Taming the Erratic

Representation and materialization in post-digital architectural design

DANIEL NORELL
Akademisk avhandling som med tillstånd av KTH I Stockholm framlägges till offentlig granskning för avläggande av teknisk licentiatexamen torsdagen den 1:a December 2016 kl 13:00 i rum A608, KTH-Arkitekturskolan, Osquars Backe 5, 100 44 Stockholm.

COVER ILLUSTRATION
Norell/Rodhe, *Erratic*, 2013
Elevation and section of digitally simulated massing study
Drawing courtesy of Norell/Rodhe
Abstract

This thesis investigates materialization and representation in contemporary architectural design practice. Due to cultural and technological shifts, the act of design is no longer squarely located in the abstract realms of drawings or digital geometries. Computer aided manufacturing, simulation and scanning offer new design opportunities that are located in the transfer between representation and material. This has given rise to a post-digital model of practice and thought, in which ‘real’ and discrete chunks of matter are incorporated at the earliest stages of design.

The thesis is practice-based, and spans in scope from design to technology to theory. The design work included explores materialization and representation from a particular point of view. In addition, it suggests a methodological approach to design, and explores the theoretical implications in this approach. These implications are addressed in two connected research questions: How can material processes, whether real or simulated, turn transfers between geometry and materialized objects into productive design opportunities? And how might material simulation alter the ways in which representations are conceptualized and used by architects? In parallel with practice-based work, the thesis suggests a theoretical framework for current issues of representation and materialization in architecture. This framework draws from the recent history of the digital turn in architecture as well as from recent design research work and theory in a post-digital turn.

This thesis makes contributions in three main areas. Through the design work *Erratic*, it makes a visceral case for how the use of material simulation might open up new ways of harnessing material agency. It positions simulation in the field of architecture in-between established polarities such as geometry vs. matter, virtual vs. real and drawing vs. mock-up. It discusses the conceptual difference between design based on geometry and design based on discrete pieces of material. Finally, it proposes that form in architecture increasingly can be conceptualized as ‘chunks,’ as opposed to reduced descriptions of geometry.

Keywords

Representation, Materialization, Post-digital, Material simulation, Chunk
Acknowledgements

Thanks to my supervisor Tim Anstey for his continuous support in initiating, developing and sharpening this thesis. A majority of the design work and the publications included in the thesis are a collaborative effort and would not have been possible without my partner-in-practice and friend Einar Rodhe. Thanks to the Architectural Technology group at the School of Architecture at the KTH Royal Institute of Technology in Stockholm and the Strong Research Environment Architecture in the Making at Chalmers University of Technology in Gothenburg, funded through the Swedish Research Council Formas, for supporting, believing in and providing a context for a largely speculative and experimental thesis. I am grateful to my co-supervisors at both these institutions: Ulrika Karlsson at the KTH and research environment director Fredrik Nilsson at Chalmers. In addition, thanks to our collaborators in developing the design work included in the thesis: Hseng Tai Lintner and Stefan Svedberg at Chalmers and Axel Wolgers at the KTH.

Several people and institutions have provided important opportunities to disseminate and critically discuss the thesis and the design work contained in it. Mario Carpo commented on the work in its early stages on several occasions when visiting the KTH. At the ACSA 101 conference in San Francisco, Marcelyn Gow chaired a paper session that provided an early opportunity to discuss the outcomes of the thesis. The Aalto University Digital Design Laboratory (ADD) and Helsinki Design Week hosted the exhibition Erratic and events associated with it, in which ADD director Kivi Sotamaa and Antti Ahlava provided responses. At the KTH School of Architecture, director of research studies Hélène Frichot organized a series of seminars and events in which valuable commentary was provided. At the Oslo School of Architecture and Design, Cheryl Ball offered feedback and an opportunity to temporarily join the PhD community in Oslo.

Stockholm, September 2016

Daniel Norell
List of appended publications

Paper A

Paper B

Poster C

Exhibition D
## Contents

1. Introduction 15  
   Research questions 17  
   Design research practice 18  
   Design work 19  
   Summary of publications 20  
   Contributions 23  
   Structure and form of the thesis 24  

2. Background and context 27  
   The digital turn 28  
   The material turn 29  
   Materialization: From geometry to material 32  
   Representation: From material to geometry 34  
   Chunks: New conceptualizations of form 36  

3. Method, practice and reflections 41  
   Methods in design research practice 41  
   Practice-based design research 41  
   Projective practice 43  
   Medium specificity 44  
   Practice 45  
   Erratic 45  
   Making the Erratic 47  
   Exhibiting the Erratic 49  
   Reflections 51  
   Material resistance 51  
   Digital materiality 53  
   Validation 56  
   Process vs. effect 56  

4. Conclusions and further research 61
Bibliography

Papers, poster and exhibition A-D
  Paper A 73
  Paper B 85
  Poster C 95
  Exhibition D 103

Biography 113
1. Introduction

Architecture as a practice and discipline is continually modified by its mediums. A drawing, for instance, is a representation that makes construction possible by referring to the real world. But it is simultaneously a design medium that can be read and interpreted by an architect during the process of conception. It is both technical and disciplinary in its nature since it conveys design intent for the purposes of materialization, while at the same time working as a platform for discourse. New modes of representation not only shift the ways in which architecture is conceived of or realized – they shift the ways in which architecture is transferred from conception to realization. Historically, these shifts have occurred following the introduction of new technologies - for instance template drawings, projective drawings and photography, to mention a few. Today, technology continues to modify how architecture is conceived and realized. Computer aided design and manufacturing has tied conception and realization closer together. The same platform can increasingly be used for sketching, communication, production and documentation.

New ways of bridging between representation and reality offer new practical and disciplinary challenges. Greg Lynn has observed that the future in which robots rather than humans fabricate building parts has arrived without anyone noticing it (Lynn 2008). Drawings are no longer necessarily interpreted by a craftsman or construction worker on site. Instead, files containing digital geometry are fed straight into machines that shape or even construct materials. This tendency calls for architects to understand and intervene in otherwise automatic processes of “translation” from digital geometry to material (Lynn 2008, 252–53). It calls for an expansion of the register of design from idealized drawings (i.e. digital geometry), to customized machine-based and material processes.

Through practice-based design research, this thesis investigates how design intent might be shifted from typical modes of representation to experimental modes of materialization.

The direction of transfer may also be reversed. Photography once revolutionized the way in which architecture could be documented ‘after the
event,’ as it made it possible to turn the real thing into a representation in a new way. Today, the widespread use of simulation and scanning allows architects to transfer aspects of real materials and buildings into drawings. This affects the ways in which representation works. With material simulation the architect can learn and design “by making” (Carpo 2014, 173). Architectural propositions that previously required structural calculations or full-scale mock-ups can now be intuitively explored in the computer. Similarly, 3D-scanning makes it possible to analyse and incorporate the irregularities and patina of both buildings and building materials into the earliest stages of design. By adopting material simulation as a driver into a design process, this work investigates the practical and disciplinary opportunities offered by this mode of representation and working.

The starting point for architectural design is no longer necessarily ideal representations of geometry. Increasingly, it is in addition material processes and representations that incorporate traces of the material world. This changes the ways in which form and matter are understood in many fields. On the drawing board or in 3D-modelling software, virtual lines and surfaces can be conjured and extended indefinitely. In contrast, a piece of material, whether real or simulated, is inherently discrete and unique in its nature. As a consequence, in architecture, as well as in mathematics and in philosophy, form is increasingly conceptualized as discrete “chunks” rather than as reduced descriptions of geometry (Bryant 2011, 270; Carpo 2014, 172; Winsberg 2010, 8). This has given rise to what has been referred to as a “post-digital” turn in architectural discourse (Borden and Meredith 2012) or “material turn” in philosophy (Coole and Frost 2010). The work presented here investigates a few practical as well as theoretical consequences of this larger turn.

Given these tendencies and developments, one can ask the following: How can material processes, whether real or simulated, turn transfers between geometry and materialized objects into productive design opportunities? And how might material simulation alter the ways in which representations are conceptualized and used by architects? As indicated before, these questions are practical as well as disciplinary in their nature. They can prompt new approaches to design processes as well as new theoretical positions. This work discusses these questions through the specifics of a practice-based design project, the installation and exhibition Erratic. The argument developed is a reflection on the work, as well as a
contextualization of it, with the aim of suggesting some more general possibilities.

Adopting ‘design research’ as a model for research expanded the range of methods and media as well as means of communication of the thesis. In terms of method, it made it possible to combine the visceral, explorative nature of design with a tradition of scholarship native to architecture as a discipline. In terms of media, it added documentation of a design project, including drawings and other artefacts, to text based articles. And the means of communication of the project included conference presentations as well as popular publications, blog posts and events in the cultural context of architecture, art and design.

This introductory chapter briefly situates the thesis in a larger landscape of research and architectural design, and elaborates on the research questions that the design research practice and the design work produced. The chapter concludes with an account of the publications included in the thesis and how they contribute to the field of research, followed by a brief explanation of the structure and form of the thesis.

Research questions

This thesis targets issues of materialization and representation in architecture’s material turn by asking two questions: How can material processes, whether real or simulated, turn transfers between geometry and materialized objects into productive design opportunities? And how might material simulation alter the ways in which representations are conceptualized and used by architects? Each of the two questions can be broken down in several ways. The first addresses the role of material specifications, customized manufacturing processes and material agency as part of the design process. The second addresses how simulation, as an alternative to digital geometry such as NURBS (Non-Uniform Rational B-Spline), polygons or subdivision surfaces, can be used as a design medium and mode of representation.

Considered together, the two research questions in addition spawn further questions. How can the use of simulation in parallel with actual manipulation of materials create feedback loops between the two? Which design methodologies may open up if designers can partially tame the erratic nature of materials by using material simulation? Further, how can simulation as a means of representation and experimentation, be
positioned in the discipline of architecture? And, finally, how does engaging with materials through simulation (rather than through geometry) as a design medium affect our understanding and conceptualization of architectural form?

The first research question is responded to through a practice-based design research project, Erratic. It is addressed in Chapter 3. The second research question suggests itself upon reflection on the work and its discursive context. It is addressed in the concluding sections of Chapter 2 and 3.

**Design research practice**

The practice-based approach to method adopted in the thesis can be situated in architecture as well as neighbouring fields. The type of design research that was undertaken for Erratic can be characterized as “design exploration” (see Fallman 2008). It entailed the synthetic aspects of design and the production of an installation, but it was driven by a research agenda rather than a client brief. The aim was not to solve a problem (though it involved a lot of problem solving), but to make an architectural statement on what is possible. The project was formulated as a response to current issues in the discipline of architecture, but it explored those issues in relation to external factors such as materials, technologies, perception and a public audience. In doing so, it can be aligned with a “projective” as opposed to a critical approach to architecture (see Somol and Whiting 2002). ‘Projective’ refers to architecture’s inherent capacity to project alternative futures, which is seen as an alternative to critical dialectics as well as conventional practice. Projective practice, it might be suggested, takes a disciplinary interest in what architecture does rather than what it is.

In addition, practice-based research has been a way to incorporate my background as a practicing architect and educator into the thesis. The work undertaken has been continuously informed by problems, approaches and modes of documentation and dissemination that are native to practice. The strong link between design and discourse present in the architecture offices where I have practiced – including Greg Lynn FORM and Zaha Hadid Architects – has been particularly influential. Conceiving and thinking architecture by combining design projects, writing, teaching
and exhibitions has simply been part of my training as an architect. It has shaped this research as well as my view on practice.

**Design work**

The most tangible part of the thesis is the installation and exhibition *Erratic* (Figures 1.1 and 1.2). This collaborative design project, supported by the strong research environment *Architecture in the Making* (funded through the Swedish Research Council), fulfilled three purposes. It worked as a probe that targeted issues of representation and materialization from the point of view of a design project. When exhibited, it provided an opportunity to make a statement about the corporeal as well as conceptual aspects that this approach could produce. After being designed, constructed, documented and exhibited, *Erratic* increasingly worked as a conversation piece – as an artefact that made it possible to situate conceptual and theoretical issues in a disciplinary landscape of architecture and design. These issues revolve around representation and materialization. *Erratic* has in addition been presented in other contexts where other, more design related issues have been on the table.

The *Erratic* installation consists of a large, pliable sack – a spheroid made from polyurethane cold foam – that was constrained in many points on an inner armature. Visually as well as conceptually, it balances precision – the exact location of each point on a grid – with frivolous material expression. This setup locates design opportunities entirely in the transfer between geometry (the points) and the resistance in the material. It precludes the use of typical geometry based digital modelling in favour of analogue models and material simulation. Simulation thus took on an unusual role in architecture – as design medium rather than verification of an already conceived design. The project became a practice-based exercise in materially conditioned design partially carried out through simulation. Simultaneously, it interrogated the methodological and disciplinary status of simulation in architecture.

Engaging in the research questions through design work has productively focused as well as widened the scope of the thesis. The conditions of the design project – its constituent materials, technologies, budget, time and exhibition venue, to name a few – have focused the research on a very narrow slot in a broad spectrum of emerging approaches. Engaging in design has at the same time opened up the thesis as it has meant that
analysis and reflection have to be mixed with proposition. In addition, design has opened up alternative avenues of communication, something that has proven valuable in spreading the results of the research to a wider community of architects and designers.

**Summary of publications**

The design-based content is complimented by four publications. These publications are ordered based on content rather than chronology. The first paper, “Erratic: The Material Simulacra of Pliable Surfaces,” (Norell and Rodhe 2014), was presented at *Fusion*, the 32nd annual conference on Education and research in Computer Aided Architectural Design in Europe (eCAADe). It followed on the completion and exhibition of *Erratic* and presents a full documentation of the project. It addresses the first research question by situating it and giving an account of the design principles, processes and methods that the project involved. It addresses the second research question by reflecting on how simulation was used in the project, conceptualizing its use from a methodological point of view as
well as from the point of view of representation. Methodologically, the paper outlines a way in which feedback loops can be created between manipulation of material and manipulation carried out in material simulation software. Specifically, it targets design with pliable surfaces – surfaces that can be bent but not stretched. It discusses how manipulation of these types of surfaces can be simulated rather than modelled with digital geometry. Finally, the paper reflects on the methodological status of material simulation as a new design medium and the ways in which it can be positioned as a test or experiment or alternatively as a representation before the event.

The second publication is a paper titled “Noise Control: Designing with Entropic Processes” (Norell 2013), that was presented at the conference New Constellations / New Ecologies, the 101st annual meeting of The Association of Collegiate Schools of Architecture (ACSA) in San Francisco. This paper provides a background and context to the first research question. It situates issues of materialization and representation in relation to contemporary architectural practices, such as Francois Roche /
R&Sie(n) and Jason Payne / Hirsuta. These practices have found ways to target the transfer between geometry and material in digital design with the random variation and fuzzy materiality caused by artificially accelerated processes of deformation and/or decay. Finally, the paper discusses the artefacts that these processes can produce - their sensibilities and experiential nature. It concludes with a presentation of two design explorations, including *Erratic*.

The third publication is a conference poster (Norell and Rodhe 2015a) that was exhibited at *Open Cities*, the 2014 International Conference in Seoul, organized by ACSA and the Architectural Institute of Korea (AIK). Peer-reviewed posters are a standard way of presenting design research at conferences such as ACSA. The poster situates *Erratic* as a design research project with a full range of media, from photographs and construction drawings to animation stills from simulation sequences. It targets the experiential qualities of the work – the design opportunities that material resistance and simulation opened up. The visual juxtaposition of different media on the poster highlights the importance of feedback loops between material manipulation and simulation, between experiment and representation, and between geometry and material. The poster won a Research + Design Merit Award at the conference.

The fourth publication, “Taming the Erratic: Artefacts of Making,” (Norell and Rodhe 2015b) is a peer-reviewed conference exhibition accompanied by a short paper. It was presented at *Making Research | Researching Making*, a conference organized by Architecture, Design and Art Practice Training research (ADAPT-r) at the Aarhus School of Architecture. This publication reflects on both research questions from a methodological point of view. It focuses on *Erratic* as a practice-based design research project by examining artefacts, such as drawings, models and mock-ups, as loci for the architectural design process. The exhibition presented a diverse set of studies carried out for the installation – simulated models as well as full-scale assemblies (Figure 3.9). These studies were collected as samples from the design process, again highlighting the importance of feedback loops between a diverse set of design mediums. The relation between process and artefact is discussed in light of two existing models of thought in architecture, process driven and effect driven design.
Contributions

The contributions made by this research can be traced across both published articles as well as in the dissemination of documentation from the design project in itself. In conferences such as ACSA and eCAADe, it is increasingly expected and even required to present novel approaches and methods with the aid of novel designs carried out by putting those approaches and methods to work. It might thus be suggested that the term ‘design research’ within this context has several implications. First, it refers to how research on method and approaches can be carried out with the support of design. Second, it refers to how the design of novel artefacts requires the support of (design) research. Third, it suggests that design might work as a scaffolding for discourse – that a designed artefact makes it possible to talk about something that would otherwise have been difficult to address. This is to say that the design work included here is central to the contribution of the thesis as a whole.

The installation Erratic has made a visceral case for how the use of material simulation might open up new ways of harnessing material agency. It suggests that material processes that are difficult to control and quantify may be incorporated as drivers of design with the aid of simulation. Methodologically, simulation allows the designer to tame these processes to the point where they can be represented and quantified with just enough precision to drive a design process forward. This in turn opens up possibilities for invigorating designs with a sense of indeterminacy stemming from material agency.

A significant part of this thesis is also spent on architectural discourse. This happens along two lines of inquiry. First, the status of simulation in the discipline of architecture is interrogated, arguing that simulation can be positioned in-between established polarities such as geometry vs. matter, virtual vs. real and drawing vs. mock-up. Second, the thesis discusses the conceptual difference between design based on geometry and design based on discrete pieces of material. It proposes that form in architecture increasingly can be conceptualized as “chunks” of matter, as opposed to reduced descriptions of geometry. This is done by aligning three contemporary references in the fields of philosophy, architecture and mathematics; Bryant (2011), Carpo (2014) and Winsberg (2010).
Structure and form of the thesis

The thesis is structured as follows. Background and context (Chapter 2), elaborates on the practical and theoretical research context of the thesis. It briefly outlines how architecture as a discipline went from a digital to a post-digital or material turn. It locates two areas of research: Material processes and transfers from geometry to material; and representation and transfers from materials and objects to geometry. These two types of engagement with the topic of the thesis are defined and elaborated with the aid of precedent studies of design research projects.

Methods, practice and reflection (Chapter 3) elaborates on how the thesis has been developed; its methodological context as well as its modes of research. First, it positions the design work in the context of practice-based design research and what has become known as projective practice in architecture. Projective practice, a relatively established approach, is further discussed in relation to medium specificity, a current issue in architectural discourse. Second, given the partially practical nature of the thesis, the chapter elaborates on the specifics of the design project Erratic, including process and dissemination. The third section of the chapter reflects on the use of materials and simulation as design mediums and concludes with some larger implications for design research.

Finally, under “Conclusions and further research”, I discuss and reflect on the thesis as a whole, including its context, research questions, contributions and suggested further research.

This thesis consists of various media, ranging from drawings and photographs, to research papers, a poster and exhibitions. Most of the media tied to the practice and design part of the thesis are gathered as figure references in Chapter 3. Two published conference papers (Norell 2013; Norell and Rodhe 2014), one published conference poster (Norell and Rodhe 2015a) and one published conference exhibition (Norell and Rodhe 2015b) are appended (Papers, poster and exhibition A-D).
2. Background and Context

Digital design has recalibrated the relation between geometry and material in architecture. With the aid of computer numerically controlled (CNC) manufacturing, it is increasingly possible to transfer geometry directly from modelling software to a materialized design. In addition, new technologies of description and analysis, like 3D-scanning and material simulation, have introduced the grittiness of the real world into the virtual world. The rift that separates representation, i.e. a drawing or similar representation of form, from the constructed artefact has narrowed. The absolute precision with which geometry can be transferred into built form has given rise to a crisis in representation in the discipline of architecture, as the distinction between drawing and object becomes increasingly difficult to make. The difference between “prosaic” transcription and “poetic” translation of architectures’ representations, once posed by Alberto Perez-Gomez and Louise Pelletier (1997, 3-8), has never seemed more relevant than now. Perez-Gomez and Pelletier critiqued the assumed “one-to-one correspondence between the represented idea and the final building” (Ibid., 3) by arguing that representations are translated (a process that requires interpretation), rather than transcribed (a process that is accurate and transparent) into built form.

As a response to this tendency, a number of architects and scholars are pursuing work that intentionally targets the relation between geometry and material in design processes. This research can be divided into two kinds. Each kind is exemplified by three references, but these are not to be considered exhaustive. The first kind targets materialization (e.g. Atwood 2011; Fure 2011; Kudless 2011). Rather than viewing the process of materialization as a matter of automatic transcription, materialization is claimed as a creative opportunity and as an act of design in itself. This can be done by purposefully introducing glitches into the process by customizing machinery or by specifying materials that ‘misbehave’ as they interface with machinery. In this way, the designer intentionally cedes geometrical control of the materialization process in order to achieve a desired result. The second kind targets representation (e.g. Besler 2012;
Rather than accepting the conventional idea that representations are idealized versions of artefacts-to-be, 3D-scanning and material simulation are used to introduce the ‘noise’ of the real world into geometry and drawing. In this way, the designer can quantify and represent material agency and entropic processes, something that has previously been impossible. Typical approaches to digital fabrication aim to eliminate noise in the transfer between geometry and object. This approach, in contrast, introduces noise at the outset of the process.

These two kinds of work can easily be thought of as diametrically opposed. In the first case, the designer relinquishes control and widens the gap between the representation and the real. In the second case that same gap seems to close by means of the predictive and descriptive power of digital analysis. This thesis sets these two approaches in relation to each other through the design research project *Erratic*. By targeting polyurethane surfaces, a pliable material with textile like properties that is difficult to control and simulate, it charts architectural opportunities that arise in both types of work simultaneously.

The background and context of this thesis is laid out in the remainder of this chapter. It is in addition addressed in two of the four appended publications. The first publication addresses it from the point of view of representation and materialization (Norell and Rodhe 2014), and the second publication (Norell 2013) brings it up in relation to practice and discourse.

**The digital turn**

The term ‘digital’ has generally been associated with both the practical as well as the conceptual and theoretical integration of the computer into architecture. It can be understood as a reaction to technological shifts, as “digital architectures” found “their legitimization in their exploitation of the latest technological advances” (Kolarevic 2005). More broadly, it can be defined as a trajectory in the recent history of architecture that drew from a convergence of technology, architectural theory and philosophy. Mirko Zardini, in his recent introduction to the exhibition *Archaeology of the Digital*, held at the Canadian Centre for Architecture and curated by Greg Lynn, writes:
However, the digital we refer to in this archaeology is not defined by the pervasive use of technology, nor is it defined solely by the use of computing power in the search for higher efficiency or speed of production. The digital we refer to is defined by experimental projects and ideas, from a specific period of time, which engaged proactively in the creation and use of digital tools to reach otherwise inaccessible results. (Zardini 2013)

A comprehensive overview of the digital turn in architecture is beyond the scope of this exegesis, but a few key ideas are worth bringing up in this context. Beyond integration of technological advances, the digital in architecture owed its transformative power to its ability to produce new conceptualizations of form and matter. It marked a shift from both analytic formalism (e.g. Rowe 1947) and collage formalism (e.g. Venturi 1966) to a theory of form based on complexity, mutation and differentiation (e.g. Lynn 1992; 1993; 1994). This new understanding of form was underwritten by calculus, the branch of mathematics behind NURBS curves and surfaces that had become readily available through modelling software (Lynn 1999). Despite the label digital, the turn came to promote the “performance” of matter (Reiser 1998) over signification and symbolism, two concepts that had dominated post-modern discourse. Finally, thanks to integration of computer aided manufacturing such as CNC-routing, the digital gave rise to a concept of mass customization. Concepts such as standard, original and copy could be challenged as designers could conceive and materialize a series of varied objects with the same ease as identical ones (Cache 1995).

These aspects of the digital turn are notable because of their wide impact, but in addition because they grew out of these authors’ simultaneous practical and theoretical engagement with new means of representation and materialization.

**The material turn**

For about 15 years, from the late 1980’s to the mid 2000’s, architecture had an infatuated relationship to everything digital. In 2005, however, architect and theorist Stan Allen described how the novelty of the work that grew out of the digital revolution had declined in favour of more mature approaches to the use of technology in architecture. Thanks to “[…] a
new generation of designers who have been educated entirely within the
digital regime [...]” architecture had entered into “[...] a relaxed rather
than complex relationship to the computer [...]” (Allen 2005, 94; 99).
Allen’s argument centred around the relationship between the real and
the virtual in architectural design. While the formal complexity and net-
worked connectivity that characterized the early experimental work had,
for the most part, taken place in the virtual realm of the computer, he saw
new opportunities emerge in the mixture of digital and analogue tech-
niques. A comparison between two films, Richard Linklater’s Waking Life
and Pixar’s Monsters Inc. (both 2001), finalized his argument. The for-
mer was shot on a small budget and is characterized by a fusion of real
actors and sites and digital animation, while the latter spends enormous
resources on making the purely digital look real. By creatively crossing
the border between digital and analogue, Linklater had found a way to
combine the inconsistencies and uncertainties of reality with the perfec-
tion and artificial nature of the virtual.

Allen’s text was an early indicator of a shift in research foci for archi-
tectural design invested in digital technology. Today, this shift is variously
described as a shift from the digital to the post-digital or as a transition
from the digital turn to the material turn. In the wake of Allen’s text, Mar-
io Carpo (2012, 2014) as well as Gail Peter Borden and Michael Meredith
(2012) have further theorized the turn from the digital to the material.
This turn can partially be attributed to two recent shifts in technology.
Carpo outlines a growing preference for design driven by material struc-
ture, where the designer makes use of “big data” or material simulation in
lieu of inert (digital) geometry. Borden and Meredith argue that new digi-
tal fabrication and construction techniques have altered the relation be-
tween raw materials and architectural application to the point where it no
longer makes sense to talk about ‘innate’ material properties or ‘natural’
materials. No materials are traditional anymore - all materials are medi-
ated. Both arguments are also substantiated historically as follows.

Carpo initially notes that, in the early 1990’s, spline geometry became
available to pioneers of digital design like Bernard Cache and Greg Lynn
through modelling software (Carpo 2014, 170). Splines and their fellow
topological surfaces are, according to Carpo, pure mathematical objects –
they are derived from mathematical functions. Inevitably, they have to be
approximated in order to be materialized and become phenomenally ac-
cessible. Even representing a spline on a computer screen is an approxi-
mation as the curve is broken down into tiny straight segments and pixels. Big data and simulation differs fundamentally from the spline driven logic in that design no longer departs from a pure mathematical object, but from a ‘real’, recorded event, or from an equally ‘real’ material structure. The digitally simulated surface, for instance, is, in a sense, as ‘imperfect’ or as ‘real’ as the materially instantiated one is. “Yesterday’s spline-dominated environment was elegant and modern; today’s data-driven design environment is messily postmodern: disconnected, broken, fragmentary, rickety, patchy, and aggregatory,” Carpo concludes (2014, 173).

Similarly, Borden and Meredith implicitly target the purity of geometry in the early digital project. Their angle, though, invokes disciplinary history rather than mathematics. “Material” in architecture, they note, was rejected by the conceptual project of the 1970’s avant-garde because it was aligned with a humanist, craft-oriented project that was ultimately to be appropriated by capitalist production and commodification (Borden and Meredith 2012, 2). One of the goals of the ‘cardboard architecture’ that the avant-garde subscribed to was consequently to suppress materiality by divorcing form from material. This approach, according to Borden and Meredith, is no longer relevant since it is increasingly impossible to stand outside of existing material networks – traditional architecture is as artificial as cardboard architecture, and cardboard architecture is as ‘real’ as traditional architecture. Implicit in their argument is the assumption that geometry has been lingering in the digital project at the expense of material because of this theoretical baggage that was inherited from the conceptual project.

In summary, for various reasons the digital project seems to be taking a material turn. Borden and Meredith suggest that it is being replaced by a “post-digital” approach that is material rather than digital in nature (Borden and Meredith 2012, 2). Whatever the case, the pertinent question is what this shift entails in terms of approaches to architectural design as well as from a disciplinary perspective. In the interest of contextualizing design approaches used in the thesis, two precedent studies that fit the previously outlined research foci materialization and representation will follow.
**Materialization: From geometry to material**

The impulse to interrogate the transfer from representation to materialized objects may seem like a knee-jerk reaction in an era when any geometry or any object can be reproduced digitally. Isn’t precise execution of a conceived design every architect’s dream? But precision comes at a price – by locating all of her agency in the representation – the drawing, the digital file, the rendering, etc. – the designer limits the impact of machines and materials on the result to the point where innovation is impeded.

One tendency among architects who target these issues is to intentionally background the purely digital part of both the process and the resulting work. Scripted procedures can be used to manipulate materials directly rather than going through the filter of CAM-software (Computer Aided Manufacturing) and CNC-machinery. Most common digital manufacturing technologies rely solely on either *subtraction* (e.g. laser cutting and CNC-routing) or *addition* (e.g. 3D-printing and contour crafting) of material. In either case, materials are specified so that the transparency between digital geometry and a materialized object is maximized. The specifics of the material are important only as long as they are subservient to geometry. As an alternative, customized procedures can be used that *manipulate* a given amount material. No material is added or subtracted, it is instead *redistributed* by means of exerting force. The designer is productively constrained by the discreteness and properties of the material.

One example of this approach is Andrew Kudless’ installation work *P_Wall*, developed in two iterations between 2006 and 2009 (Kudless 2011; Figure 2.1). *P_Wall* investigates how form can emerge as a negotiation between constraints placed by the designer and the agency of a specific material. It consists of a number of cast panels that are assembled and mounted on a wall in a gallery space. The process behind the project can be summarized as follows. A plaster slurry is cast on top of an elastic membrane that is constrained in a set of carefully distributed points. The weight of the slurry causes the membrane to expand until equilibrium is reached, resulting in a smoothly bulging surface with a recessed dimple for each constraining point. No representation of the curvaceous geometry of the panels exist prior to materialization. The gap between the object and representation could not be wider as the ‘blueprint’ for the design consists solely of a drawing of points and a scripted material procedure. Though evidently computational in its nature, *P_Wall* is, with the excep-
tion of the distribution of constraining points, designed and manufactured entirely in the analogue realm.

Kudless’ work emphasizes the designed artefact as a circumstantial result of a set of instructions and specifications. *P_Wall* relies on a ‘recipe’ or ‘score’ for its making, a technique that already informed conceptual art from the 1960’s. This scripted procedure intentionally introduces an element of chance into the process by letting the agency of, for instance, materials, machines and human beings affect the outcome. This reading of the work downplays the importance of established tropes like craft and performance in order to open up new avenues of thought. As already noted, *P_Wall* lacks traditional projective representations prior to construction. This makes mock-ups and live testing essential, something that requires extensive resources. Further, the project implicitly locates inert geometry (the points) in the realm of representation and vital material (the elastic surface and plaster slurry) in the realm of the real. While this parsing may seem perfectly sensible, it nevertheless enforces an established dichotomy that seems to be at odds with possibilities brought about by new technologies like 3D-scanning and material simulation.

Figure 2.1: Andrew Kudless, *P_Wall*, San Francisco Museum of Modern Art, 2009. Photograph courtesy of Matsys.
**Representation: From material to geometry**

Representation pertains to the set of conventional means of conception and communication available to architectural design. Drawings and models refer to objects and materials in the real world, while simultaneously acting as design mediums and platforms for discourse. Directing focus to issues of representation may first seem to be at odds with the historiography provided in this thesis. Is not the shift from the digital to the material in architecture a shift in focus from geometry to matter, or from representation to artefact? But this assumption ignores the rapidly changing status of representation in the field. Representations in architecture are no longer necessarily idealized versions of artefacts to be.

This is evidenced by designers that create feedback loops between geometry and material by channelling the properties of an object or piece of material into the representation. This approach blurs the distinction between the two worlds, not by attempting to make both ‘clean’, but by making both ‘dirty’. Material simulation introduces the methodology of the ‘wet’ experiment into the virtual world, making it possible to harness the suggestive powers of material agency in the computer. Similarly, 3D-scanning transfers minute variations in form, colour and texture into the realm of idealized geometry. It is important to emphasize that the power of this approach relies on the combination of computation and representation. Merely handling large quantities of data is not enough – it is not until the data is turned into some form of representation that the designer can receive visual feedback.

This approach can be exemplified by Erin Besler’s work *Cube* (Figure 2.2). *Cube* investigates how “translational discrepancies” can be productively introduced into a design process (Besler 2012, 149). It consists of a series of cubes made from low-density foam that have been sculpted by a hotwire mounted on a computer controlled robotic arm. The first cube in the series is ‘perfect’ – a precise transcription of platonic geometry. This cube is subsequently scanned and the resulting point cloud is used to create new cutting profiles that can be fed into the hotwire cutter for fabrication of the next cube in the series. As ‘noise’ inevitably enters into the system due to limitations in both scanning and fabrication equipment, each cube in the series becomes increasingly distorted. Rather than viewing this distortion as an accident or a nuisance, this project intentionally turns the “gap” between object and representation into a design opportunity (Besler 2012, 150).
Cube is of relevance here because it outlines an approach to architectural design based on feedback between representation and a materialized object. It suggests that this feedback can be incorporated as a driver in the design process. Further, the project is a call to rethink representation as something more than an abstraction of reality ‘before the event’.

P.Wall and Cube exemplify two current design research trajectories that have been important in formulating and developing this thesis. Though technically sophisticated, they both result in work that does not foreground its reliance on digital technology. While different in content, they share an approach to research in which technical and material aspects are covered and coupled with a critical, disciplinary framework. This coupling suggests more general opportunities that go beyond the particularities (and oddities!) of the artefact to suggest a relevance beyond a narrow technical niche.

Figure 2.2: Erin Besler, Cube, 2011. Courtesy of Erin Besler.
Chunks: New conceptualizations of form

Architecture as discipline has a history of relying on form that can be described, quantified and analysed through orthographic drawing. With this commitment to representation comes a dilemma: How to handle and conceptualize forms that escape typical modes of geometrical description? Architecture’s incorporation of calculus-based form in the 1990’s and current incorporation of material simulation has pushed the edge of formal and mathematical analysis, but the discipline has lately been slower in developing an accompanying discourse on form. This section will suggest that a shift from geometry and/or calculus based modes of representation to modes based on material and/or material simulation may have larger implications for how architectural form is understood and analysed. This is done by aligning three, previously unrelated contemporary references from the fields of architecture (Carpo 2014), mathematics (Winsberg 2010), and philosophy (Bryant 2011). In varying ways, these three authors all interrogate the relation between form and matter through the concept of *chunks* – discrete objects or pieces of ‘material’.

As stated previously, Mario Carpo has begun to theorize a shift from design driven by inert (digital) geometry towards design driven by material structure (Carpo 2014). Design in the digital turn was largely based on the geometry of vector primitives native to calculus: Points, splines and surfaces. These primitives – the basic components of typical modelling software – are derived from pure mathematical functions. In their ‘raw’ state, they lack fundamental architectural properties such as thickness. A curved surface, for instance, may have to be broken down into segments, facets, or other discrete elements in order to be materialized. Material simulation and scanning, however, offer a very different conceptual starting point for design. Traces of the real, material world can be incorporated at the earliest stages of design. The abstract language of points, lines and surfaces is supplanted by discrete pieces of material, or “chunks”, with properties and character. Mario Carpo writes:

> The inherent discreteness of nature (which, after all, is not made of dimensionless Euclidean points nor of continuous mathematical lines but of distinct chunks of matter [...] is then engaged as such, ideally, or in practice as close to its material structure as needed, with all of the apparent randomness and irregularity that will inevitably appear at each scale of resolution (Carpo 2014, 172).
Spline modelling provided early digital designers with more than just a new tool. It gave some of them a new design medium that had larger implications for the discipline. Calculus, the branch of mathematics behind splines, offered architects like Greg Lynn a new way of understanding fundamental architectural concepts like form and tectonics (Lynn 1999; 1996). In his book *Science in the Age of Computer Simulation*, a study of simulation from the point of view of philosophy of science, Eric Winsberg outlines the difference between calculus and simulation as mathematical models (2010). A complex material system, like a turbulent flow of water, may be impossible to solve mathematically with differential equations - it is said to be analytically intractable. “To overcome this problem, the simulationist ‘discretizes’ the equations and solves them with brute [computational] force” (Winsberg 2010, 8).

Instead of tracking changes over infinitesimal intervals, which is what calculus and its differential equations do, simulation considers finite, or discrete, intervals. Consequently, the key is to use a “fine grid”, i.e. a sufficiently small unit, as a starting point - like a stitch in a fabric, or a voxel, for instance - instead of an infinitesimally small unit (Winsberg 2010, 8). The mathematical underpinning of simulation differs from that of the pure mathematical objects of calculus in that the starting point is not infinitesimal geometric intervals, but small pieces, or ‘chunks’.

The concept of chunks suggests that reduced and idealized geometrical descriptions do not take precedent over ‘real’ pieces of material. This way of understanding the world is aligned with two linked strands of contemporary philosophy known as New Materialism and Speculative Realism. These strands respond to a need for philosophy to address problems of ontology, agency and politics through an updated understanding of matter. A defining feature of the ontologies that belong to new materialism(s) is that they explicitly target “how we might conceive of matter and materiality outside of the dualism of the material and the ideal” (Coole and Frost 2010, 37). Similarly, Levi R Bryant suggests a “flat ontology” where all entities – corporeal and incorporeal – are equally ‘real’ and effectual in the real world (Bryant 2011, 269). This may in the context of architectural form be positioned in relation to historical notions of the ‘low’, such as the formless, as well as the ‘high’, such as the ideal and eidetic. According to Bryant, platonic forms, for instance, are not more true and ‘real’ than the appearance of forms in real space. Bryant thus asserts that we should resist the impulse to reduce objects in search of an essence, as nothing is
more essential than anything else. In lieu of reduction, Bryant offers translation. An object, or “chunk” of matter (Bryant 2011, 270), is never a mere vehicle, or host, for ideological “content,” as that content is always translated depending on the material character of its host (Bryant 2011, 275).

In this reading, these references begin to suggest a working definition of ‘chunks’ for architecture. Can the concept of chunks be turned into an approach to architectural design? This would entail going from chunk as a concept and a noun, to chunking as an activity and a verb. Whether appearing in the form of virtual voxels or as real pieces of material, chunks, as the name suggests, are discrete. Design that considers chunks rather than infinitely extendable topological surfaces considers a specific and finite amount of ‘material’ at the outset. A chunk of material, whether real or simulated, has properties that are irreducible to geometry. As implied by Bryant, it can never be a passive receptacle for ‘content’, as that content inevitably is translated depending on the character of the chunk. Bryant’s concept of translation (2011) parallels Perez-Gomez’ and Pelle-tier’s concept of transcription and translation (1997), described in the outset of this chapter. Geometry or meaning cannot be transferred onto matter without undergoing a translation that depends on the value laden nature of representations, tools and materials.

The interest that this research takes in going beyond current, semi-automated processes of materialization enabled by CAM-software and CNC-fabrication, should be viewed in this discursive context. Similarly, the interest in simulation as a design medium and mode of representation is tied to the mathematical underpinning of simulation, an underpinning that differs fundamentally from that of spline modelling. The linking of simulation to the concept of chunks is central to the thesis and will be further dealt with under Digital materiality (Chapter 3). Some wider implications of chunking on representation and materialization are dealt with under Conclusions and further research (Chapter 4).
3. Method, practice and reflections

This chapter outlines and situates the methods associated with the design research practice that is contained in the thesis. It gives an account of how that practice shaped the research throughout, from the initial choice of methods to modes of communicating the results. The first part provides an overview of methods. The second section describes the design work itself, its process as well as documentation and dissemination. The third section is a reflection on the methods used and the design process, focusing on material manipulation and simulation, accompanied by a few suggested implications for practice-based design research in architecture.

Methods in design research practice

The research draws from two approaches to method associated with practice. The first is practice-based design research, an approach common in design and the arts. The second is projective practice, a model for practice that is native to architecture as a discipline. Under Medium specificity, a critical account of projective practice is provided in light of more recent events.

Practice-based design research

Practice-based design research constitutes an approach to methodology for research in architecture that is relatively established. Murray Fraser stresses, however, that design research, unlike other forms of research in architecture, does not openly proclaim its methodological approach (Fraser 2013, 2-3). It does not contain a defined set of procedures. At closer inspection, it might thus not be possible to define design research as a method, but rather a myriad of methods used by individual practitioners to produce new insight and knowledge.

This thesis was developed through a practice-based design research project. ‘Practice-based’ connotes research that is pursued through
practice. This approach integrates creative work as the basis for knowledge and communication. In so doing, the development of an argument relies on an “experiential component,” belonging to, for instance, an artefact, as much as it relies on reflection and cognition (Biggs 2004). ‘Design research,’ on the other hand, generally refers to how a set of activities, techniques and tools used in design practice can be used towards research.

Michael Biggs has suggested that a defining feature of practice-based research is its reliance on aesthetics and the realm of experience (Biggs 2004, 7-8). Most if not all types of research, he argues, arise from practice or have some implications for practice, ruling out this as a defining criterion for practice-based research. Similarly, relying on empirical experiments, with for instance materials, is insufficient as a criterion. Rather, practice-based research is based on experiential aesthetic judgements, evoked through process. “[...] experience,” Biggs writes, “may be necessary at the stages of problem identification and specification; [...] and in the process of communication and dissemination” (Biggs 2004, 8). Practice-based research may be able to provide answers to certain types of questions and problems. In addition, it is a good way to communicate the results of research to a wider audience. What Biggs ultimately suggests, however, is that the artistic inquiry native to this type of research may aid the formulation of new problems and questions that would otherwise have been impossible to raise.

Daniel Fallman has described design research from the point of view of activity rather than method. Though outlined in relation to interaction design, his model may be applied to architecture as well. He positions three archetypical design research activities – practice, exploration, and studies - in a triangle. This triangle sets up a field in which design research can be positioned. The first activity, design practice, refers to a researcher engaging in design within an architectural practice. Though this type of work may engage client briefs, budgets, etc., it does so with a research question in mind. Like practice, design exploration is “synthetic and proactive” in its character (Fallman 2008, 7). Unlike practice, however, exploration is driven by a “problem-setting” mentality, and it is typically self-initiated and driven by the researcher’s own agenda. It is propelled by ideals or theory and seeks to provoke or challenge the status quo. Design studies, finally refers to a mode of activity that falls close to traditional scholarship and generation of academic knowledge. This type
of activity looks for general principles rather than particular designs (Ibid., 9). Most successful design research projects, Fallman argues, cannot be statically located in any of these three types of activity. Instead, they move in between different parts of the triangle. These moves provide changes in perspective rather than changes in practice as the design researcher intentionally drifts between, for instance, the engagement that belongs to practice or exploration, and the critical distance native to studies.

This work should be viewed in relation to these approaches. It has developed in close relationship to practice and many of its questions as well as arguments have been a direct result of findings made through experiential artefacts. Building on Biggs’ argument, it suggests that sensory qualities of the design work may provide support for arguments being made in the thesis, but in addition that they may be a prerequisite for formulating the very same arguments. The design research activities in the thesis have oscillated between Fallman’s exploration and studies, between design work and formulation of arguments through writing.

**Projective practice**

While the approach and methods of this work can be located in practice-based design research and its interdisciplinary and multimodal spirit, it owes as much to *projective practice*, an approach that comes out of the core of the discipline of architecture. Projective practice emerged in the early 2000’s as a critique of, and alternative to, critical practice. Robert Somol and Sarah Whiting have argued that it shifts attention from architecture’s autonomy to its performance, from asking what architecture *is*, to asking what it *does*, and finally, from theory to practice (Somol and Whiting 2002). In retrospect, it might be suggested that what projective practice did was to legitimize experimental material practice as a way to drive the discipline of architecture forward. Stan Allen argued that material practices “[...] transform reality by producing new objects or new organizations of matter [...]” as opposed to hermeneutic practices that are “[...] devoted to interpretation and the analysis of representations [...]” (Allen 2000, xviii-xix). The former “[...] involve operations of the translation, transposition or transcoding of multiple media,” while the latter generally relies on writing as a primary medium (Ibid., xix). Similarly, Michael Speaks distinguished between architectural practices that use design to solve problems that have been formulated in advance, and those...
that innovate by using design to create “[… ] plausible solutions to problems that have been stated but whose larger implications have not been formulated” (Speaks 2002, 18).

The distinction between critical practice and projective practice is important from the point of view of method. Work associated with critical practice has been described as process driven, while work associated with projective practice can be characterized as effect driven (Norell and Rodhe 2015b). We argue that both these established models have shortcomings that become increasingly apparent when it comes to the role that mediums and artefacts play in the design process.

**Medium specificity**

In the 2002 text that launched projective practice, Somol and Whiting observed that “[…] all architecture now automatically occupies a de facto critical status” (2002, 73). Today, one might say the very same thing about projective practice – it has been assimilated into almost all corners of practice and academia. With this now dominant position comes exposure to critique. Sylvia Lavin, one of the early proponents of the projective approach, has recently criticized modes of practice that have been associated with it. The reliance on material practice has produced a climate in which the construction of pavilions and other full-scale assemblies is over-emphasized and taken as a sign of novelty in itself (Lavin 2012). “The result is that while firms specializing in hospital or stadium design would once have been understood to be separated from pavilion architects by a vast ideological divide, today they increasingly operate in accordance with the same values of efficiency, service, and art as added value,” Lavin poignantly argues (Ibid.). Similarly, the merging of practice and research that promised new ways of accumulating knowledge has become commonplace to the point where it is increasingly difficult to distinguish between the innovative and the formulaic (Lavin 2013).

It might in retrospect be argued that one of the effects of projective practice and its emphasis on material practice is its tendency to carve increasingly narrow niches of practice and research based on medium specificity. Medium must here be understood broadly, from ways to conceptualize architecture to highly specific material processes. Both Sylvia Lavin and Michael Meredith have recently observed that this has led to a “post-medium” condition in architecture (Lavin 2011; Meredith 2013). A detailed account of this tendency is beyond the scope of this exegesis, but
a few points are important to bring up. Constructing narrow niches of research based on, for instance a singular material support (e.g. plastic forming) or a particular type of geometry (e.g. subdivision surfaces), may seem perfectly valid. But at the same time we all know that architecture as a practice as well as a discipline relies on the joining, coordination, and transfer of multiple materials, mediums and processes. The craftsmanship and technical expertise tied to the workings of a single material, whether hands-on or computerized, does not equate with an architectural understanding of the possibilities and limitations tied to the same material.

The work presented here has been influenced by these recent developments. The design work has been conceived and constructed by intentionally combining multiple mediums ranging from digital simulation to analogue manipulation of materials. This has led to a more multifaceted design process, where the coordination as well as the discrepancies between mediums must be productively handled.

**Practice**

The approaches to method outlined above were synthesized in a collaborative design research project. This allowed the thesis to adopt a technical and material as well as cultural and disciplinary focus that was aligned with the research questions. Asking *how* something might happen, rather than *why* or *what*, is something that (projective) practice does well. Moving between the specificities of design exploration and the more general possibilities that can be extrapolated through design studies has shaped the thesis as a whole.

The design work that forms a large part of this thesis has been developed by Norell/Rodhe, the practice that I co-founded with Einar Rodhe in 2012. The practice, as well as some approaches used in the design of *Erratic*, partially came out of a graduate design studio that Einar and myself taught at the KTH School of Architecture in 2011. The collaborative part of the work includes the design project as well as published articles. We have jointly presented the work in both academic and popular contexts.

**Erratic**

*Erratic* was formulated as an attempt to study the tension between precise design intent and materials that behave erratically (Figure 3.1). It
started as a response to current issues of materialization and representation in architecture, as outlined under Background and context (Chapter 2) and in the second appended paper (Norell 2013). In addition to pointing to the issue of material agency, the title of the project also gave it its massing – erratic blocks that have been tumbled by glacier ice are commonly found all over the Nordic region. For a full description of the project, see the first appended paper (Norell and Rodhe 2014).

The role of the design work and the process behind it is important in relation to the themes of practice-based design research and projective practice, as outlined in the previous section. In both these approaches, design work is not to be seen as a proof of concept that follows from a theoretical statement of a problem. Rather, the design work becomes indispensable in formulating new problems that begin to shape the thesis. In light of this, the section Making the Erratic focuses on the interplay between design work and extrapolation into more general possibilities. ‘Making’ thus refers to the design and construction of the work, but in addition to the making of research enquiries that happened in parallel. Following the making, the research enquiries were further developed and
responded to through exhibition and dissemination – in academic as well as popular contexts.

As a result of this overall process, design and intellection became intertwined. The typical hierarchy between making – design, fabrication, construction – and exhibiting – documentation, editing, communication – partially dissolved.

**Making the Erratic**

*Erratic* consisted of an installation in which a thick, pliable polyurethane surface – essentially a large, spheroid sack – was constrained in hundreds of points onto a rigid inner armature. The sack was designed to be considerably larger than the armature, so that plenty of excess material was left between each constraining point. The force exerted by the constraining points made the surface bend, twist and furl in a seemingly random manner. Formally, there was a tension between the rectilinear grid of points and the meandering surface. Further, while the location of each point could be designed and placed with precision, the resulting behaviour of the surface was difficult, if not impossible to predict. We designed
the piece by carefully placing the points, and in-between the material had its way. The project became an exercise in design where a minimum of geometric input (the points) yields a maximum of material output. Its title, *Erratic*, served to suggest a concept of designed unpredictability, and in addition pointed to the visual characteristics of the randomly ‘wandering’ surface.

So far the project seemed to be aligned with a conventional separation between representation and a materialized design: Some aspects of architecture can be designed, quantified and represented ‘before the event’ (for instance through orthographic drawing), while others are dependent on material manipulation and must be tested ‘live’. In other words, while pure geometry can easily be described in the Euclidian space of the drawing, the constructed artefact is inevitably affected by the noise of the real world.

The work on *Erratic* took an interesting turn when we started using simulation software to simulate how the material could be manipulated (Figure 3.2). This was a necessary step in order to be able to quickly design variations without producing time-consuming mock-ups. To a certain extent, we could now predict the erratic behaviour of the material. In the software, the agency of the real world material co-existed with the Euclidian space of the armature drawing (Figure 3.3). Material agency could suddenly be designed, quantified as well as represented. This was a first issue that the work seemed to prompt: Simulation in architecture challenges the typical separation between representation and a materialized design, between Euclidian space and the real world.

As work progressed it became increasingly important to fine tune the relation between analogue scale models and full-scale mock-ups on one hand and simulated models on the other. Parameters in the simulation software, such as bend and compression resistance, were tweaked to achieve conformity with the analogue tests. But tuning also worked the other way. The material that the surface of the installation was made from, polyurethane cold foam (i.e. foam rubber), is isotropic and comes in a variety of thicknesses and densities. This meant that the properties of the material could be tweaked in parallel to achieve a better conformity with the simulation. It should be stressed that the fine tuning of the two realms was not an end in itself. It continued only to the point where we had a good enough conformity between the two for the purposes of designing the piece. The second issue that the work on the project prompted
thus had to do with process and method and the creation of feedback loops between simulated material and real material.

**Exhibiting the Erratic**

*Erratic* was exhibited twice, first in the solo-exhibition *Erratic* at the Aalto University Digital Design Laboratory (ADD) in Helsinki (2013), and subsequently in an exhibition titled *Taming the Erratic* (2015) that was included as part of the conference *Making Research | Researching Making* at the Aarhus School of Architecture.

At ADD, our exhibition was part of the program for Helsinki Design Week, which meant that it reached a broad audience within architecture and design. The installation was sited in ADD’s double height gallery and lobby space and the exhibition of models and drawings continued in their lecture space and machine room. In addition to an exhibition opening event ADD, we co-organized a pop-up exhibition and panel discussion around the project at the Helsinki Design Week venue. During one day, we displayed models and drawings as part of ADD’s exhibition in the
design week, culminating in the panel discussion *Erratic Design* with Einar Rodhe and myself, Antti Ahlava of Aalto University’s Department of Architecture, Tim Anstey of KTH School of Architecture, and ADD director Kivi Sotamaa. Thanks to an invitation from Helsinki Design Week director Kari Korkman, we were included as presenters at the official PechaKucha night, where our talk reached a large, international audience of architects, designers and the general public.

The exhibition at the Aarhus School of Architecture was part of a conference on research through making. The exhibition was peer-reviewed and accompanied by a short paper. The conference gathered people from a variety of design disciplines active at the threshold between practice and academia. Though open to the public, this exhibition targeted a research community as well as faculty and students at the school in Aarhus.

In both these exhibitions we wanted a setup that acknowledged the importance of shifts between analogue and digital design mediums. In addition to the analogue installation (or photographs of it in the case of the latter exhibition) and its preceding models and mock-ups, we devised a series of drawings and models based on the digital simulations that we had undertaken. Several simulated massing studies were 3D-printed and mounted in both exhibitions. These models contributed to the thesis of the exhibition by visually emphasizing the ambiguous nature of simulated materiality. They balanced the abstract nature of representation with the vitality of real materials.

Through these two exhibitions, the design work and concepts associated with it were disseminated to an academic context of researchers as well as to a larger, culturally oriented audience of architects and designers. In keeping with this attitude, the work in the thesis has been documented and circulated through published conference papers as well as through popular architecture and design blogs. The exhibition at ADD was presented and promoted at Archinect, one of the largest architecture blogs in the world. An entry about the work was accepted for publication at suckerPUNCH, an architecture blog that promotes explorative design research work globally. These two publications in turn generated numerous additional features and reposts, in popular contexts such as design blogs, as well as in academic contexts such as the Architectural Association in London and UCLA in Los Angeles.
Reflections

Reflections on the methods deployed in the thesis are dealt with along two lines of enquiry. The first line is material and technical in nature and deals with the design process of Erratic. This line is covered under Material resistance, Digital materiality and Validation, as well as in the first and third amended publications (Norell and Rodhe 2014; Norell and Rodhe 2015a). The second line, covered under Process vs effect as well as in the fourth appended publication (Norell and Rodhe 2015b), reflects on a few more general implications for design research in architecture.

Material resistance

The statement that “Architects do not make buildings; they make drawings of buildings,” once famously made by Robin Evans, has today become somewhat exhausted in the discipline (Evans 1989, 21). Although intended to target representation as a problem of translation from drawing to building, it can be used to perpetuate the conventional distinction between design (i.e. drawing) as a mainly conceptual pursuit that targets idealized geometry, and building as a material pursuit that deals with material in the real world. As outlined in Chapter 2, this distinction can be challenged by incorporating material manipulation and material simulation working in tandem.

The act of drawing, whether by analogue or digital means, is associated with a particular set of design methods that are projective and virtual in their logic. It may involve orthographic projection, it is done to scale, and it is subject to little or no material resistance. The idea that the dynamic nature of materials can provide a different methodological starting point for design is nothing new. Historical examples are plentiful and range from Frei Otto to Sigurd Lewerentz (Norell and Rodhe 2014). Today, the broad diffusion of digital fabrication technology has given rise to an increased significance of this approach.

The act of manipulating one or several pieces of material is methodologically distinct from drawing. It deals with discrete pieces of material that each come with a genesis – their properties and character. Like the objet trouvé in art - the found object – an object or piece of material derives its identity from the designation placed upon it by the designer, as well as from its genesis in the real world. It has a certain amount of re-
sistance to the agency of the designer. The designer may react to this gen-
essis by amplifying or subverting it, but cannot ignore it.

The resistance exhibited by objects or pieces of materials comes in dif-
ferent kinds. It might be associated with the physical properties of a ma-
terial, such as the soft flexibility of the pliable polyurethane surface that
we used to design and build *Erratic*. This property turns the design pro-
cess into a game of push-and-pull in which a force applied to the material
by the designer generates an immediate response as a deformation in the
material – a wrinkle. Another kind of resistance can be associated with
the inherent identity of an object or piece of material – its connotations as
well as its haptic qualities. Again, in our case the material was polyure-
thane, commonly known as foam rubber. This material, in its raw state, is
not particularly beautiful and its connotations range from cheap, yel-
lowed mattresses to featureless insulation material. The way in which we
manipulated this material, from constraining into shape to finishing it
with plaster powder, was a way to come to terms with its identity and
accompanying associations (Figure 3.4 and 3.5).
Digital materiality

Erratic interrogates the extent to which material simulation introduces materiality into the abstract realm of digital geometry. As stated under Chunks (Chapter 2), the mathematics of simulation is based on discretization, or on small chunks. In simulating fabric, each chunk works like a stitch. For the design development, we used a particle-spring based software that considers each edge in a dense mesh as a spring of restricted length (Figure 3.6). Points on the mesh can be moved and constrained and parameters like elasticity, thickness and weight can be set and adjusted. Results of a certain set-up can be animated, viewed and tweaked in real time. In certain respects, this made it possible to manipulate digital geometry as if it was composed of matter.

The kinds of feedback that the designer can receive through this type of material simulation are ambiguously set in-between drawing and material experiment. In our work with Erratic, simulation was used to create orthographic drawings (Figure 3.3) that were used in design development.
as well as to quantify and specify materials. At the same time, simulation was used as an equivalent of material tests carried out in scale models and mock-ups (Figure 3.7; 3.8). In these experiments we received immediate feedback in the form of articulation that resulted from simulated material resistance. In other words, the simulacra – the image or drawing that represented the material – was as important in the design process as the simulation (Norell and Rodhe 2014).

As outlined in the first appended paper (Norell and Rodhe 2014, 148), material simulation is significant as a means of modelling pliable surfaces. Modelling textile like materials with digital geometry remains a challenge. NURBS surfaces have limitations when it comes to describing a range of curvatures and maintaining continuity over a larger swatch of fabric. Some of these issues can be solved by using subdivision surfaces. Both types of modelling, however, are methodologically distinct from manipulating an actual piece of fabric. In either case, the designer essentially starts from a flat surface. Adding formal features to the surface with NURBS or subdivision modelling inevitably affects its resolution as well as its surface area. Manipulating a non-elastic and discrete surface is
fundamentally different in that material is redistributed but never added. This places productive constraints on the designer as each successive move generates an immediate response that in turn limits any consecutive move.

The design process undertaken for Erratic suggests some more general possibilities for simulation as a design medium. In the field of philosophy of science, Eric Winsberg has acknowledged the difficulty of positioning simulation “on the methodological map” – is it applied theory, empirical experiment or simply a third and new type of knowledge (Winsberg 2010, 136-37)? A similar type of enquiry about its methodological nature may be directed at architecture. Material simulation combines features from both abstract (digital) geometry and the material experiment. It grants the designer with the projective and descriptive powers of orthographic projection and quantification that are native to digital modelling, while simultaneously introducing some of the resistance native to a real and discrete piece of material. In fact, the range of design methods implied by material simulation are closer to those of the ‘live’ material experiment, where the designer sets something up in order to ‘see what happens,’ than they are to typical modes of drawing and digital design.

Figure 3.7: Erratic assembly process at ADD: Polyurethane sack lowered over armature and connected to struts (top). Snapshots from digitally simulated constraining process: A spheroid mesh constrained in 200+ points (bottom). Courtesy of Norell/Rodhe.
**Validation**

Validation is a key concern when working with simulation. Its purpose is getting a “good enough” match between simulation and experimental data (Winsberg 2010, 20). A specific method of simulation typically gains credentials over time, as it proves to be accurate enough to predict real-world happenings. This was a main concern in our work with Erratic, as it became important to match simulations to models and mock-ups that were material tests. We used simulation to study the massing of the installation and 3D-printed those studies as models at scale 1:25 (Figure 3.2). These models were used in parallel with material tests – 1:5 scale models and 1:1 scale mock-ups in which polyurethane surfaces were point wise constrained to a substrate or armature (Figure 3.8). As described under Practice in this chapter, step-by-step, simulated studies and material studies had to be matched to each other. Properties of the simulated material, such as bending and stretch resistance, were tweaked digitally, and corresponding properties of the polyurethane foam, such as thickness and density, were varied in dialogue with our fabricator.

**Process vs. effect**

The process of going between simulation and experiment, between digital and analogue design mediums, leads to some general remarks on practice-based design research in architecture. To recapitulate, practice-based research integrates creative work as a basis for knowledge and communication. Shane Murray has suggested that “design research in architecture leads to the production of several forms of knowledge with varying degrees of visibility” (Murray 2013, 96). Knowledge can be embodied in the final outcome of the research – the creative work itself, where it is visible to those trained in the discipline. In addition, knowledge might be generated in the process of design in ways that require an account of what actually took place during that process (Ibid.). In terms of documentation and formatting of the research, it might be assumed that the former puts an emphasis on the ‘effect’ of the designed artefact on a subject, while the latter emphasizes diagrams, sketches, mock-ups, or other similar accounts of design decisions made during the process.

The degree to which the process is made visible in design research is however not just a question of communicating knowledge. When process is put on display, it may easily slip into a narrative that affects the experience and reading of the design work (Norell and Rodhe 2015b). The de-
sign work may for example risk being reduced to a linear series of design decisions based on program or context. Withholding process in favour of an unimpeded encounter with the design work itself may on the other hand rob the work of an important register.

In architecture, this friction between process and effect can be traced to two models of thought (Norell and Rodhe 2015b). Process driven architecture can be attributed to Peter Eisenman’s early work that emphasized the design work as a registration of a set of scripted procedures – epitomized in his axonometric drawings that documented an entire process as a series of three-dimensional transformations (see Allen 2006). Effect driven architecture can be exemplified by the work included in the more recent Matters of Sensation group exhibition, organized in 2008 by Artists Space in New York (see Artists Space 2008). Propelled by the integration of digital fabrication into architecture, the exhibition featured large scale architectural prototypes, but no traditional scale models or drawings. Process was withheld entirely in order to focus on ‘sensation’ – the visitor’s encounter with the designed artefact.

The conference exhibition Taming the Erratic: Artefacts of Making (Norell and Rodhe 2015b) looked for alternatives to these two established models. It focused on the nature of the artefacts behind Erratic – models, mock-ups, construction drawings, animations of simulations, videos and customized assembly tools. Displayed next to each other, these artefacts made the making of the project visible, but they did not attempt to construct a linear narrative of a design process (Figure 3.9). Each item unlocked an aspect of the installation expressed through a specific design
medium. Overall, the exhibition was an attempt at finding a format that does not reduce the work on display to an index of process, nor considers it solely for its sensory effect in the encounter with a subject.
4. Conclusions and further research

The practice-based design research presented here has addressed questions of representation and materialization in post-digital architectural design. These questions are actualized by the ways in which digital design has narrowed the rift that separates drawings from constructed artefacts. In response, a position on how architecture might engage with material processes and simulation has been elaborated. This position springs from the disciplinary, material and technical perspective of a design project as well as from a theoretical point of view. The scope is admittedly broad, from the specifics of design to more open ended discourse. This is important in a field that by convention often resorts to narrowly defined technical problems that target a singular material support or a geometrical system. The contribution lies in the coupling of visceral aspects of actual and digital manipulation of materials to a larger framework of thought. This framework has made it possible to locate and develop larger methodological as well as theoretical consequences suggested by the design work.

Two related research questions have been addressed. The first deals with how materialization in architecture may move beyond what has become standard processes of automatic transcription in digital design and fabrication. By targeting a customized material process, the work locates design opportunities in the transfer between geometry and material. The second deals with how simulation and scanning may introduce the ‘noise’ of ‘real’ objects and materials into geometry and drawing. By targeting material simulation, a case is made for how this new design medium opens up possibilities for harnessing material agency. Further, simulation is positioned methodologically and disciplinarily as a medium that straddles established polarities such as geometry vs. matter, virtual vs. real and drawing vs. mock-up. Combined, these two questions highlight that materials and objects, whether simulated or real, offer a starting point for architectural design that differs fundamentally from that of the drawing or geometry. In this approach, the designer needs to be able to *tame the erratic* – to artistically handle various kinds of resistance offered by, for
instance, a piece of material. This can be done by manipulating materials directly, or by means of digital manipulation or representation, such as simulation and scanning.

The interplay between design and intellection in the research can be broadly situated within projective practice. The kind of design practice that the research relies on is not pursued as a practical response to a theoretical problem that has been formulated in advance. Rather, it is a reflexive one in which the visceral aspects of design aid the formulation and resolution of new arguments and theoretical standpoints. The virtue of the design project *Erratic* consequently does not lie in its ability to shed light on a technical and performance oriented query, such as optimizing the exactitude achievable with digital simulation of fabric. It does, however, raise significant conceptual and methodological issues that arise from the use of digital simulation, as opposed to digital modelling, as a design medium. Similarly, the installation is not a showpiece that exhibits technical research carried out in advance, but a work that is driven by a disciplinary design research agenda.

The approach that this research has taken towards technology in architectural design positions simulation and scanning as design mediums rather than as ‘tools’. The point clouds of 3D-scanning and the voxels and meshes of material simulation are not just new tools that offer more precise measurements or quantifications by, for instance, making site surveys more precise or by testing the structural capacity of beams. Their micro-structured objects and material aliveness, respectively, constitute new mediums that are waiting to be explored and theorized. Because of their ambiguous status between representation and real thing, they challenge established disciplinary categories such as drawing, model, mock-up and material process. Further, these issues are discussed in relation to ongoing debates about medium specificity in architecture.

Similarly, the concept of ‘chunk’ that has been elaborated is applicable in both the digital and the material world. In a digital design environment, objects are typically defined by position, dimension and visual characteristics. With the exception of linking objects to standard products in a BIM (Building Information Modelling) environment, these objects lack a specific material referent. Chunks, if defined digitally through simulation or scanning, differ in that they throughout the design process are open to forming alliances with both the virtual and real. Discourse surrounding digital design has a history of forming concepts around specific
mediums, such as a geometrical system – think of NURBS geometry, for instance. The concepts put forward here, such as chunking, follow this tradition in that they partly depart from opportunities provided by material manipulation and simulation. The difference, however, lies in that chunking is not exclusively tied to one material support or geometrical system, nor to either the digital or the analogue realm. It is a post-medium specific concept, to borrow Michael Meredith’s term, in that its very premise is that it exists in-between design mediums.

The work presented here points to several possibilities for further research. A broad, discursive scope has been central to identifying these possibilities, that span from design and technology, to history and theory. The following paragraphs summarize three emerging trajectories of research and suggest how these might be extrapolated into further research. The first is oriented towards history and theory, the second is second is oriented towards design and technology, and the third towards methodology.

First, this research suggests that ‘chunking’ in architecture can be tied to a larger re-conceptualization of matter in contemporary thought. This might in turn provide opportunities for new conceptualizations of architectural form. Architecture has a long history of relating formal analysis to mathematics. In the 1940’s Colin Rowe argued that similar geometrical principles underwrote both a 16th century Palladian villa and a 20th century Corbusian villa (see Rowe 1947). Rowe’s analysis drew from geometry, a branch of mathematics that deals with properties of space such as proportion and position. In the late 1990’s Greg Lynn’s theories of form drew from calculus – the mathematics behind then newfound spline-modellers – as a mathematical model (see Lynn 1999). While Rowe’s discourse centred around timeless ‘harmonious proportions’ measurable with geometry, Lynn argued for architectural form that instead was differentiated and ‘mutated’ with the aid of calculus. Viewed in this context, simulation and the mathematics behind it might open up new avenues of architectural thought. The architectural world is no longer populated by perfectly proportioned geometrical primitives, nor by infinitely malleable and extendable curves and surfaces, but by ‘real’ and discrete chunks of matter. These chunks partially resist the agency of the designer by virtue of their genesis – their history, properties and identities as objects.

New technologies of representation and materialization have for quite some time now focused design research and accompanying discourse on
process oriented problems of ‘translation’ from geometry to material, or vice versa. Much less attention has been paid to developing a discourse on architectural form that can handle and classify the ways in which these translations incorporate and give rise to ‘noise’ and inconsistencies. As shown in Chapter 2, simulation, as a mathematical model, differs fundamentally from that of calculus (see Winsberg 2010). A shift in focus from geometry and/or calculus based modes of representation to modes based on material and simulation is bound to have larger consequences for how architectural form is understood and analysed.

Second, design that draws from chunks considers a finite amount of ‘material’ at the outset. Design is thus not a product of imposing will onto formless and featureless matter. This approach resonates with a current situation in which architecture is increasingly conditioned by an aging building stock as well as scarcity of material resources. Architectural up-cycling of existing materials, building components and whole built structures requires a different mind-set in which a specific, limited stock of matter becomes instrumental for design. Coincidentally, ‘stock’ is how most CAM-software labels the piece of material that a fabrication machine will do work on. ‘The stock’ is the virtual, dimensioned representation of, for example, a standard piece of material, such as a sheet of plywood. For quite some time now, digital fabrication has called upon designers and architects to creatively integrate the ways in which geometry interfaces with a piece of material. This suggests a further possibility: That the stock in itself can be rethought conceptually. No longer limited to standard, seemingly featureless piece of material, the stock is destined to become something that is repurposed and unique. By coupling simulation, 3D-scanning, and robotics, there is a potential to define and dimension a stock that is unique in nature. This expands the material register of (post-) digital design. Opportunities like this have largely been ignored in a field that continues to focus on the (precise or imprecise) transfer of geometry onto standardized materials, or, alternatively, on the construction of materials from scratch.

Third, a crucial aim of the work presented here is to develop a specific approach to technology within practice-based design research in architecture. This approach can be characterized as both playful and critical. It is playful in that the thesis shamelessly adopts and repurposes technology (material simulation carried out in animation software) that does not originate from the field of architecture or building construction. At the
same time, it is in addition critical in that the use of this technology is reflexive and points to larger disciplinary issues. Research on technology in architecture is nowadays often defined in terms of building technology – towards technology that targets building construction. While this is perfectly valid and even necessary, such research may nevertheless run the risk of losing a firm connection to the discipline of architecture. This thesis suggests that research on technology might be defined towards architectural technology – towards research that focuses on technologies as design mediums used by architects. Technology, then, becomes a way of rethinking, augmenting or interrogating aspects of fundamental architectural concepts, such as representation, materiality, tectonics or form.

Such an approach to design research and technology in architecture requires a renewed focus on the interplay between representation and material as well as between process and effect. It is neither ‘critical’ and focused on autonomy, drawing and process; nor is it ‘projective’ and focused on performativity, pragmatics and ‘effect’. Rather, as suggested here, it is in the transfer between these oppositional terms that opportunities are located. Here, the terms materialization and representation both refer to the act of pulling ‘stuff’ from the drawing to the real world, or the other way around. This approach is post-digital in its nature and suggests a ‘flat ontology’ in that it does not revolve around a hierarchy between design mediums. Drawings and materials, digital and analogue, the eidetic and the formless, etc., are, to borrow Bryant’s phrasing, “equally real and effectual” in the world as well as in the discipline of architecture. And the transfers and tensions between them that much of this thesis centres on, would not be possible without both worlds.
Bibliography


Paper A

Erratic: The Material Simulacra of Pliable Surfaces

DANIEL NORELL
AND EINAR RODHE

Published in
Fusion, Paper proceedings of the 32nd International Conference on Education and research in Computer Aided Architectural Design in Europe (eCAADe)
145-152
Paper B

Noise Control: Designing with Entropic Processes

DANIEL NORELL

Published in
New Constellations / New Ecologies, Paper proceedings of the 101st Annual Meeting of the Association of Collegiate Schools of Architecture (ACSA)
283-288
Poster C

Erratic

DANIEL NORELL
AND EINAR RODHE

Published in
Open Cities: The New Post-industrial World Order,
Poster proceedings of the Association of Collegiate
Schools of Architecture (ACSA) / Architectural Institute
of Korea 2014 International Conference
10-11

The poster was one of three winners of a Research +
Design Merit Award at this conference
Exhibition D

Taming the Erratic: Artefacts of Making

DANIEL NORELL
AND EINAR RODHE

Published in
Biography

Daniel Norell is an architect, researcher and educator. He studied mathematics in Uppsala before receiving two master's degrees in Architecture, first from the KTH Royal Institute of Technology in Stockholm, and later from University of California Los Angeles (UCLA) in the US. He has worked in the offices of servo, Greg Lynn FORM and Zaha Hadid Architects and was co-founder of the architecture research collective Krets. Currently, Daniel lectures and writes about architecture, technology and culture, is senior lecturer and director of the master’s programme in architecture and urban design at Chalmers University of Technology in Gothenburg, and co-founder of Stockholm-based architecture studio Norell/Rodhe.