly aware of this field, and some of this speculative work in this field has been developed concurrent with the course of my PhD.

[9] See Paul Nicholas, D*esigning Material, Materialising Design,* 2013. p.11-12.

[10] See Paul Nicholas, D*esigning Material, Materialising Design,* 2013. p.11-12.

[11] See Skylar Tibbits, “Design to Self-Assembly” in Achim Menges, *Material Computation: Higher Integration in Morphogenetic Design* Architectural Design, (2012), pp.68-73 and http://www.selfassemblylab.net/ (consulted on 15/01/2015).

[12] See Manuel Kretzer (eds.), Alive: *Advancements in Adaptive Architecture*. (2014). pp.72-77. and http://materiability.com/ (consulted on 15/01/2015).

GENERIC OR SPECIFIC MACHINES

In The last decade we have seen an increased use of general purpose robotic arms for digital fabrication in architecture. Pioneering work was done in this field by Gramazio & Kohler at the ETH Zurich since 2005[14] and has been followed by robotic fabrication labs at Sci-Arc, RMIT, TU Delft, and ICD/ITKE at University of Stuttgart amongst others. Results of research in robotic fabrication has been published and discussed at the Robots in Architecture conference[15], and a substantial part of the research presented at the Fabricate conference[16], and a number of publications.[17]

The use of industrial robots in digital fabrication extends the possibilities within this field substantially and these robots can handle different methods of fabrication at a large scale. In contrast with other CNC equipment, such as a mill, router or laser cutter, these robots are not specialised for one specific fabrication method. Typically these robots have more degrees of freedom, their motion is not limited to the three axis found in CNC equipment I have worked with in the cases of this exegesis. These robotic arms are generic machines in their motion, but they allow for highly specific fabrication processes to be executed. Since they are not designed for one specific fabrication method, controlling the movement of the robot arm requires defining tool-paths, in a process similar to the one explored in the encoded matter project.

Some practitioners and researchers, such as Marte Malé-Alemany, Andrew Atwood[18], Joris Laarman[19] or Peter Webb[20], have gone beyond customising existing fabrication equipment, as I did in the fabmod project by designing alternative tool heads for an existing machine, and build their own fabrication machines. Most notable example of this is FABbots[21] research project lead Marte Malé-Alemany at the AA and IAAC, consist of a series of bespoke fabrication robots that explore different ways of fabrication using sand, water, clay and wax. The produced material samples have highly specific materiality that clearly showcases both its robotic control and material process, similar qualities as the projects I described in the allographic machines exploration.

[13] See Achim Menges, “Material Computation: Higher Integration in Morphogenetic Design”, in Achim Menges, *Material Computation: Higher Integration in Morphogenetic Design* Architectural Design, (2012). and http://icd.uni-stuttgart.de/ (consulted on 15/01/2015).

[14] Gramazio & Kohler, *Digital Materiality in Architecture* (2008), pp. 49-56.

[15] At the moment of writing two Robots in Architecture conference have been held in 2012 and 2014, See www.robotsinarchitecture.org, (consulted on 20/12/2014).

[16] Two Fabricate conferences have been organised in 2011 and 2014, see Ruairi Glynn and Bob Sheil (eds.), *Fabricate: Making Digital Architecture* (2013) and Fabio Gramazio, Matthias Kohler and Silke Langenberg (eds.), *Fabricate Negotiating Design and Making.* (2014).

[17] Fabio Gramazio, Matthias Kohler, and Jan Willmann (eds.), *The Robotic Touch: How Robots Change Architecture* (2014), Fabio Gramazio and Matthias Kohler (eds.) *Made by Robots: Challenging Architecture at a Larger Scale*, AD May/June (2014) and Wes McGee and Monica Ponce de Leon (eds.),Robotic Fabrication in Architecture, Art and Design (2014).

[18] Andrew Atwood, “Monolithic Representations’ in Gail Peter Borden and Michael Meredith (eds.), *Matter: Material Processes in Architectural Production* (2011). pp. 205-2013.

Designing fabrication equipment from scratch or using robotic fabrication is an area where this research could be expanded; I have had to limit my engagement with this field during the course of my PhD, due to constraints in time and the focus being on agencies present in the readily available fabrication machines. In the *Kinetic Pavilion*, and the *Drawing Robots* projects, I have built bespoke kinematic and robotic elements; I have not included them in this exegesis because these projects do not directly deal with the engagement with making and materiality.

It is my contention that the main argument of my research would still apply to robotic fabrication and building bespoke fabrication tools: technologies and materials are not neutral and will influence the design outcome, consequently technologies and materials have agency. To what degree a design process would benefit from negotiating with these agencies, would need further research into robotic and bespoke fabrication. From my research I conclude that this negotiation requires both an intellectual and embodied engagement with the codes and processes, the actual making and materialisation of the work, it is my belief that this is similar for robotic fabrication, and even more so for bespoke fabrication equipment. This belief builds on evidence found in scholarship, but mainly on my intellectual and creative inquiry, my experience with assembling, maintaining and modifying fabrication machines, engaging with the code that runs them and is evident in the material artefacts produced. In other words, there remains a productive gap between design notations, whether it takes the form of a simulated model, an encoded file, or a drawing and the build material artefact, regardless of its scale. Negotiating agency is not about closing this gap, but to paraphrase Robin Evans for a final time, to reach further destinations than those we have hitherto been content to strive for.

19 Joris Laarman, Sasa Jokic, Petr Novikov, Luis.E. Fraguada and Areti Markopoulou, “Anti-Gravity Additive Manufacturing”in Fabio Gramazio, Matthias Kohler and Silke Langenberg (eds.), *Fabricate Negotiating Design and Making*. (2014). pp. 216-223.

20 Peter Webb & Mick Pinner, “Terra Therma” in Ruairi Glynn and Bob Sheil (eds.), *Fabricate: Making Digital Architecture* (2013).pp.94-97.

21 Marte Malé-Alemany and Jordi Portell, FABbots: Research in Additive Manufacturing for Architecture in Fabio Gramazio, Matthias Kohler and Silke Langenberg (eds.), Fabricate Negotiating Design and Making. (2014). pp. 216-223. and https://fabbots.wordpress.com/ (Consulted on 20/10/2014).

CONCLUSION

This exegesis documents my investigation in a number of recurrent themes, interests and urges that propel my creative practice. The work presented in this exegesis can be seen as turning my experienced frustration of designing at a distance from the actual making, into an active engagement with making and materiality. While I initially saw computation and digital fabrication as tools to engage with making and materiality, through this research I have come to understand computation and digital fabrication as design media.

Through conducting the projects that make up this research, I have come to understand that my interest in making things, in tinkering with code and struggling with machines, is an interest in how design ideas materialise and manifest themselves. In my design practice matter, code and machine all influence the formation of design ideas, they all have agency, and within digital fabrication all these agencies are at play and mutually inform one another. After conducting this research, I can best summarise designing within the mangle of post-digital practice, mediated through computation and digital fabrication, as negotiating agency.

EPILOGUE

In the proceedings of the most recent Fabricate conference, we find a conversation between Matthias Kohler and Mario Carpo, a short excerpt[22]:

Mario Carpo: "At some point, the feedback loop between the machine and the material will be so fast that it will become almost analogous to the immediate bodily perception of a traditional craftsman. Is the stuff you are doing going in this direction?"

Matthias Kohler: "Technologically you are absolutely right, the sensory abilities of robots are moving toward a direct response to their physical environment. But what is important here is that the architect can now program those abilities. Architects won't just design form by predefining a geometry that subsequently be built by a highly sophisticated machine, such as the one you have just described. Instead they will design the behaviour and responsiveness of the machine itself. They design this ability up-front, and then it is executed at the time when the building takes place. So, even when you as the architect are not on site you can be virtually present through your robots."

Mario Carpo: "The immaterial presence of the architect through the design of robotic behaviour does not recreate the role of the architect in a humanistic, Albertian, modern sense of the term, but being a master builder, someone who has to be on site. And in this sense it would be building as making, not by making a drawing of the design of it but by training your teams of technical agents or your crew of machines."

I look forward to a future of design and making with more attuned and responsive fabrication machines, and continue the negotiation with their agencies, as I have uncovered through this research. From my experience of assembling, maintaining, and programming my own ‘crew of machines’ and developing design projects in exploring their allographic qualities, I doubt what is proposed in the conversation above. My research contradicts the assumption that an ‘immaterial’ of ‘virtually‘ presence in the form of a responsive routine, programmed up front, can replace actual spatial, bodily experience and the tacit knowledge needed for making. Once again technology is presented as completely transparent and completely determined, closing the gap between designing and making. Programming a responsive routine, or training a crew of machines up front, from my experience can not anticipate all the intricacies needed for making, in other words there still remains a productive gap between designing and making.

[22] Mario Carpo in conversation with Matthias Kohler, in Fabio Gramazio, Matthias Kohler and Silke Langenberg (eds.), *Fabricate Negotiating Design and Making.* (2014). pp. 17-18.

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APPENDIX

LIST OF PROJECTS

Gothic Sculptures, prototypes and installations for Wim Delvoye Studio, 2006-2007.

Manifest, in situ workshop with Tiemen Schotsaert and Floris De Bruyn, 2008.

Material and Digital Modelling Lab, workshop with Tiemen Schotsaert, 2009.

Digital Design & Fabrication In Architecture, workshop with Kristof Crolla, Jeroen van Ameijde and Tiemen Schotsaert, in collaboration with Martine Valembois and Annemie Demeulemeester and SCA Packaging, 2009.

Digital Room, interactive installation with Michiel Helbig, 2009.

Performing Qualia II, interactive kinetic installation for Dolores Hulan and Carl Desmet (Noumenon design), 2010-2011.

De Tafel, prototypes and installations for an interactive table with Carl Bourgeois, Marc Godts, Michiel Helbig in collaboration with Siemens, Saint-Gobain and Art economy, 2010-2011.

99h99m^3, in situ full scale temporal and spatial installations with Tiemen Schotsaert and Michiel Helbig in collaboration with SCA Packaging, 2010.

Supermodels, workshop with Tiemen Schotseart, Michiel Helbig and Pieterjan Ginckels, MMlab 2010.

CrMyYbK, magazine editing and design, designing and making installation, with Pieterjan Ginckels, MMlab 2010.

Kinetic Pavilion, interactive kinetic prototype, for Yannick Bontinckx and Elise Elsacker, 2010, shortlist for IBBT 2011.

Lowpoly Lamp, design software and prototypes, 2011

MMlab Sessions I: Mod, remix and modding workshop, MMlab, with Michiel Helbig and Pieterjan Ginckels, 2011.

Fab Mod, hacking digital fabrication machines, MMlab, 2011.

Peanut Bench, design prototyping and making of furniture, with Bart Mermans, 2011.

[un]mediated, design studio interior architecture, with Michiel Helbig, 2011.

Sphere Inversion, coding, prototyping and fabrication for Patrick Labarque, 2011.

Jail Break, competition design for art integration project, with Frederik De Wilde and Frederik Vanhoutte, 2011.

Low Tech Adaptable, adaptable ceiling installation, MMlab, 2011.

Dazzle Lamp, coding prototyping and fabrication, MMlab, 2012-2013.

Encoded Matter, coding prototyping and fabrication, iMal, 2012 - 2013.

Material and Digital Form Finding, coding and prototyping, research project, MMlab 2012.

MMlab Sessions II: Blog / Off, workshop on visual culture, it-architecture and blogs, with Pieterjan Ginckels, 2012.

Maker Wall, competition design for TexFab Applied competition, with Tiemen Schotsaert, 2012.

Object Oriented Eclecticism, coding and prototyping workshop, with Gilles Retsin and Isaie Bloch, MMlab 2012.

Drawing Robots, interactive drawing robots workshop, with David Bowen and Robin Schaeverbeke, 2012.

[Re]Active Prototypes, coding and prototyping, research project, MMlab, 2013.

Reciprocal Bend Strips, coding and prototyping, research project, MMlab, 2013.

MMlab Sessions III: Tranformator X, workshop on hybrid space, with Pieterjan Ginckels, MMlab, 2013.

Adaptive Aggregations, computational design and simulation workshop, with Phil Ayres and Hollie Gibbons, CITA Kopenhagen, Denmark, 2013.

Spectra, coding for installation project by Pelican Avenue, Carolien Lerch and Michiel Helbig, 2013.

The Bearable Lightness Of Being, workshop with, Robert Vierlinger, Matthew Tam, Kristjan Nielsen, Klaas De Rycke at Smart Geometry Hong Kong, 2014.

Werk.Plaats.Werk, in situ design studio with Michiel Helbig and Robin Schaeverbeke in collaboration with Re-vive and De Binnenweg, 2014

CREDITS FOR IMAGES

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Exploration I: Design and Making.

Fig. 2, 3 & 5. Images were published in Corneel Cannaerts, Models of / Models for Architecture: Physical and Digital Modelling in Early Design Stages, *Computation: The New Realm of Architectural Design* [27th eCAADe Conference Proceedings], Istanbul (Turkey). (2009), pp. 781-786.

Fig. 9-10. Photographs by Floris De Bruyn.

Fig. 11. Poster by Kristof Crolla and Jeroen Van Ameijde.

Fig. 12-16. Images were published in Corneel Cannaerts, *Physical and Digital Modelling in Architecture,* Proceedings of the Design Modelling Symposium Berlin 2009: Concepts Beyond Geometry : 05.10 - 7.10.2009, University of the Arts Berlin (Berlin: Univ. der Künste, 2009).

Exploration II: Code and Matter.

Fig. 1-2 Posters designed by Pieterjan Ginckels and Corneel Cannaerts.

Fig. 4-6. Wim Delvoye D11 (scale model 1/4), 2007, laser-cut stainless steel ,L 184 x 97 x H 82 cm, ©studio Wim Delvoye, Belgium, used with permission.

Fig. 18-23. Photographs by Isaie Bloch, edited by Gilles Retsin, used with permission.

Fig. 24. Photograph by Carl Desmet, used with permission.

Fig. 26. Photograph by Tiemen Schotsaert, used with permission.

Fig. 54. Poster by Phil Ayres and Hollie Gibbons, used with permission.

Exploration III: Allographic Machines.

Fig. 26-27. Photographs by Michael Strasser and Pelican Avenue, used with permission.

Fig. 50-54. Photographs by, Wim Slanders, Ruben Rosseel & Maxim Rotsaert used with permission.

SOURCE CODE

Source code for the projects mentioned will be shared on www.cannaerts.cc and openprocessing.org.

EXTENDED RESUME

PROFESSIONAL EXPERIENCE

2011 - 2015 : Phd researcher at SIAL | RMIT, overseas, based in Belgium.

2010 - … : cofounder of the Mixed Media Lab, Sint-Lucas School of Architecture
MMlab is a research lab at Sint-Lucas School of Architecture Ghent. The MMlab is a permanently under construction free-space, a platform that brings together people from different fields, a laboratory that engages with creative potential of media and technology in architecture. MMlab houses a digital fabrication and physical modelling workshop and an audiovisual studio and office spaces.

2009 - 2011: coordinator Mixed Media Department, Sint-Lucas School of Architecture
Since August 2009 I coordinate the Masters programme of the Mixed Media Department, which employs 25 teachers and researchers with a background in architecture, visual arts and media. The main focus was setting up a new curriculum for 2010-2011.

2009 - … : cofounder of fabriek.org, a digital modelling and fabrication agency
Fabriek was set-up by an interdisciplinary team consisting of an architect, a product designer, interior designer, and engineer architect. Fabriek provides modelling and digital fabrication services for artists, architects and designers.

2007 - … : tutor and researcher, Sint-Lucas School of Architecture

I have been teaching media classes and design studios, and organising workshops and events, within and outside the Sint-Lucas School of Architecture. Results of these are collected on www.mmblog.be

2006 - 2007: freelance designer for Wim Delvoye Art
For artist Wim Delvoye, I have designed and coordinated fabrication of several artworks, mainly for his gothic series. Advanced modelling and fabrication techniques where used in the production of these works (scripting, 3D printing, lasercutting, plasmacutting).

2006 - ….: registered architect with Orde van Architecten

2005 - 2006: intern-ship with Volt Architecten

2004 - 2005: intern-ship with Lefebure Architecten

2004 - 2007: co-founder of ccdc.architects with David Claus

RESEARCH EXPERIENCE

conferences & seminars

2014: Radical Materiality, Faculty of Architecture, KU Leuven.

2012: Generator.X 3.0: from Code to Atoms. Brussel, iMAL, February 2012.

2012: Encoded Matter; Artival. Luik, PopUpBox, March 2012.

2012: Computational Design Modelling and Digital Fabrication; lecture on Digital Design & Fabrication. Gent, Universiteit Gent, 13/03/2012

2012: Encoded Matter; lecture for Dorkbot Brussels. Brussels, iMAL.

2012: Making Things with Code; lecture for New Line. Gent, WhiteSpace.

2012: Encoded Matter; lecture for Open House Brussels. Brussel, iMAL.

2012: organisatie: Object Oriented Eclecticism. MMlab, LUCA School Of Arts. Gent.

2012: (mede)organisatie: Interatcive Robots. MMlab, LUCA School Of Arts. Gent.

2011: Pecha Kuch Ghent Volume 10, LUCA School Of Arts. Lecture: Making Things with Code

2011: iMade – proeftuin van snelle, lokale productie op maat, Oxfam C2C network, Brussel, Lecture: Creative Coding for Bespoke Production

2011 - … (co)organising: Processing Ghent. DOK. Gent.

2011: Design Modelling Symposium, Universität der Kunste, Berlin (Germany)

2010: Share && Tell, timelab, Ghent (Belgium)

2010: Dream Team Dinner, Design Vlaanderen Gallerie, Brussels (Belgium)

2009: Open Platform (Smart Geometry), TU Delft (Netherlands)

2009: Design Modelling Symposium, Universität der Kunste, Berlin (Germany)

2009: eCAADe – Computation: the New Realm of Architectural Design
Istanbul Technical University (Turkey)

2009: Computational Toolmaking Seminar, Yildiz Technical University, Istanbul (Turkey)

2009: Communicating (By) Design, Sint-Lucas School of Architecture, Brussels (Belgium)

2009: By Design For Design, Sint-Lucas School of Architecture, Brussels (Belgium)

2008: NODE08: Forum for Digital Arts, MESO, Frankfurt (Germany)

2008: eCAADe – Architecture in Computero, Artesis Hogeschool Antwerpen (Belgium)

2008: Hybrid Spaces: How art creates networks and visualises hybrid space, Z33, Hasselt (Belgium)

publications

2011: Kinetic Pavilion: Extendible and Adaptable Architecture., in Computational Design Modelling. C. Gengnagel, A. Kilian, N. Palz and F. Shreuer(Eds). Berlin-Heidelberg: Springer Verlag,

2010: Parametric Design and Digital Fabrication: new Modes of Digital Design, in Kwintessens, 4e trimester, jaargang XIX, pp 46-52

2010: [M]ixed [M]edia [Lab], in MMMAG01, Sint-Lucas School of Architecture, Brussels, pp 62-69

2009: Projective Modelling: Shifting Media Spaces, in Reflections 13 (Research Training Sessions), Sint-Lucas School of Architecture, Brussels (Belgium), 2009, pp 237-250

2009: Models of / Models for Architecture: Physical and Digital Modelling in Early Design Stages, Computation: The New Realm of Architectural Design [27th eCAADe Conference Proceedings], Istanbul (Turkey), pp. 781-786

2009: Teaching Physical and Digital Modelling in Architecture, Concepts Beyond Geometry, proceedings of the Design Modelling Symposium, Berlin (Germany) 2009, pp 99-105

2008: Digital Bricolage: New Media and Architecture, in Reflections 9 (Research Training Sessions), Sint-Lucas School of Architecture, Brussels (Belgium), 2009, pp 237-250

EDUCATION

2007 – 2009: Research Training Sessions, Sint-Lucas School of Architecture

2003 - 2004: Master in Architecture of Human Settlements, Katholieke Universiteit Leuven

2001 - 2003: Master in Architecture, Universiteit Gent.

1998 - 2001: Bachelor in Architecure, Universiteit Gent.