THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Cultivating the Erratic

Architectural representation and materialisation after the digital turn

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022

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ISBN 978-91-7905-678-0

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Doctoral Thesis at Chalmers University of Technology
Doktorsavhandlingar vid Chalmers tekniska högskola
Series number: 5144 in the series Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie (ISSN 0346-718X)

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Funding agencies
C-ARC, Chalmers University of Technology
FORMAS through Architecture in the Making, Chalmers University of Technology
The ARQ Foundation

Cover illustration
Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, 2020

Printing
Chalmers Reproservice,
Gothenburg 2022

Abstract

This thesis investigates representation and materialisation in contemporary architectural design. 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, physics simulation, and 3d-scanning offer alternative possibilities for design by incorporating the often-erratic qualities of extant objects and materials. These developments call for architects to intervene in and theorise technological transfers between representation and material reality that might otherwise become matters of mere expediency.

Spanning in scope from design to technology to theory, the thesis is developed through a combination of analytical enquiry and design driven research. The design works included, *Erratic* and *Completions*, explore materialisation and representation against a critical review of key concepts associated with the 'digital turn' in architecture during the 1990s and 2000s. The thesis interrogates how those concepts have been developed and challenged in the decades after this turn. Key to the analysis is a critical enquiry about the nature of architectural representation and the significance of theoretical frameworks gleaned from other areas of enquiry, including materialist and post-digital thinking. The implications of the design work are explored by positioning physics simulation and 3d-scanning as means of representation through an interlacing of thinking from such frameworks with detailed accounts of technical apparatuses involved in conception and production.

Overall, the thesis aims to build a new position for architectural conception and production. It argues that the means of representation that facilitate architectural design have agency, and that simulation and scanning offer a contemporary context in which the effects of such agencies can be productively observed. This opens a disciplinary discussion on issues of projection, translation, and codification and their role in shaping the architectural imagination. The discussion also extends beyond such architectural concerns and into political critique, as practices, technicalities, and histories of representation condition how we view the world, how we operate in it, and might even modify how we view ourselves.

Keywords: 3d-scanning, Agency, Design driven research, Materialisation, Physics simulation, Representation.

List of appended publications

This thesis is based on the work contained in the following publications:

I

Norell, Daniel, and Einar Rodhe. 2014. "Erratic: The Material Simulacra of Pliable Surfaces." In *Fusion, Proceedings of the 32nd annual conference on Education and research in Computer Aided Architectural Design in Europe (eCAADe) - Volume 2*, edited by Emine Mine Thompson, 145-152.

II

Norell, Daniel, Einar Rodhe, and Karin Hedlund. 2021. "Completions: Reuse and Object Representations." In *Distributed Proximities, Proceedings of the 40th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, edited by Brian Slocum, Viola Ago, Shelby Doyle, Adam Marcus, Maria Yablonina, Matias del Campo, 446-455.

III

Norell, Daniel. 2021. "Geometries with Agency: Mathematics of Form Revisited." *Architectural Research Quarterly* 25 (3): 255-265.

IV

Norell, Daniel. 2013. "Noise Control: Designing with Entropic Processes." In *New Constellations / New Ecologies, Paper Proceedings of the 101st Annual Meeting of The Association of Collegiate Schools of Architecture (ACSA)*, edited by Ila Berman and Ed Mitchell, 283-288.

Acknowledgements

I want to thank my main supervisor Tim Anstey for his continuous support in initiating, developing, and sharpening this thesis. I am especially grateful for his tireless close reading and insightful suggestions that have shaped this thesis as well as made it inspiring to work on. The support of my examiner and second supervisor Fredrik Nilsson cannot be overstated, not just for his encouragement and critical intervention at key moments in the development of the thesis, but also for offering funding and a context for the thesis throughout. The design work and some of the publications included in the thesis are a collaborative effort and would not have been possible without my partner-in-practice Einar Rodhe.

The thesis has been developed across almost a decade, two universities, and with the support of several funding bodies. The second half of the thesis was developed at the Division of Architectural Theory and Method at the Department of Architecture and Civil Engineering at Chalmers University of Technology, where I have been a member of the faculty for the last decade, and it was funded through C-ARC at Chalmers, with additional project funding provided by the ARQ Foundation. The first half of the thesis was developed at the KTH Royal Institute of Technology's School of Architecture in affiliation with the research environment Architecture in the Making at Chalmers, funded by the Swedish Research Council Formas. I am grateful to many current and former colleagues at both these institutions, including my head of division at Chalmers, Maja Kovács, my second supervisor while at the KTH, Ulrika Karlsson, and our collaborators for the design work, Karin Hedlund, Hseng Tai Lintner, and Stefan Svedberg, at Chalmers. In addition, the thesis has been influenced by ongoing conversations with friends and colleagues that I have collaborated and taught with throughout these years: Pablo Miranda and Jonas Runberger with whom I founded the design research collaborative Krets back in the early 2000s; my long-time teaching partner Jonas Lundberg at Chalmers; my studio colleagues Naima Callenberg, Peter Christensson, Jens Olsson, Kengo Skorick, and Malgorzata Zboinska, also at Chalmers; Frida Rosenberg at the KTH, with whom I curated a lecture series while at the KTH that included inspiring dinner conversations with invited guests; as well as my partners in the research project Interiors Matter, Ulrika Karlsson, Cecilia Lundbäck, Einar Rodhe, and Veronica Skeppe. Project work at Chalmers was supported by workshop masters Peter Lindblom and Tabita Nilsson.

As this thesis partially relies on scholarship of design work, I am grateful to several practices and individuals for generously allowing me to include their work in publications and for their encouraging shoutouts, including Damjan Jovanovic, Greg Lynn, and Michael Meredith and Hilary Sample of MOS. I am especially grateful to Greg for the time I spent in his research studio while being a graduate student at UCLA in the mid 2000s, for hiring me to join his practice after I graduated, as well as for his continuing support.

Several individuals have provided important opportunities to discuss and disseminate the thesis and the design work and publications 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 Oslo School of Architecture and Design, Cheryl Ball offered feedback and an opportunity to temporarily join the PhD community in Oslo. Based on research under development in the thesis, Johan Bettum generously made me part of the Städelschule Architecture Class community in Frankfurt by continuously inviting me to lecture, teach, and review student work. Mick Wilson offered valuable insight on method as part of a course he gave at HDK-Valand at the University of Gothenburg. Finally, large portions of the thesis and some of the publications contained in it have been graciously reviewed in different stages of development by Isabelle Doucet at Chalmers, by Hélène Frichot at University of Melbourne, and by Claus Peder Pedersen at the Aarhus School of Architecture.

I dedicate this thesis to my partner Ulrika, our daughter Iris, and our son Ivar.

Stockholm, July 2022
Daniel Norell

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1 Introduction

Architecture as a practice and as a 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 materialisation, 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 realised but change the ways in which architecture is transferred from conception to realisation. Historically, these shifts have occurred following the introduction of new technologies – for instance template drawings, projective drawings, and photography, to mention a few. Today, the different types of representation used by architects have exploded. The use of media such as drawings, videos, photographs, models, prototypes, and software, means that technology continues to modify the practice of architecture. This expanding plethora of media does not just offer new possibilities for design. Each medium comes with an agency – an inner logic – that in turn may condition the act of design as well as the discourse that surrounds it.

New ways of bridging between representation and materialised objects offer new practical and disciplinary challenges. Greg Lynn once observed that the future in which robots rather than humans fabricate building parts has arrived without anyone noticing. Drawings are no longer necessarily interpreted by a craftsman or construction workers 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 and theorise 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 idealised digital geometries, to customised machine-based and material processes. Through design driven research, this thesis investigates how design intent might be shifted from typical modes of representation to alternative modes of materialisation.

The direction of transfer may also be reversed. Photography once revolutionised the way in which architecture could be documented after the event of construction, as it made it possible to turn the real thing into a representation in a new way. Today, the widespread use of physics simulation and 3d-scanning allows architects to transfer properties of extant materials and artefacts into

representations, creating points of departure for design. Visual and physical properties belonging to a specific building element or chunk of material, such as materiality or stiffness, can be apprehended and explored intuitively in the Euclidian space of a digital design interface. The realism offered by these techniques upsets a typical design process that moves from abstract notations such as sketches, diagrams, or line drawings, towards increasing levels of detail and concretisation.

To consider architectural representation from the point of view of transfers to and from materials and objects is to place emphasis on moments of exchange. But architectural design does not typically 'happen' in the gap between drawing and object, neither in the act of making, nor in the act of observing and parsing what is seen into the medium of drawing. It happens when one is immersed in the medium and when the imagination is subject to its conventions, whims, and strictures as well as exposed to the shoptalk and discourse that it is associated with. Design can in this sense be understood as a "cultural technique", as a result of technical and discursive practices (Siegert 2015b, 121).

These developments prompt questions about transfers between representation and material reality as design opportunities, as well as about how scanning and simulation can be understood as means of representation. The thesis addresses those questions against a critical review of key concepts associated with the "digital turn" (Carpo 2013) that occurred in architecture during the 1990s and 2000s and explores how those concepts have been furthered and challenged in the decades after this turn. Key to the analysis is a critical enquiry about the nature of architectural representation and the significance of theoretical frameworks gleaned from other areas of enquiry, including materialist and post-digital thinking. Simulation and scanning are positioned as means of representation and design through an interlacing of thinking from such frameworks with detailed accounts of technical apparatuses involved in conception and production of design work.

While this thesis interrogates how the sometimes-erratic agencies of extant materials, humans, and machines might enter the design process intentionally at points of contact between drawing and artefact, in addition it argues that means of representation such as scanning and simulation hold agency by influencing the act of design. It does so through the lens of a design practice, as well as through an attempt to position that practice in relation to a larger discursive framework dealing with architectural, political, and materialist perspectives on representation.

The questions are addressed through design driven research as well as through analytical inquiry and they are discussed in relation to the specifics of two design projects, *Erratic* and *Completions*, that form part of the thesis. The thesis, then, emerges as a meditation on the projects and on the publications connected to them. The contributions of the thesis are communicated through scientific publications that document the design work and expands on it through theory building, as well as through dissemination into a popular context of architecture and design.

This introductory chapter briefly situates the thesis in a larger landscape of research, architectural design, and culture, and elaborates on the research questions in relation to that background. It introduces the design projects included in the thesis and sets the processes and insights that they produced in relation to the research questions. 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.

Situating the thesis

This thesis can be broadly situated in relation to digital design in architecture as a field of research. The field is generally understood to have grown out of architecture's 'digital turn', beginning in the early 1990s. The impulse to combine the technicalities of design with the construction of a broader discursive framework stems from this background: Digital design in architecture may have been prompted and legitimised by technological shifts, such as the emergence of computer aided design (Kolarevic 2005), but it has in retrospect been defined as a trajectory in the recent history of architecture that drew from a convergence of technology, architectural theory, complexity science, and philosophy (Carpo 2013; Zardini 2013).

Since the 2000s, a central concern in the field is the transfer of information (and of design intent) between representations and existing or materialised objects. The concern with such transfers is actualised in various ways by recently popularised techniques that involve the migration of data between a digital and a physical medium. This thesis draws from experimental developments across three areas where such transfers are significant: digital fabrication, simulation, and 3d-scanning. Digital fabrication is an established area of research that encompasses many techniques and approaches (e.g., Iwamoto 2009; Borden and Meredith 2012; Gramazio, Kohler and Langenberg 2017; Borden and Meredith 2018), while simulation and 3d-scanning can be considered as more narrow concerns in the field with applications that may be part of a larger setup for fabrication.

An overarching theme in relation to these emerging means of design, materialisation, and representation is the entanglement of digital and physical media, of drawing and artefact, of the virtual and actual, of the ideal and the material. The entanglement can for example occur in fabrication, as a by-product of the process of transfer between geometry and material, or when a digital object defined through scanning or simulation takes on the visual and physical properties of a real piece of material. The proliferation of terms and concepts such as "digital materiallurgy" (Fure 2011), "phygital" (e.g., Testa 2017), and "material representation" (Borden and Meredith 2018) are an indication of the significance of this theme. These terms and concepts can in turn be viewed in relation to recent trajectories in other fields, such as "post-digital" discourse in media theory (e.g., Berry and Dieter 2015), or what has been referred to as the "material turn" in philosophy (e.g., Coole and Frost 2010). The subtitle of this thesis, *Architectural representation and materialisation after the digital turn*, reflects this theme and the fact that its concerns emerge after, and go beyond, those addressed during the 'digital turn'.

The field of digital design in architecture has since its inception been driven forward through close affiliations between academia and design practice, and digital techniques have had, and continue to have, wide-ranging implications for architectural production. The widespread use of fabrication, scanning, and simulation has been propelled by increased availability of machines and software that support them. Fabrication has made possible the manufacturing of small series of unique building parts in ways that have begun to challenge a prevailing logic of mass production and standardisation; scanning is used for documenting existing buildings and objects for the purposes of adaptive reuse or historical preservation; and simulation of physical properties has become a viable alternative to traditional calculation or physical mock-ups and prototypes.

The origination and diffusion of these techniques outside the architecture and building industry means that they feature prominently in popular and consumer culture. Developments are driven by global technology corporations, as well as by independent initiatives and informal networks that honour open-source principles. The construction of three-dimensional digital geometry based on photographic images, a technique for scanning known as photogrammetry, turns regular cameras or mobile phones into scanners. This has for example given rise to map applications such as Google Earth 3D that feature three-dimensional geometry of terrain and buildings that draw from satellite, aerial and street level imagery, as well as to open databases of downloadable virtual copies of significant artefacts. The construction of digital worlds in the gaming industry, complete with

gravity and objects that possess material properties, relies on similar principles of physics simulation as those used in popular modelling software in architecture. And the proliferation of open 'fab-labs' throughout many cities has made digital fabrication techniques such as CNC-routing, 3d-printing and laser cutting publicly available. Overall, this means that digital design technologies have become part of a global infrastructure of information technology that shapes cities and buildings (e.g., Easterling 2014), as well as urban life.

Technologies used in digital design prompt speculation as well as critical responses and controversy. Debates in architecture and neighbouring fields have for example centred on the role of new techniques such as computer rendering or scanning in shaping a contemporary landscape of architectural representation (e.g., Jacob 2018; May 2019), on issues of authorship or authenticity that spring from the pairing of scanning and fabrication for the production of copies or replicas (e.g., Cormier and Thom 2016), or on issues of geopolitics and surveillance (e.g., Levin, Frohne, and Weibel 2002; Steyerl 2017; E. Weizman 2018). The presence of these debates suggests that the incorporation of emerging technologies in architecture must stay wary of the ways in which such technologies construct subjects as well as objects. Technologies, in short, can inherit human bias depending on by whom and for whom they were developed.

Digital design in architecture is well positioned to engage, develop, and communicate an informed use of new technologies. A large part of the research undertaken in the field can be characterised as design driven and involves the production of digital platforms as well as physical artefacts. Pieces of software, drawings, installations, pavilions, prototypes, mock-ups, etc., are often instrumental in generating new knowledge in the field. Such visceral manifestations of research provide alternative opportunities for dissemination of the research into practice as well as into the public realm. Yet, the role of the design work in design driven research typically goes beyond being a proof of concept. It is constructive rather than objective, as it often attempts to transform or intervene in an existing reality (e.g., Dunne and Raby 2018). The constructive impetus of design driven research resonates with the propositional nature of representations such as drawings or models in architecture – as manifestations of the not-yet-built that foreshadow a near future.

Much of design driven research in digital design in architecture targets new possibilities for analysis, design, and construction. The aim is typically to establish new workflows and approaches to architectural design that are informed by the use of technology. In addition, some design driven research strives to underwrite, construct, debate, or communicate new discourse. Architecture has a long

tradition of speculative projects with such discursive ambitions. While there may be a legacy of relying on methods from design driven research in digital design, such methods and the means of communication that they offer are rarely discussed or made explicit in the field. Similarly, while there may be a legacy of using digital design to produce new discourse, such ambitions are nowadays often an exception rather than a rule. The contributions made by this thesis partially rely on the crossing of these fields and modes of practice, and on explicitly discussing the relation between them.

Positioning the research in a critical and discursive framework can help overcome the positivistic tone of some of the research produced in digital design. The technicalities of digital design, such as means of projection, 'materiality', and the "operations" of a particular digital medium do not just provide opportunities, they also come with a particular agency that structures design work and its accompanying discourse (Alexander and May 2020). While this thesis involves an opportunistic outlook on these new techniques, in addition it attempts to uncover and discuss such inherent agencies.

Overall, this thesis and the design work contained in it both explore possibilities that come with specific technologies and meditate on the larger discursive and cultural impact of the same technologies.

Research questions

In relation to the context outlined above, the thesis asks two main questions. First, how might transfers between representation and existing or materialised objects become productive design opportunities? This question can pertain to both directions of transfer, from representation to object, as well as from object to representation, including approaches that rely on transfers back and forth between the two states. It is explored in relation to current techniques where those implications and effects can be felt: fabrication involving simulation and scanning. The second research question follows upon meditation on the first: How can simulation and scanning as relatively recent means of representation be positioned in relation to a rich discourse on representation developed since the beginning of the digital turn?

Considered together the two questions prompt a further, third question: What are the agencies of means of representation and techniques for design such as simulation and scanning? Two aspects of agency are of interest. The first aspect is the inner workings of the technique as a medium, its 'materiality' and parsing of information, as well as its technicalities and 'operations' and how those condition design. The second aspect is the construction of discourse around technique and

issues of representation and materialisation in architecture, and how such discourse in turn might shape design practice.

The three research questions are explored through design driven research as well as through theory building. The first question is responded to through design driven research and the artefacts that it results in, as laid out in Chapter 3. The second question is discussed in relation to implications of these results in Chapter 3, as well as in relation to a theoretical and historical context in Chapter 4. The third question is addressed in the implications laid out in Chapter 3 and discussed in Chapter 4

Design research practice

The development of this thesis relies in part on a design research practice. Adopting design driven research as a model for inquiry 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 explorative nature of design with a tradition of scholarship native to architecture as a discipline. Two types of research under the umbrella of 'design driven research' have been important for the development of the thesis: Practice-based research, and design research. '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 (Fallman 2008). In terms of media, these approaches add documentation of design projects, including drawings and other artefacts, to text-based output. And the means of communication of such research often include conference contributions as well as exhibitions and popular publications, blog posts and events in the cultural context of architecture, art and design.

The interest in design driven research is autobiographical. Pursuing design as research has been a way to incorporate my background as a practicing architect and as design studio faculty into the thesis. The strong link between design and discourse present in the architecture offices where I have practiced, including Greg Lynn FORM and Zaha Hadid Architects, as well as in my post-graduate master's studies at UCLAs Department of Architecture and Urban Design, has been particularly influential. Conceiving and thinking architecture by combining design, writing, teaching, and exhibitions has been central to my training as an architect. It has shaped this research as well as my view on practice. Further, my



Figure 1.1. Daniel Norell and Einar Rodhe, *Erratic* installation, Aalto University Digital Design Laboratory, 2013.

studies at UCLA occurred at a particular moment in time in the mid 2000s, towards the end of the digital turn in architecture. While at UCLA, I could sense an urge among faculty such as David Erdman, Marcelyn Gow, Sylvia Lavin, Thomas Y. Levin, Greg Lynn, Jason Payne, and Michael Speaks to challenge the then prevailing context of digital design in architecture. There was a conscious push towards producing new work and discourse that would shift focus away from by then well-travelled paths inherited from the early days of the digital turn. The context in which this thesis is set has surely evolved since then. But the impulse to pursue a thesis and the curiosity that sparked it in part dates to then.

Design work

The most tangible parts of the thesis are the collaborative design projects *Erratic* (Figure 1.1 and 1.2), an installation created through physics simulation and fabrication, and *Completions* (Figure 1.3, 1.4, and 1.5), three artefacts based on 'completion', or repair, of salvaged building elements surveyed with 3d-scanning and fabrication. Broadly speaking, these projects fulfilled three purposes. They worked as probes that targeted issues of representation and materialisation from the point of view of design processes. When disseminated, they provided



Figure 1.2. Daniel Norell and Einar Rodhe, *Erratic*, 3d-printed massing studies carried out with physics simulation, Aalto University Digital Design Laboratory, 2013.

opportunities to make statements about the corporeal as well as conceptual aspects that this approach could produce. After being designed, constructed, documented, and disseminated, they increasingly worked as conversation pieces – as artefacts that made it possible to situate conceptual and theoretical issues in a disciplinary and critical landscape of architecture and design. The design projects are thus neither to be considered as proofs of concept or illustrations of a theoretical proposition, nor are they problem solving prototypes for design conceived in a discursive vacuum. They are the result of an extended parallel investment in design research and theory building that has resulted in scientific publication as well as in suggestive imagery with a circulation in practice-related and popular contexts. The development of approaches, processes, and arguments through the design work is the main content and driver of several of the publications included in the thesis.

The fact that the thesis departs from design work has conditioned its engagement with discourse. Reflecting on these works, the thesis identifies a need to contextualise, reframe, as well as reformulate some of the existing discourse of architectural history and theory. While the engagement with such discourse emerged as a by-product of the design practice, it took on a more significant – indeed essential – role as the work progressed.

Summary of publications

The design-based content in the thesis is complimented by four publications. These publications are ordered based on content rather than chronology. The two design projects, *Completions* and *Erratic*, are documented and expanded upon in one publication each, while the other two publications expand on the discursive context.

The first publication, "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) and published in its proceedings. The paper followed on the completion and exhibition of *Erratic* and presents a full documentation of the project. The premise of the paper is a discussion on the role of material manipulation in architectural conception, and how such manipulation might serve as an alternative to conventional means of representation such as drawing. The paper outlines a workflow for fabrication that includes feedback loops between manipulation of pliable material and corresponding manipulation carried out in physics simulation software. It addresses the first research question by situating it in relation to the specifics of project and giving an account of the design principles, processes and methods that the project involved. It addresses the second and third research questions by discussing how simulation was used in the project, conceptualising its use from a methodological point of view, and further begins to reflect on how simulation can be positioned as a new medium of representation.

The second publication, "Completions: Reuse and Object Representations," (Norell, Rodhe, and Hedlund 2021) was presented at *Distributed Proximities*, the 2020 conference organised by the Association of Computer Aided Design in Architecture (ACADIA) and published in its proceedings. The paper reviews how 3d-scanning and fabrication have been used to survey extant material for the purposes of reuse and recycling as well as for experimental preservation. Through the design project *Completions*, it proposes a method for integrating used building elements and materials into a digital workflow and elaborates a design position in relation to this practice. The first research question is targeted through the transfer of qualities from object to representation and back again that scanning and fabrication makes possible, and through the specific design process and artefacts that result from it. Finally, the paper addresses the second and the third research question by initiating a discussion on the bias of scanning as a means of representation.

The third publication, "Geometries with Agency: Mathematics of Form Revisited" (Norell 2021) is an article published in Cambridge University Press'



Figure 1.3. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, window frame, 2020.

journal *Architectural Research Quarterly*. It is history-theory oriented and does not report on design work completed in the thesis. It addresses the second and third research question by providing a disciplinary narrative for the use of simulation and 'physics engines' in architecture. This is done by revisiting Greg Lynn's notion of 'mathematics of form', that in the 1990s formed part of a larger argument for a return to the rigorous use of mathematics in architecture. Extrapolating Lynn's notion of mathematics of form, the article suggests that the mathematics that facilitates architectural production has agency – that it influences the way in which we read and understand form. Finally, the article examines physics simulation as a current means of architectural production that may have a new kind of agency in architectural design and discourse.



Figure 1.4. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, door panels, detail, 2020.

The fourth publication, "Noise Control: Designing with Entropic Processes" (Norell 2013), was presented at the *New Constellations / New Ecologies* conference, the 101st annual meeting of The Association of Collegiate Schools of Architecture (ACSA) and included in its proceedings. The paper was written specifically for a session themed "Synthetic Ecologies: The Imbalancing Act of Entropic Architecture" (Gow 2013) that addressed the use of representations for translation of instructions to material output. This paper provides a discursive background to the first research question. It surveys the work of design research practices that deliberately relinquish control over materialisation by introducing 'noise' from entropic processes such as weathering. These practices have found ways to turn the transfer between geometry and material into an opportunity for design, often



Figure 1.5. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, mantel piece, 2020.

through fuzzy materiality caused by artificially accelerated processes of deformation and/or decay. Finally, the paper discusses the 'strangeness' of the artefacts that these processes can produce and how they are typically documented. It concludes with a presentation of two design studies, including *Erratic*.

Further conference publications are referenced in the thesis but not appended (Norell and Rodhe 2015a, 2015b, 2016, 2021).

Contributions

The contributions that this thesis makes can be traced across both publications as well as in the dissemination of imagery and documentation from the design

projects in themselves in popular contexts. The fact that the thesis spans from design work to theory building makes it multi-layered, and each design project and each publication uncovers a set of discrete issues that are discussed in relation to the overall output of the thesis.

The *Erratic* project makes a visceral case for how the use of physics simulation might open new ways of channelling physical material properties into a virtual design process. It suggests that material processes that are difficult to control and quantify may be incorporated as drivers of design with the aid of such simulation. Methodologically, physics simulation allows the designer to cultivate such 'erratic' processes to a point where they can be represented and quantified with just enough precision to drive a design forward. The project contributes to a larger reconceptualization of digital design that intentionally let go of geometrical control by allowing material agencies to affect the transfer from representation to material.

The *Completions* project similarly makes a case for how photogrammetry, a readily available 3d-scanning technique, opens ways of channelling visual material qualities into representations. It proposes and contextualises a specific approach to reuse in architecture, where used elements and materials are claimed, surveyed, and assembled with complimentary parts. By combining scanning with fabrication, it explores how scanning as a means of representation may foster alternative ways of designing with used entities. The project has contributed to a growing body of work that shifts the focus of digital design, from practices that create 'nonstandard architectures' from standard materials to practices that document and cultivate the often-erratic qualities of extant and nonstandard materials.

A significant part of the thesis is in addition spent on theory building. This mainly unfolds in the third paper and in the exegesis, but is also present in the other, more technical papers. The discourse happens along two lines of inquiry that come into focus upon reflection on the design work. The ways in which simulation and scanning can transfer properties and qualities from real building elements and chunks of material to the Euclidian space of modelling software are contextualised and interrogated in relation to a wider discourse on representation in architecture. Further, the thesis discusses the conceptual difference between design based on digital geometry and design based on the mediation of specific pieces of material. Finally, the thesis argues that means of representation such as simulation and scanning hold agency in themselves and establishes an analytical position with regards to such agencies. The question of agency is discussed in relation to disciplinary concerns that pertain to representation and extends that

discussion into critique by considering materialist and political implications of representation. By aligning technical as well as historical-theoretical discourse, the thesis contributes to a larger critical examination of design techniques after the digital turn.

Structure and form of the thesis

The format of the thesis reflects the fact that it has been under development in parallel with engagements in practice and teaching across a period of almost ten years. The thesis has emerged through recording design projects and publications over time. Both formally and conceptually, it can be read as a selective compilation of the work of a reflective design research practice under constant development. These specific characteristics of the thesis have also, perhaps counterintuitively, prompted its generic structure into five chapters: Introduction; Background and context; Method: Explorations, implications, debates; Agency: Material, representation, technics; and Conclusions. Adopting a 'dumb' structure such as this has lent an order to the collection of work and ideas presented. The structure has allowed the thesis to centre on the commonalities between the two design projects and the publications, as an alternative to unfolding the thesis as a succession of discrete entities, each with its own set of issues.

Background and context (Chapter 2) elaborates on the design oriented and theoretical research context of the thesis and presents a review of the research areas in which the thesis acts. It briefly outlines how architecture as a discipline went through a digital as well as a material and a post-digital turn. It locates three areas of research: Material processes and transfers from geometry to material; representation and transfers from materials and objects to geometry; and finally work that relies on looping such transfers to integrate extant materials into a digital workflow. These three types of engagement with the topic of the thesis are defined and elaborated with the aid of precedent studies of design driven research projects.

Method: Explorations, implications, debates (Chapter 3) elaborates on how the thesis has been developed, its methodological context as well as its modes of research. It positions the design work in the context of design driven research and elaborates on the specifics of the design projects *Erratic* and *Completions*, including their production and dissemination. Further, the chapter proposes three methodological implications of the design work that position simulation and scanning as means of design and representation. Finally, the chapter revisits disciplinary debates that arise out of an intermingling of practice and theory.

Agency: Material, representation, technics (Chapter 4) shifts focus from the design work towards a broader, more analytical discussion by constructing theory

in response to the practice. In so doing, the chapter departs from three themes that target the issue of agency of means of representation to elaborate an analytical position in relation to a present-day situation. The chapter situates scanning and simulation as means of representation in a larger discursive context by examining their disciplinary as well as political implications.

Finally, under Conclusions (Chapter 5), I summarize and reflect on the thesis, including its context, contributions, and suggested further research.

2 Background and context

Digital design has recalibrated the relationship between representation and artefact in architecture. Fabrication handles transfers from geometry to material with a previously unseen ease and directness, and new means of documentation and analysis, such as 3d-scanning and physics simulation, transfer some of the grittiness of the real world in the opposite direction, from material to geometry. The precision at which transfers between material and geometry can occur has narrowed the gap that traditionally separated drawing from building and has given rise to new debates on architectural representation. 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" 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, several 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. The first targets materialisation, or transfers from geometry to material. Rather than viewing the process of materialisation as a matter of automatic transcription, materialisation is claimed as a creative opportunity and as an act of design (e.g., Kudless 2011; Russo and Mueller-Russo 2012). This can be done by purposefully introducing material agencies into any given process. In this way, the designer intentionally cedes geometrical control of the materialisation process to achieve a desired result. The second kind targets representation, or transfers from material to geometry. Rather than accepting the conventional idea that representations are idealised versions of artefacts-to-be, 3d-scanning (e.g., Shaw and Trossell 2014; Saunders 2018) and physics simulation (e.g., Dourtme et al. 2012) are used to introduce the idiosyncrasies of the material world into drawn geometries. Combining the two approaches by going back and forth between material and geometry opens new possibilities for digital design to move beyond a standard stock of materials to incorporate unique and extant materials into a digital workflow (e.g., Lynn 2009; Devadass et al. 2016; Clifford and McGee 2018).

This brief reading of the field as well as the design work contained in the thesis will here be situated in relation to relevant developments in digital design in architecture with a particular emphasis on the relation between design, technologies, and discursive frameworks. It begins as an intentionally broad but selective account of the emergence of the field during the 'digital turn' and gives an overview of some key concepts and tropes that have been associated with that shift. It continues by tracking how some of those concepts have been challenged and developed in more recent materialist and post-digital discourse and practice, including links to frameworks in other disciplines such as philosophy and media theory. These more recent concerns and influences are tied to a trajectory of disciplinary thinking on architectural representation that emerges in parallel with, and as a response to, the digitalisation of architectural production that came about during the digital turn. Finally, the chapter provides a review of relevant design driven research work that targets transfer between representation and materialised object, or the other way around.

The digital turn

The label digital design in architecture suggests reciprocal relationships between technologies, practices of design, and disciplinary concerns. Such relationships beg questions of origin, agency, and impetus. Should developments in the field be viewed as responses to new technologies that are out there, waiting to be integrated into architecture? Or is the field driven forward by the formulation of ideas and concepts springing from disciplinary concerns that, upon reflection, require the architect to reach out for new means of drawing and making? This section considers how such questions cut to the core of recent accounts of the emergence of the field of digital design in architecture and provides a foundation for discussing the status and self-image of the field.

Digital design in architecture has been closely associated with the practical as well as conceptual and theoretical integration of the computer into architecture that occurred in the late 1980s, throughout the 1990s, and in the 2000s. The emergence of the field is generally understood in relation to larger technological shifts occurring during this period, such as the birth of the World Wide Web, the introduction of cell phones, and desktop computing, as well as more specifically in relation to the increasing availability of computer aided design (CAD) and manufacturing (CAM) technologies. The literature that appeared as the field matured tended to stress this relationship between technology, design, and research, as new digitally enabled architectures found "their legitimisation in their exploitation of the latest technological advances, new digital means of conception

and production, and the corresponding aesthetic of complex, curvilinear surfaces" (Kolarevic 2005, 5).

The availability of technology is not enough to explain the emergence of the digital in architecture during this period. Looking back, Mario Carpo (2013) bracketed 20 years of development in the field, from 1992 to 2012, under the banner of "The Digital Turn". In examining the early writings of authors such as Greg Lynn (1993), Foreign Office Architects (1996), and Stan Allen (1997), Carpo noted that a preference for curved forms had appeared among these authors without any reference to the software needed to draw such forms. The interest in a specific formal language seemed to have been prompted by purely architectural debates, and there were few if any mentions of technology. This lead Carpo (2013, 9) to conclude that the digital in architecture emerged in response to dominant trajectories at the time, "as a deliberate mediation or synthesis between Post-Modern unity of form and Deconstructivist fragmentation".

Another attempt to summarise this formative period of development in the field was made almost simultaneously with the exhibition and research programme *Archaeology of the Digital*, curated by Greg Lynn and hosted by the Canadian Centre for Architecture in 2013. Rather than tracing the development of discourse, this programme departed from a few early, influential building design projects, examined through layers such as "authors, machines, software, companies, related disciplines, institutions, etc." (Zardini 2013, 5). Lynn, like Carpo, sought a multi-layered and temporally bracketed understanding of the digital in architecture, as evidenced in Mirko Zardini's (2013, 6) introduction to the project:

> 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.

Lynn (2013, 14), in his curatorial statement, presented a concluding assessment of the digital turn that aligned with Carpo's:

> The computer was not an alien technology but more correctly an extension and invention based on many of the design methods that emerged as historicist postmodernism waned.

Two issues are at stake in these accounts of the history of recent past. The first is the relationship between technology and discourse as drivers of digital design research in architecture. Viewed next to each other, Carpo's, Lynn's and Zardini's accounts testify to the fact that the digital turn in architecture converged around alliances between technology and discourse. The design and research practices that came to be associated with the turn certainly made use of technologies that became available in parallel with it, but the discourse was largely formulated as a response to theoretical and aesthetic concerns. This ambiguous relation between technology and discourse has since become a defining feature of digital design in architecture. And while the field certainly has paved the way for the absorption of digital techniques into practice, development has rarely been prompted solely by technical concerns.

The second issue that is at stake is a broad narrative for the development of the field over time. Carpo was quick to point out that his label "the digital turn" was not meant to signal the end of digital design in architecture. Nevertheless, to understand the field in relation to a specific period and a specific set of practices and concepts suggests that 'the digital' was a discrete trajectory in architecture that came to an end as digital technology became normalised and the discursive horizon evolved. This view can be contrasted against the idea of continuously evolving field, supported by an established collection of associations and outlets for research. Notably, some of these associations, such as ACADIA, the Association for Computer Aided Design in Architecture, were founded in the early 1980s, well before the digital turn came into full swing.

Together, these two issues serve as an introduction to a brief account of some of the more important ideas and concepts of the digital turn as well as later developments. In addition, they work as a characterisation of this thesis: Situated in a field that thrives on connections between theoretical concepts and technical knowhow, with a name that steadily becomes anachronistic as digital practice becomes the new normal.

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. For about 15 years, from the late 1980s to the mid 2000s, architecture had an infatuated relationship to everything digital. During the early years of this period, digital design came to connote activities that occurred almost exclusively in software interfaces on computer screens. The use of basic computer aided design and manufacturing (CAD/CAM) was widespread but transitioning from three-dimensional digital geometry to materialised object was still cumbersome, thus limiting the impact of such technologies. This, along with the popularisation of the

World Wide Web, gave rise to work and discourse that centred on purely digital entities – on virtuality and cyberspace. The tendency was evidenced in titles such as "Architects in Cyberspace", published by *Architectural Design* (Pearce and Spiller 1995), and "The Virtual House" issue of *ANY* magazine (Rajchman 1997). As Carpo (2013, 8) noted, some of the architects and theorists whose work was included in these publications imagined that virtual spaces would replace physical ones.

Such aspirations to an all-digital architecture were lingering in the field even as digital manufacturing became popularised during the early 2000s. Digital manufacturing employing computer numerically controlled (CNC) machines for the making of physical entities from digital files provided a direct link between design and construction, one where drawings – or files – were 'inputted' rather than interpreted by a human. Architects suddenly found themselves in closer proximity to manufacturing as they could communicate directly with CNC-machines on the factory floor. The barriers between architect and builder seemed to be eroding (see SHoP 2002), and discourse tended to recast the figure of the architect as a new "master builder" who was in control of a whole "digital continuum" of production, from design, to manufacturing and assembly (Kolarevic 2005, 7-8). A prerequisite for such a model of operation was the precision and predictability with which digital information could be translated by CNC-machines. There was a promise of closing the gap between representation and building, a promise that surely prompted a more nuanced and disciplinary debate on representation that unfolded in parallel with the digital turn. Concepts linked to representation and drawing, such as translation, projection, and authorship, were interrogated in string of publications by Alberto Perez-Gomez (1982), Robin Evans ([1986] 1997, [1989] 1997, 1989), Alberto Perez-Gomez and Louise Pelletier (1997), Stan Allen ([2000] 2009b), Tim Anstey (2007), and Mario Carpo (2011). These critical accounts of representation became important as ideas linked to the digital turn started to wane in the early 2010s, something that will be dealt with in the coming section Representation and materialisation.

Beyond integration of technological advances, the digital in architecture owed its transformative power to its ability to produce new conceptualisations of form and matter. It marked a shift from analytic formalism (Rowe 1947), collage formalism (Venturi 1966; Rowe and Koetter 1978), and deconstructivism (Wigley 1988) to a theory of architectural form based on complexity, mutation, and differentiation (Lynn 1992, 1994, 1999). This new understanding of form was underwritten by calculus, the branch of mathematics behind spline curves and surfaces that had become readily available through modelling software in the

1990s (Lynn 1999). In the computer, such geometries are defined through weighted anchor points that allow the designer to vary the curvature within a set configuration of points. Deleuze's notion of the fold provided a philosophical starting point for such work and thinking, together with his reading of Leibniz's calculus-based mathematics of continuity (Deleuze 1993). A brief disciplinary account of this development considering recent events is provided in the article "Geometries with agency: Mathematics of form revisited", included in this thesis (Norell 2021).

The calculus-based variability of digital geometry, paired with possibilities offered by digital fabrication, in addition gave rise to a concept of mass customisation. Notions such as standard, original and copy could be challenged as designers conceived and materialised series of varied objects with almost the same ease as identical ones (Cache 1995, 2011; Migayrou 2003). Such thinking was, as noted earlier, not just a product of new technology – it resonated with broader cultural concerns and a postmodern quest for variation in lieu of modernist standardisation. One point of origin was Bernard Cache's and Gilles Deleuze's concept of the "Objectile", that proposed a non-standard mode of production that "allows the manufacture of a different shape for each object in the same series" (Cache 1995, 88). By connecting the digital design software that was popularised in the 1990s with computerised industrial production that had been around since the 1960s, this and other similar concepts of variable design gave digital design an increased relevance for building design and construction (SHoP 2002; Kolarevic 2005).

The linking of the digital and the material that commenced during this period also took other, more materialist, guises. As a critique of signification and symbolism, two concepts that had dominated postmodern discourse, architecture was increasingly considered for its 'performance', for its ability to act in the world. This included conceptualising buildings as material and structural organisations rather than as conveyors of meaning. In the late 1990s, drawing from the theories of Manuel DeLanda (1992) and Sanford Kwinter (1992), Jesse Reiser (1998) argued that early conceptualisations of digital architecture as virtual risked shifting architecture out of the material realm altogether, or alternatively, risked promoting architecture as simply a receptacle for electronic media. In response to this tendency that rendered architecture ineffective as a material construct, Reiser (1998, 50) proposed an architecture that was informed by material as a medium, where "material formations are inextricably linked to the computational logics inherent in materiality itself". Such thinking spawned further work that sought to find elegant and optimised architectural form derived from the potential

performance of materials through physical modelling (e.g., Hensel, Menges, and Weinstock 2004).

These aspects of the digital turn are notable not only because of their wide impact, but in addition because they grew out of a simultaneously practical and theoretical engagement with new means of representation and materialisation.

If one zooms out from the specific theoretical tropes and technological developments that fuelled the digital turn, it becomes possible to detect some overarching ideological traits that can be associated with it. As both Carpo (2013) and Zardini (2013) noted, the establishment of the field coincided with a general neoliberal political turn and a decline of the welfare state. Architecture became an "interiorised" occupation, less concerned with expressing its civic status and external circumstances than with its own systems of realisation (Zardini 2013, 7). A lack of more critical stances allowed a certain technological positivism to flourish. As the field matured, some work was developed in anticipation of technological developments that never seemed to arrive. According to Lynn (2013, 11), such work was often justified solely by the phrase "in the future…", as opposed to being grounded in theoretical, cultural, artistic, or disciplinary criteria. It is perhaps no coincidence that a significant amount of research and speculative design work during this time resulted in physical objects that were labelled "prototypes", a term borrowed from engineering and industrial design, suggesting that the work should be considered as an early step in the development of a commercial product (see e.g., Gannon 2009). These ideological biases are worth pointing to as a reminder of a recent past, but in addition because they still hold sway over parts of the field, despite some attempts to overcome them that will be accounted for in the coming sections.

In conclusion, digital design in architecture can be understood both as a broad and continuously evolving field and as a distinct, bracketed historical trajectory in architecture with its own set of tropes and discourse.

The material turn

In the mid 2000s, 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. Due 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 networked connectivity that characterised 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 techniques. A comparison between two films, Richard Linklater's *Waking Life* and Pixar's *Monsters Inc.* (both 2001), finalised his argument. The former was shot on a small budget and is characterised by an overlay 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 threshold between digital and analogue, Linklater had found a way to combine the inconsistencies and uncertainties of reality with the perfection and artificial nature of the virtual.

Allen's text was an early indicator of a shift in research foci for architectural 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, Katie Lloyd Thomas (2007), Mario Carpo (2012, 2014), as well as Gail Peter Borden and Michael Meredith (2012, 2018) have further theorised the turn from the digital to the material. Under the banner of "Material Matters", Thomas noted that a new attention to materials emerged as theoretical frameworks that do not parse the world into distinct categories of form and matter began to align with digital fabrication processes that introduced direct links between conceptualization and production. Carpo outlined a growing preference for design driven by material structure, where the designer makes use of 'big data' or physics simulation in lieu of inert (digital) geometry. Borden and Meredith argued that new digital fabrication and construction techniques have altered the relation between 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 mediated.

In all three instances, arguments are also substantiated historically. Thomas (2007, 2-4) traced the discipline's valuation of form over material back to philosophical traditions. Plato's as well as Aristotle's theories positioned pure form as something that is superior to, as well something that precedes, its material realisation. Such priorities are encapsulated in the concept of 'hylomorphism' that stipulates that 'hyle', or matter, is shaped by 'morphe', or form. As Thomas (2007, 4) argued, such use of the singular term 'matter' over the more specific and pluralistic term 'material' has furthered the devaluation of material in architecture:

> Hylomorphism, which understands materials as a subset of matter, does not provide a way of positively distinguishing materials, and underscores the architectural tendency to use materials as mere finishes, exchangeable and superficial.

Carpo (2014, 170) noted that, in the early 1990s, spline geometry became available to pioneers of digital design like Bernard Cache and Greg Lynn through modelling software. Splines and their fellow topological surfaces are pure mathematical objects – they are derived from mathematical functions. Inevitably, they must be approximated to be materialised and become phenomenally accessible. Even representing a spline on a computer screen is an approximation as the curve is broken down into tiny straight segments and pixels. Big data and simulation differ 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 equally 'real' but simulated material properties. A digitally simulated surface, for example, is, in a sense, as 'imperfect' or as 'real' as the materially instantiated one is. Carpo (2014, 173) concluded:

> 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.

Similarly, Borden and Meredith (2012) targeted the focus on form and geometry in the early digital project. Their angle, though, invoked disciplinary history rather than mathematics. "Material" in architecture, they noted, was rejected by the conceptual thinking of a 1970s avant-garde headed by Peter Eisenman because it was aligned with a humanist, craft-oriented project that was ultimately to be appropriated by capitalist production and commodification. One of the goals of the 'cardboard architecture' that Eisenman and others subscribed to was consequently to suppress materiality by divorcing form from material. This conceptual 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 inherited from a conceptual project. This assumption is corroborated by the fact that Eisenman is considered as one of the instigators of the digital turn.

The increased importance assigned to materials and artefacts in architecture during the last decade coincides with a larger 'material turn' in other disciplines. Examples of theoretical frameworks associated with this turn include actor-network theory and new materialism. These frameworks have undoubtedly influenced the articulation of concepts within architecture, but links between philosophical frameworks and architectural concepts have, with some exceptions

(e.g., Latour and Yaneva 2008; Hale 2012; Ruy 2012; Nilsson 2013), rarely been made explicit. The intention here is to point to a few such links, with an emphasis on materials and representation.

Broadly speaking, new materialism responds to a need for philosophy to address problems of ontology, agency, and politics through an updated understanding of materials and materiality. Material thinking has, according to new materialists Diana Coole and Samantha Frost (2010), often been conditioned by idealities such as language, values, and meaning that are valued higher than materiality. Influenced by natural sciences as well as ethical and political concerns such as climate change, new materialism opposes an allergy to 'the real' that was native to linguistic forms of theory by positioning matter as an active agent. 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). Materiality, it is argued, is not reducible to other processes – it is "more" than matter – it is "active, self-creative, productive, unpredictable" (Coole and Frost 2010, 9).

The idea that artefacts and materials may hold agency is a concern that new materialism shares with actor-network theory. The link between the two frameworks has been explored by Jane Bennett (2010, viii), who quotes the term "actant", used by Bruno Latour (2004a), to highlight such agencies:

> An actant is a source of action that can be either human or nonhuman; it is that which has efficacy, can do things, has sufficient coherence to make a difference, produce effects, alter the course of events. It is 'any entity that modifies another entity in a trial,' something whose 'competence is deduced from [its] performance' rather than posited in advance of the action.

Latour and Albena Yaneva (2008) have addressed some consequences of such agencies for architectural representation. According to them, drawings and other means of representation typically describe buildings in an ideal and static state, before their constituent materials have aged, and before they have been transformed by their users. Whether this is a problem of convention or of medium specificity is perhaps debatable. Nevertheless, a typical plan or section drawing of a building is a freeze-frame that does not account for a temporal dimension, and its linework does not capture the agencies of materials. Replacing the drawing board and the stylus with the Euclidian space for design in software interfaces on computer screens has not done much to change this situation, they argue: "Matter is much too multidimensional, much too active, complex, surprising, and counter-

intuitive to be simply what is represented in the ghost-like rendering of CAD screen shots" (Latour and Yaneva 2008, 86).

Notably, by framing material agency as a problem for architectural representation, Latour and Yaneva advanced a more general reappraisal of the importance of materials and of material practice in architecture as the discipline intersected with the material turn. The question was no longer 'materials have agency – how does this affect architecture?', but rather 'how can material agency be addressed in a discipline that engages materials at a distance, where the engagement is conditioned by representation?'

In some respects, ideas that have been associated with the material turn in architecture, such as the agency of materials, might seem simply like an extension and continuation of a certain vitalism that was present already in the materialist work of DeLanda, Kwinter, and Reiser. But even in such work, the role of materials was often limited to physical computing, such as form-finding, of preconceived forms. Idealised representations such as renderings and vector geometries took precedent over real materials and objects, and materials were conceptualised for their ability to maximize the transparency between digital geometry and machined object, rather than for their agency or ability to shape design. These views on representation, matter, materials, and materiality stand in contrast to concerns raised during the material turn.

The post-digital turn

The reformulation of concepts and ways of practicing digital design in architecture that have taken place during the last decade can certainly be attributed to the influence of a material turn in philosophy and the social sciences. But there are other theoretical frameworks that have recently exerted an influence on the field. One of those frameworks is post-digital thinking in media theory. Like new actor-network theory and new materialism, post-digital theory was, with some notable exceptions (e.g., Manninger and del Campo 2017; Abrons and Fure 2018) imported into architecture without mention of its links to other fields. Borden and Meredith (2012, 2), for example, casually concluded that

> our re-emerging interest in physical form and visceral effects is a way of playing with a post-postmodern need for realism and a *post-digital* need for quantifiable techniques and evaluation (emphasis added).

Sam Jacob has similarly argued for alternative approaches to architectural representation under the banner of "post-digital drawing" (Jacob 2017, 2018).

Both Borden and Meredith and Jacob adopt the term post-digital without further contextualisation in relation to media theory, and so do many others (e.g., Holzer 2008; Tamre et al. 2014; Carpo 2018). Against the background of the digital and material turns, this section will attempt to capture some of the concerns that post-digital theory has given rise to in architecture. These concerns are in part overlapping and emerge in parallel with material concerns raised in the previous section, so the bracketing of the two into two separate turns is rhetorical and only indicative of their distinct links to other fields.

In October 2013, media theorist Florian Cramer did a Google image search for the term 'digital'. As expected, the results were varied. Images depicted all sorts of digital 'stuff', from arrays of zeros and ones, to stylised circuitry boards. But all of them, or at least all the ones that Cramer (2015) chose to capture in a screengrab that he published two years later, shared some visual characteristics: A bluish tint, and a futuristic sensibility. This observation led him to conclude, that beyond definitions of 'digital' offered in media theory, the term had become broadly associated with high-tech, cultural coolness, and high-fidelity cleanness. Cramer's assertion and the work that followed under the banner 'post-digital' may be understood as a search for alternatives for the digital that lie outside or beyond these expected results. The 'digital', that had once opened possibilities for new kinds of work and thinking in the arts and architecture, had stagnated in its cultural form.

Delving deeper into Cramer's (2015) reasoning, published as "What is 'Post-digital'?", it is tempting to conduct a parallel experiment by rerunning his web search experiment using 'digital architecture' as a search phrase (Figure 2.1). At a first glance, the resulting images seem to share some features, just like Cramer's did. Most of them are photo realistic computer renderings that depict buildings, and most of them indeed have futuristic sensibility and a greyish blue tint, although this aspect is less homogenously featured this time around. On closer inspection, the search reveals some of the stylistic staples and research tropes of design during the digital turn in architecture, such as smooth curvatures, algorithmically variegated lattices in the form of building envelopes, and agglomerations of self-organised units. Both search results, in all their crudeness, unravel basic connotations of 'digital' and 'digital architecture' – connotations that by now have become well-travelled at best or cliché at worst.

The term post-digital, coined by musician Kim Cascone (2000), indicates a move away from familiar connotations of 'digital', such as perpetual technological progress and high-fidelity representation (see Norell 2013). Digital information technology must, according to Cramer (2015, 20), be untied from "techno-

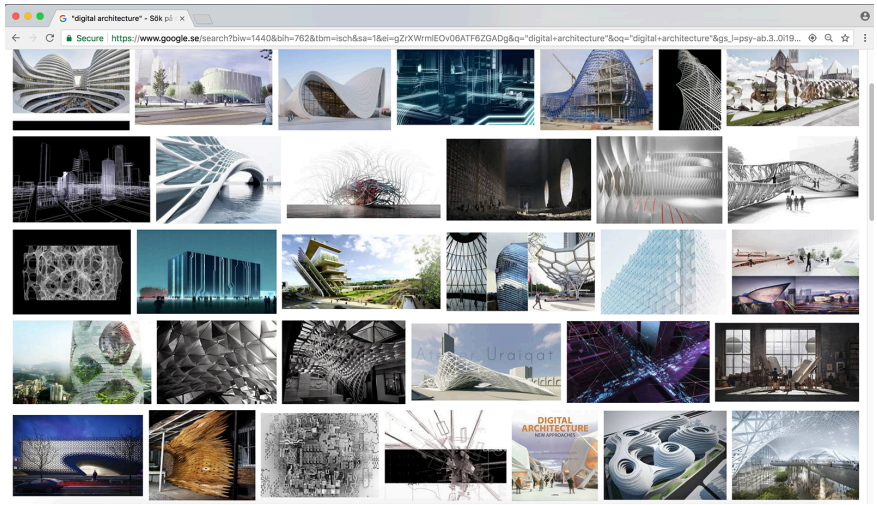


Figure 2.1. Google.se image search for 'digital architecture', April 2018, showcasing some of the stylistic staples of digital design in architecture.

positivist innovation narratives" that are out of sync with our contemporary world. Promoted by magazines like Wired and companies like Google, these narratives still place digital technology in a niche that dates to the 1990s. One example is the distinction between 'new' and 'old' media that suggests that new media such as websites and online platforms are progressive alternatives to corporate old media such as newspapers and television, something we know no longer to be true. The new media that we associate with digital technology have become as established and mainstream as, and even more corporate than, old, analogue media (Cramer 2015, 22).

These characterisations of the digital in media art and theory resonate with Lynn's (2013) and Zardini's (2013) as well as Carpo's (2013) critical accounts of digital design in architecture during the digital turn, as referenced in the previous sections. That tendency to put digital technology on a pedestal may be understood as a reaction to the initial scarcity and exclusivity of digital technology. A workstation equipped with the very first version of a 3d-modelling software was probably a rare digital sight in an otherwise analogue world of architecture in the early 1990s. This has since changed drastically – digital technology is now ubiquitous, and it permeates almost all aspects of daily life. Similarly, digital technology has been integrated into almost all corners of architectural practice, inside and outside academia. The use of design software and fabrication is no

longer a sign of novelty. The allure of post-digital thinking in architecture lies in acknowledging a need for alternative narratives for the digital in architecture.

Under the banner of post-digital, media theory and media art have produced new conceptualisations and design approaches that consider materials and materiality through the lens of digital technology. Such work, according to media theorist Christiane Paul (2015), often includes objects that are manifest in material form, but that are conceptually and practically shaped by digital processes. Artists such as Clement Valla produce new kinds of materiality, or "neomateriality", that do not stem from the workings of a specific material medium (such as paint and brush), but from crossing the boundaries between digital and analogue mediums (Paul 2015). Valla's work *Surface Proxy* (2015) is a set of objects constructed according to the workings of machine vision and digital modelling software. Valla used photogrammetry (image-based 3d-scanning) to document a selection of historical relics, a process that separates the properties of an object into geometry, i.e., a mesh, and texture and colour, i.e., an image map that is fitted onto the geometry. New copies of the relics were subsequently manufactured using these two kinds of data. The digital geometry was used to manufacture full-scale versions of the objects by means of 3d-printing. These 'blank' objects were then shrouded in their own image as texture and colour documented in the image maps were printed onto cloth that was fitted onto the objects like clothing or drapery.

To separate the totality of an object into geometry and texture/colour is an operation that machine vision and rendering software does automatically. Valla's objects have an intense, gritty, and tangible materiality, that is partly a by-product of these standard digital protocols. Photogrammetry, modelling software, and fabrication are combined to produce a new ontology of objects. This ontology constructs an inexact representation of the real world. Limits in for example the resolution of the scan and the draping of the geometry become evident at close hand. In addition to forming a part of the neomateriality of the objects, these limitations make clear that Valla uses digital technology to non-positivist ends. The endgame is not to showcase perfect representation or lossless transfer of information between digital and analogue realms, but to interrogate the conceptual and practical consequences of routinely applied digital processes for materials and materiality. Post-digital practice acknowledges that materiality today is a result of a mash-up of material and digital technology. Materiality is no longer solely defined by traditions of craft or discipline, but by a combination of chunks of material, software and hardware, and human agency.

The general disenchantment with digital technology that comes with the post-digital has resulted in thinking that targets the role of representation. As Sam Jacob

(2018, 179) has noted, architecture has increasingly become "embodied representation" thanks to digital technology. The ease with which architects nowadays can transfer between representation and materialised object through fabrication, or between object and representation through scanning amounts to a new situation in which one can design and make by sampling multiple sources of both digital and analogue origin. A virtual model obtained through scanning is both a documentation of a recorded object and a basis for production through digital fabrication. Jacob's installation *One Thing After Another* (2016), for example, explores a path in which the realness of scanned, scaled, and fabricated near-replicas of a garden shed coexists within a representational dimension.

Representation and materialisation

Representation pertains to the set of conventional means of conception and communication available to architectural design. Typically, architectural drawings work as a link between idea and material construct but are distinct from the object that they represent. A drawing such as a plan or a section is in this sense doubly projective. Technically speaking, it is an orthographic projection since it depicts something through parallel lines connecting the plane of the drawing with an imaginary object. But it is also a projection 'forward' into the future, as the drawing depicts an object that does not yet exist. This latter aspect is in certain traditions what separates an architect's drawing from an artist's painting. A painting depicts something that exists prior to its representation, while the architectural drawing flips the vector of projection, something that Robin Evans ([1986] 1997, 165) once referred to as the drawing's principle of "reversed directionality".

Evans' discourse on representation, laid out in several influential essays in the late 1980s, distinguished between the forward projective nature of most architectural drawing, and specific types of representations where information is projected backwards, from the object to the medium. Cameras, Evans (1989, 19) noted, provide an example of such backward projection. A camera performs in a process which takes three-dimensional information and makes it two-dimensional. Some types of architectural drawings, such as as-built drawings and studies of existing buildings, perform in a similar process of backward projection. This category of drawings document something after the fact of construction and is therefore by default disassociated from the speculative nature of regular architectural drawings. Yet, as Evans (1989, 20) pointed out, such drawings are not "simple truth-conveyors" as there is "a constant interplay between the passive portrayal and the active remodelling of reality". The imagination of a

draughtsperson, as well as of the viewer of the completed drawing, alters what is seen, something that can be viewed as a form of projection.

Architectural representation, whether orthographic or imaginary in nature, has traditionally implied transfers across the gap between two dimensions and three dimensions as well as between drawing and building. The emergence of digital design seemed to turn such transfers into mundane operations. Modelling software automated orthographic as well as perspectival projection, and digital fabrication provided semi-automatic ways of transferring from such software to materialised objects. However, the adoption of the term "translation" by Evans ([1986] 1997), Alberto Perez-Gomez and Louise Pelletier (1997), as well as by Stan Allen ([2000] 2009b), implied that such transfers are neither neutral nor transparent, and should be viewed as a meditation on these developments. Perez-Gomez and Pelletier (1997, 3), for example, stated that:

> Architectural conception and realisation usually assume a one-to-one correspondence between the represented idea and the final building. Absolute control is essential in our technological world. Although drawings, prints, models, photographs, and computer graphics play diverse roles in the design process, they are regarded most often as necessary surrogate or automatic transcriptions of the built work. However, an invisible perspective hinge is always at work between these common forms of representation and the world to which they refer. To disclose appropriate alternatives to the ideological stagnation plaguing most architectural creation at the end of the second millennium, the first crucial step is to acknowledge that value laden tools of representation underlie the conception and realisation of architecture.

Evans ([1986] 1997, 154) similarly spoke of "translations from drawing to building", implying that "things can get bent, broken or lost on the way", and Allen ([2000] 2009b, 7) remarked that "difference, as much as correspondence, configures the translations between drawing and building".

A more explicit take on the implications of digital design for the gap between design and construction was offered a decade later by Mario Carpo, who recontextualised the issue in relation to new modes authorship that emerged during the digital turn. Qua Carpo (2011, 78), during the Renaissance the concept of projective scale drawings established the architect as author by introducing a "notational gap" between design and construction. Carpo exemplified his argument through studies of the Renaissance humanist and architect Leon Battista

Alberti. When drawings were completed, as Carpo argued, they were simply to be executed so that the building became an identical copy of what was drawn. Following Nelson Goodman's (1976) parsing of art as either autographic and made by its author, or allographic and notated by its authors and executed by others, Carpo reasoned that digital design in architecture paradoxically encompasses both modes of authorship. On one hand, fabrication technologies such as 3d-printing and CNC-routing have made it possible for architects to personally intervene in, and tamper with, the gap between design and construction in ways that seem almost autographic (Carpo 2011, 33). But the very same technologies have on the other hand closed the gap by making it possible to execute an exact copy of geometry kept in a file, "anywhere, anytime, regardless of the presence of its author" (Carpo 2011, 78).

This trajectory of thinking on representation can be furthered by considering transfers across such 'gaps' in relation to thinking gleaned from the material and the post-digital turns. New materialism and actor-network theory challenge the binary of the ideal and the material, suggesting an active role for materials in the process of materialisation, and critiquing the reduction of materiality and temporality that conventional means of representation, including CAD-drawings, result in. Post-digital concepts, such as neomateriality or embodied representation, acknowledge that materiality nowadays is a by-product of digital processing and that a technique such as 3d-scanning turns even the passive documentation of an existing object into a blueprint for design and production. To draw, to trace, to model – is nowadays more than ever to move, to transfer. The ease and frequency at which transfers in either direction occur softens the drawing-building dichotomy, and both directions of transfer can increasingly be forward-looking in nature. The space between drawing and building has become less of an empty 'gap' that, as Evans and others once observed, requires interpretation and translation, and more of a messy grey zone characterised by mundane transfers back and forth between the two states.

In what follows, this framework will be used to review relevant design driven research projects based on the direction of transfer between geometry and material.

Materialisation: From geometry to material

The popularisation of digital fabrication during the 2000s is a subtext for the renewed interest in materialisation. Fabrication is typically understood to be a process of production that transfers information from geometry to material through CAM software and a computer-controlled machine that shapes material.

Initially, design research work that explored fabrication tended to focus on relatively direct means of transfer. For example, in Lisa Iwamoto's Digital Fabrications (2009), work was sorted into categories of operation such as sectioning, folding, contouring, and forming, all of which relied on precise cutting and shaping of material. As Iwamoto remarked, digital fabrication was often the last step in an all-digital process that included modelling, visualisation, structural analysis, etc. Since then, fabrication has increasingly come to connote a wider range of approaches that include digital as well as analogue processes.

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

A 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 explore and manipulate materials directly rather than going through the filter of CAM-software 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 typically specified so that the transparency between digital geometry and a materialised object is maximised. An alternative approach is to use customised procedures to manipulate a given amount material. No material is added or subtracted; it is instead redistributed by means of exerting force. The design process is productively constrained by the discreteness and properties of the material.

This approach was explored in Andrew Kudless' (2011) installation work *P_Wall* that investigated how form can emerge as a negotiation between constraints placed by the designer and the agency of a specific material. The project consisted of several cast panels that are assembled and mounted on a wall in a gallery space. The process behind the project can be summarised as follows. A plaster slurry is cast on top of a horizontal elastic membrane that is constrained in a set of 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 at each constraining point. No representation of the curvaceous geometry of the panels exists prior to materialisation. 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* was, except for the distribution of constraining points, designed and manufactured entirely in the analogue realm.

Kudless' work emphasised the designed artefact as a circumstantial result of a set of instructions and specifications. *P_Wall* relied on a recipe or score for its making, a technique that already informed conceptual art from the 1960s, and, according to the analysis of authors such as Mario Carpo (2011), from periods long before that. The scripted procedure intentionally introduces an element of chance into the process by letting the agency of, for instance, materials and machines as well as human beings affect the outcome. This reading of the work downplays the importance of established tropes like craft and performance to open new avenues of thought. *P_Wall* relied on mock-ups and live testing, something that requires extensive resources. Related research work, such as Rhett Russo's and Katrin Mueller-Russo's (2012) *Flabella* projects explored subdivision surface modelling to anticipate the outcome of dynamic processes that involve pliable materials. But even if such modelling can be employed to approximate visual results, its logic of topological deformation is at odds with a process of real material manipulation. In subdivision modelling, geometry can be stretched and tweaked without regard to basic constraints such as material properties or even keeping the surface area constant. As Kudless (2011, 105) noted in his conclusion, simulation could be a way to swiftly explore design variations that integrate physical forces and procedural aspects.

Projects such as *Flabella* and *P_Wall* were indicators of a shift in digital design. Transfers from geometry to material through means of fabrication were no longer considered as a matter of mere expediency, where the role of material properties and qualities were downplayed in favour of precision and predictability. By allowing active agencies of materials to shape the outcome, these projects stand in contrast to previous conceptualisations of fabrication techniques such as Iwamoto's.

Representation: From material to geometry

For all that writers such as Evans, Perez-Gomez and Pelletier, Allen, Anstey, and Carpo focussed on issues of representation, a wider investigation of these issues among academic practitioners was rare during the digital turn. Many conferences and anthologies tended to focus on making and fabrication where emphasis was placed on material, rather than on representation as an act or an entity worthy of consideration (e.g., Kolarevic 2005; Iwamoto 2009). In the early 2000s, installations, prototypes, and other material constructs, had for the most part

replaced drawing as a primary means of exploration. By the early to mid 2010s, this situation led some to conclude that the practice of drawing was in crisis within the discipline. Initiatives such as "Is Drawing Dead?", a symposium held at Yale University School of Architecture in 2012, and the *Drawing Futures* (Allen and Pearson 2016) conference began to address representation in the aftermath of the digital turn. Representation, it was argued, has always been tied to technological developments such as drawing instruments and printing processes, so the continuous incorporation of digital technology into architecture should not necessarily imply a diminishing or less creative practice of drawing (Migayrou and Sheil 2016; Allen and Pearson 2016).

A growing attention to issues of representation characterised the years that followed. Concepts such as "post-digital drawing" (Jacob 2017) and "embodied representation" (Jacob 2018) widened the scope and expressions of digital representation and addressed the discursive incorporation of 3d-scanning. Drawings and images created through digital means became more legitimate as terminal carriers of design driven research. This development occurred in parallel with the popularisation of technologies such as 3d-scanning and physics simulation. Rather than creating idealised versions of artefacts to be, these means of representation reverse the direction of transfer, from material to geometry. They channel or recreate the visual or material properties of a physical entity into a digital replica.

In architectural practice, both simulation and scanning are increasingly used as a preparatory step towards construction. But such technologies can in addition be considered as design mediums, as "augmentations" of drawing as an expressive tool, as proposed by Laura Allen and Luke Caspar Pearson (2016) in *Drawing Futures*, that included a presentation of the use of simulation for *Erratic* (Norell and Rodhe 2016). Scanning and simulation are becoming central in contemporary architectural production and design research practice, something that can be attributed to their capacity to span digital and physical states. Physics simulation introduces the methodology of the 'wet' experiment into the virtual world, making it possible to apprehend physical material properties in the computer, while 3d-scanning transfers minute variations in form, colour, and texture into the realm of digital geometry.

Simulation of material properties and physical forces was introduced into architecture through experimental work in the 1990s. It was popularised during the 2010s when it was integrated into common modelling software as well as made available through game developer engines that were appropriated by architects. Often referred to as 'physics simulation', simulation adds dynamic properties to

graphic objects as well to their surrounding 3d-modelling environment. For example, material properties such as rigidity, or global properties such as gravity, may be considered. A designer can set up an experiment and see it unfold over time as a 'solver' continuously calculates forces and updates the scene. Or alternatively explore objects and properties in real-time and receive instant feedback. A more extensive genealogy of physics simulation in architecture is laid out in the third publication (Norell 2021).

Strictly speaking, physics simulation does not entail an automatic process of transfer of properties from a piece of material to its counterpart in a digital environment. Rather, the correspondence between the two is often gradually fine-tuned, often in relation to a fabrication process. What is significant, however, is that simulation imbues graphic objects and environments in a digital modelling interface with material agency, making it possible to represent and intuitively play around with such agencies. This hybridisation of digital and physical environments has become instrumental in many fabrication processes and as previously noted, to create a digital counterpart to a material process can diminish the need for resource intensive mock-ups.

A relevant example of a physics simulation is the particle-spring method, often used to approximate the behaviour of pliable materials such as fabric. A surface is described as a dense mesh of edges and nodes, where each edge is defined as a spring with a restricted length, and each node is given a mass. This method is commonly used for structural calculations, but, following Kudless' (2011) prompt, several projects have instead used this method to establish a counterpart to a fabrication process. In the *Digital Plaster* project (Dourtme et al. 2012), for example, the particle-spring based method is used to explore how analogue constraints in a process of fabric casting plaster can be simulated digitally. As the authors noted, in this kind of work, simulation becomes part of the design process, and varying degrees of accuracy between simulation and material experiments are acceptable (Dourtme et al. 2012, 227).

While simulation apprehends material agencies by infusing graphical objects in a digital environment with dynamic properties, 3d-scanning captures a different spectrum of such agencies. Scanning records dimensional and visual properties of existing entities and transfers them into a measured digital model. It is used extensively for the survey of artefacts, buildings, and land to stake out future interventions as well as for preservation purposes. The development of techniques for automated means of survey are tied to developments in geometry, photography, and computer graphics. For example, photogrammetry, a technique for extracting a measured drawing from multiple perspectival images, was

pioneered in the late 19th century, following advancements in principles of perspective and projective geometry as well as the invention of camera photographs (Allais 2020). And principles of digital image processing developed in the 1960s automated such reconstruction of three-dimensional objects from two-dimensional images (Manovich 1997). Today, two common techniques for scanning exist, photogrammetry and laser scanning. Both techniques deal with the problem of reconstructing a scene of three-dimensional objects in a Euclidian space.

Scanning technologies such as these can produce precise and hyper realistic representations that come with a sense of objective disclosure. Yet, they construct alternative conceptions of objects and spaces as much as they document them. This is evident in recent research that employs scanning towards speculative architectural representation. Since the early 2010s, the practice ScanLAB has used laser scanning to produce point cloud drawings that reveal aspects of scenes that normally elude architectural representation. Their building surveys, for example, uses the conventions of orthogonal projection to create sections that slice through inhabited residential buildings, exposing the degree to which spaces are shaped by events and objects post construction and post occupancy (Shaw and Trossell 2014). Spaces are defined as much by furniture and objects as they are by floors, walls, and ceiling. The abstract delineation of space that a conventional line drawing produces is downplayed in favour of texture and colour, highlight and shadow. Andrew Saunders has made similar use of laser scanning to produce alternative conceptions of the interiors of baroque churches. While customary formal and spatial analysis has tended to reduce baroque architecture to underlying geometries and composition, point cloud drawings instead foreground the totality of such spaces, including "figural, chromatic, and material articulation" (Saunders 2018, 390).

As a means of representation, scanning, like simulation, addresses a temporal dimension that is normally absent from architectural drawing. The scanning process records a space or an artefact and produces a snapshot at a particular moment in time. The level of detail present in a typical point cloud drawing supports an attentive way of reading that can unravel new narratives. Recent work by Ines Weizman (2018) and the Centre for Documentary Architecture shows how photogrammetric documentation of architectural fragments can be used to uncover alternative histories of some of Adolf Loos' canonical houses, designed in the early 20th century. The work exemplifies how the inscription of past events in the surfaces of these fragments can form a basis for further research and speculation.

…And back again

Combining these approaches to transfers in either direction between material and geometry can create loops that open new possibilities for design by tying materialisation and representation together. This kind of work challenges the smooth perfection and exactitude of typical digital design processes, but it does so by dutifully surveying extant material that typically comes with unique qualities arising from age and wear and tear. The 'noise' that thereby enters the process is not necessarily a result of a lossy translation, but rather arises from a mediation and digital representation of the grittiness of physical objects with a genesis in the real world. The aim is often to incorporate extant materials and unique objects into a digital design process by gleaning methods and concepts from practices of reuse, appropriation, and experimental preservation. The scanning process' ability to capture the 'material history' of an artefact or environment by recording detailed formal features, textures, and shifts in colour, is central to this category of work.

During much of the digital turn, design research was directed towards overcoming the limitations of mass production by turning nonstandard fabrication processes onto a standardised stock of materials (see e.g., Migayrou 2003; Iwamoto 2009). Sheets of plywood were routed and laminated, sheets of plastic were formed over customised moulds, bricks were rotated and stacked, lumber was carved or bent. The liberation of form that took place during this time was largely conditioned by the regularity and homogeneity of the chunks of material that a specific machine could do work on. Considered in relation to this recent history, today's means of digital survey offer opportunities to apprehend and explore qualities of existing and used building elements and materials that are materially heterogenous. Two lines of inquiry relevant to such practice can be outlined (see Norell, Rodhe, and Hedlund 2021).

In the first approach, scanning or other means of digital survey are used to integrate a unique stock of materials into a digital fabrication and assembly process. In Greg Lynn's (2009) *Recycled Toy Furniture*, used plastic toys were scanned, arrayed digitally as if they were figurative bricks, and then carved robotically to interlock with each other. More recent work has similarly targeted the unique geometries of 'raw' tree branches as elements in the design and fabrication of a three-dimensional truss (Devadass et al. 2016) or documented and carved the irregular geometries of concrete rubble for the purpose of fitting them to each other in a masonry wall (Clifford and McGee 2018). The aim in this kind of work is typically manifold: To integrate used materials into a digital workflow by granting remote access to their often-unique geometries and qualities, as well

as to explore such material for effects that enrich and expand the vocabulary of digital design and fabrication in architecture. The second approach relies on scanning and fabrication for the transfer of forms or qualities from an existing entity onto a new stock. In the context of experimental preservation, this can entail the production of replicas of significant artefacts (e.g., Cormier and Thom 2016). In adaptive reuse of historical buildings such techniques can be used to negotiate fits between new and existing building elements (e.g., Buthke et al. 2020).

These two approaches highlight how multiple transfers between geometry and material can amount to an alternative proposition for digital design in architecture in which means of representation and materialisation are combined to target the idiosyncrasies of extant material. If work during the digital turn was mainly concerned with forward projection, from geometry to standardised materials in all-digital processes, the work introduced here uses both forward and backward projection to incorporate the genesis of extant material.

3 Method: Explorations, implications, debates

Designing, exhibiting, writing, and publishing, are activities that can inform each other. They produce artefacts, such as drawings, models, installations, and texts, that can be contextualised within a broad body of theory that has grown up around design driven research. The development of this thesis relies on relationships between such activities and artefacts to produce and disseminate new insight. In its attention to discourse, the thesis also relates to recent disciplinary debates particular to architecture (and unexplored in other design fields) about how design practice interrelates with discursive theory. This chapter first provides an overview of how the thesis 'fits' into categorisations drawn in design driven research. Second, it gives an account of the development of the design projects *Erratic* and *Completions* and continues by exploring the methodological implications of these projects when viewed in relation to their discursive context, as laid out in Chapter 2. Finally, the chapter frames the design projects and their implications against architecture's internal concern with the contested relationship between practice and theory.

Design driven research

In architecture design generates and disseminates knowledge. The label design driven research is nowadays taken to include a wide range of alternative formulations of this phenomenon. The recent Conference for Artistic and Architectural Research (CA^2RE), developed across a series of events 2017-2022, for example, adopts the label as an umbrella for related approaches such as artistic research, research by design, practice-based research, and creative practice research. This type of research is not easily formalised as a set of procedures, as it is located within the idiosyncrasies of a specific practice and as its results partially rely on designed artefacts as an outcome. As several authors have noted, design driven research does not openly proclaim its methodological approach, nor does it connote a single set of ideas concerning research (e.g., Rust, Mottram, and Till 2007, 10; Fraser 2013, 2-3). It may thus not be possible to define design driven research as a method, but rather as a collection of related methods used by individual practitioners to produce new insight and knowledge. Yet, there are common traits of this type of research, often defined through an emphasis on

either practice based research, or design research, two related and overlapping terms under the umbrella of design driven research.

Practice based research connotes "research in which the professional and/or creative practices of art, design or architecture play an instrumental part in an inquiry" (Rust, Mottram, and Till 2007, 11). 'Practice', does not imply a method of research, but is rather an activity that can be employed in research if it contributes to an inquiry that the research centres on. The liaison between research and practice is not exclusive to practice based research. Most types of research, as Michael Biggs (2004) has argued, arise from practice, or have some implications for practice, ruling out this a defining criterion. Nor can practice based research be defined through the reliance on empirical models of conducting experiments with for example materials. Rather, practice-based research is based on experiential "aesthetic judgements", evoked through process (Biggs 2004, 7-8).

Design research shifts attention from an extended engagement with design based in a practice, to the design project and the various activities that it spans as a basis for research. Murray Fraser (2013, 1-2) has defined architectural design research

> as the processes and outcomes of inquiries and investigations in which architects use the creation of projects, or broader contributions towards design thinking, as the central constituent in a process that also involves the more generalised research activities of thinking, writing, testing, verifying, debating, disseminating, performing, validating, and so on.

Such a varied approach to research is implied in the activities of many canonical architects, from Vitruvius to Rem Koolhaas, who have engaged in writing and scholarship as well as in design (Hill 2013; Fraser 2013).

The approach developed in this thesis should be viewed in relation to this brief and selective account of design driven research. Developed through two design projects, and near an architecture practice, the work aims to uncover knowledge and discuss issues that would have been difficult to raise without the support of design work. These relationships between practice, design, and thinking can be further interrogated. Christopher Frayling (1993) distinguished between research activities as being "for", "into/about" and "through" design. "For" design involves activities that serve design, such as precedent studies, while "into/about" design involves taking a step back from the design process to observe and analyse the activity to improve the practice, and "through" design implies that the actual process of design and its outcomes serves the research (for adaptations of Frayling

see Rust, Mottram, and Till 2007; Murray 2013). Daniel Fallman (2008) has described design research using a similar tripartite parsing of activities. Fallman, an interaction design researcher, positions three typical activities, "design practice", "design exploration", and "design studies", in a triangle that sets up a field in which design research activities can be positioned. Both practice and exploration imply a direct engagement with design that is "synthetic and proactive" in nature, while design "studies" refers to a mode of activity that falls close to academic scholarship and that looks for general principles and concepts.

This thesis has continuously been informed by intentionally drifting between practice, exploration, and studies. In addition to contributions relating directly to the design practice and explorations, the thesis aims to contribute to an area equivalent, for architecture, to what Fallman termed "studies" in his analyses of research around interaction design. The thesis thus deliberately investigates the wider implications of these contributions in relation to theory building in architecture. This discursive analysis can be seen as a part of the design driven research practice. In linking practice, explorations, and studies, two conceptual categories have been crucial: the notion of constructive practice, and the idea of the artefact.

A constructive practice

Discourse surrounding the characteristics of design driven research often hinges on the crafting of distinctions between this form of research and more 'conventional' or scientific modes. This can happen through the rehearsal of opposites, such as those between design and science, between tacit and academic knowledge, or between synthetic and analytical approaches. While probing these distinctions can be productive to varying degree, they amount to a difference in perspective and tradition rather than in method and activity. What characterises the design research pursued in this thesis is not only a question of how things are done, but a question of mindset and of outlook on the world, something that can be encapsulated through the notion of constructive practice.

One point of origin for such thinking is Herbert Simon's characterisation of design in *The Sciences of the Artificial*. While "the natural sciences are concerned with how things are", "design, on the other hand, is concerned with how things ought to be", Simon ([1969] 1996, 114) declared. Design is, in Simon's phrasing, a "science" of the artificial rather than of the natural, one that "devises courses of action aimed at changing existing situations into preferred ones" (111). It constructs rather than assesses. More recently, designers Anthony Dunne and Fiona Raby (2018, 58) have similarly outlined design as a means to construct

alternative realities: "A story or an idea becomes a constructed reality at the moment it is given form and materially embodied whether as an object, stage set or photograph". Designers, they argue, need to move beyond a binary view that "divides ideas, things, and thoughts into 'real' and 'not real'" in order to "uncover alternatives to how things are now" (51). Such binaries are not just at odds with the nature of design, they often play a role in suppressing "undesirable" ideas by calling them out as "unrealistic". From a designer's point of view, reality is not something static and given whose workings are to be analysed, but something that is dynamic and continuously under production.

To frame architecture and design as constructive practices may seem redundant or a matter of common sense. But 'constructive' suggests wider connotations that resonate with larger shifts in society as well as in architecture and other disciplines. Issues facing the world today, such as the climate crisis, are 'real' but they may require 'constructive' approaches. This was foreshadowed with Bruno Latour's (2004b) distinction between "matters of fact" and "matters of concern". A critical mind, Latour reasoned, must not just move away from established truths by deconstructing them, but must also attend to urgent matters of concern through other, more constructive means of engagement. The climate crisis is a fact, but it is also a matter of concern that requires us to assemble and to care. The following quote summarises Latour's (2004b, 246) position, and it is, for the sake of the argument being pursued here, tempting to substitute the word 'critic' with 'architect' or 'design researcher':

> The critic is not the one who debunks, but the one who assembles. The critic is not the one who lifts the rugs from under the feet of the naïve believers, but the one who offers the participants arenas in which to gather. The critic is not the one who alternates haphazardly between antifetishism and positivism like the drunk iconoclast drawn by Goya, but the one for whom, if something is constructed, then it means it is fragile and thus in great need of care and caution.

As noted in Chapter 2, Latour's thinking contributed to a material turn that was paralleled in architecture where it paved the way for a more direct engagement with matter and materiality. In the context of architecture, where practice is increasingly conditioned by a scarcity of raw materials and a need to operate within flows of extant material, the term constructive can however be misleading. Borden and Meredith (2012), for example, adumbrated that architecture as a material practice should neither be "extractive", nor "constructive" in nature, but instead can be characterised as "manipulative" as it increasingly must rely on

manipulation of existing materials and buildings and the relations between them, rather than on extraction or construction. This notion of a practice that constructs and intervenes by intercepting, exploring, and assembling artefacts and materials has informed this thesis throughout.

Artefacts

The production of artefacts has been central to the work presented here. These artefacts, such as drawings, models, installations, and exhibitions, accumulated knowledge and raised issues through their process of conception and making, as well as made that knowledge and those issues visible to a wider audience. Wensveen and Matthews (2015) have outlined four approaches to artefacts, or "prototypes" in product design research, that might be considered in relation to this work. An artefact might play a role in an experiment that involves human participants, addressing functional or aesthetic criteria, such as the testing of furniture prototypes. Alternatively, it might be considered as an instrument of inquiry, as a means of collecting, measuring, or recording something, an approach familiar to architecture with its rich history of developing and customising systems for measuring, drafting, and notation. In both these instances, the artefact is a vehicle to generate knowledge about a subject, object, or a context. A third kind of artefact, they argue, is the "research archetype", whose role is more exemplary and relies on criticality and reflection. "Research archetypes are physical embodiments of concepts, understandings or design spaces that can be argued to constitute contributions to the discipline" (Wensveen and Matthews 2015). The *Faraday chair* by designers Dunne & Raby (Dunne 1999), for example, is a conceptual furniture piece that articulates a "techno-ideological agenda" (Wensveen and Matthews 2015) by suggesting that psychological comfort can be provided by shielding a subject from electromagnetic radiation from everyday appliances. Finally, the process of making an artefact may be the research outcome. In this case, "the process is documented, analysed, critically assessed and written up, and the research contribution is tied not to the artefact itself as much as to how the artefact was crafted" (Wensveen and Matthews 2015).

Whether the artefacts contained in this thesis figure in one role or the other has been a matter of casting rather than something that is determined at the outset of the projects. As Wensveen and Matthews point out, the same artefact may very well fulfil different roles in relation to different research contexts. As work on design projects in the thesis has progressed, different artefacts have been presented as a research archetype in one context by disclosing conceptual and theoretical issues and withholding process, while the process of creating the very same artefact

has been the contribution in another context. Most if not all the design research projects referred to in Chapter 2 can be understood as making both disciplinary and process-oriented contributions. Even in more technical contexts such as ACADIA, many authors tend to suggest theoretical or historical foundations for their work (e.g., Kudless 2011; Clifford and McGee 2018). Such examples emphasise that the various categories of artefacts laid out by Wensveen and Matthews must not necessarily be discrete; rather these projects highlight that particular significances that can attach severally to a single object.

Explorations

In the thesis, the approaches to method outlined above were synthesised in two collaborative design explorations, *Erratic* and *Completions*. These projects are partly analytical in their nature as they chart some possibilities offered by emerging technologies and material processes, but they can mostly be characterised as being constructive in that they exemplify and argue for alternative approaches to representation and materialisation with implications for the discipline as well as for design practice.

The design explorations were developed in partnership with Einar Rodhe, currently senior lecturer at Konstfack University of Arts, Crafts and Design in Stockholm. The work commenced with the *Erratic* project in 2012 when we were both members of the faculty at the KTH School of Architecture. The *Completions* project was initiated in 2019 and developed between Chalmers and Konstfack, in collaboration with Karin Hedlund, artistic lecturer at Chalmers.

Erratic

Erratic explores a customised fabrication process in which the physical properties of a material are allowed to shape the formal outcome (Figure 3.1). The project examines how such properties can be mediated and explored using physics simulation software (Figure 3.2). It negotiates the tension between the precision of typical of digital design and the 'erratic' behaviour of a material. In addition to pointing to this issue of material behaviour, the title of the project suggested its massing. Erratic blocks that have been displaced and tumbled by glacier ice are commonly found in the landscape all over the Nordic region. The project resulted in several artefacts, such as a large-scale installation, imagery, drawings, film clips, two exhibitions, and written material. For a complete documentation of the project, see the first publication (Norell and Rodhe 2014); for a background, see the fourth publication (Norell 2013).



Figure 3.1. Daniel Norell and Einar Rodhe, *Erratic* installation, Aalto University Digital Design Laboratory, 2013.

An important part of the *Erratic* project was 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 orthogonal grid of points and the meandering surface. 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. For example, when applying force on a smaller surface patch through just a couple of constraining points, the surface might be equally inclined to bulge in either direction to form a recess or a protrusion. In short, the piece was designed by carefully placing the points, and in-between the material had its way. The project became an exercise in design where a minimum of predefined geometric input, i.e., the points, yields a maximum of material output. The project 'happens' almost entirely in the transfer between geometry and material. Its title, *Erratic*, served to suggest a concept of designed unpredictability, and in addition pointed to the visual characteristics of the randomly wandering surface.



Figure 3.2. Daniel Norell and Einar Rodhe, *Erratic*, 3d-printed massing studies designed with physics simulation.

So far, the project seemed to be aligned with a conventional separation between representation and artefact: Some aspects of architecture can be designed, quantified, and represented 'before the event', for instance through conventional drawing or modelling, while others are dependent on material exploration and must be tested 'live'. The development took a productive turn when we started using animation software to simulate how the material could be manipulated (Figure 3.2, 3.3, 3.9, 3.11). This was a necessary step to be able to quickly design variations without producing time and resource consuming mock-ups. We needed to, and to certain extent succeeded in, predicting the erratic behaviour of the material. Using simulation, the sack could be defined as a mesh surface, as a fine net of edges and nodes where constraining points could be placed. Animating the location of the points would cause the surface to bulge between the points. Gravity as well as physical properties of the surface could be set and adjusted. This allowed us to simultaneously consider the physical properties of the sack and the precise placing of the points in a Euclidian space (Figure 3.3). Material properties could suddenly be quantified as well as represented. This was a first issue that the work prompted: Simulation in architecture challenges the typical separation between representation and a materialised design, between model and material experimentation.

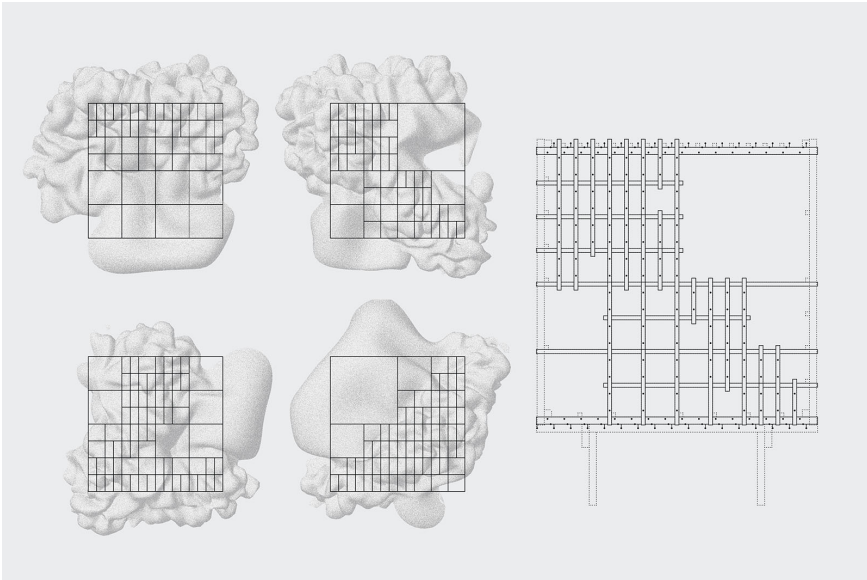


Figure 3.3. *Erratic*, elevation studies showing relationship between simulated surface and armature (left), and typical elevation of armature (right).

As work progressed it became increasingly important to finetune the relation between analogue scale models and full-scale mock-ups on the one hand and simulated models on the other. Parameters for the simulation, 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 prompted thus had to do with the relation between the material and its mediated counterpart.

The design and production of *Erratic* took place in the first half of the 2010s, at a time when the field of digital design took a material turn and when simulation of physical systems became readily available to architects. This was also a time when such simulation made its way into popular culture. Video games launched in the late 2000s, such as *Angry Birds* and *World of Goo*, allowed a user to explore the laws of physics playfully and intuitively in real-time, often to comical effect.



Figure 3.4. *Erratic*, mock-up for conference exhibition Making Research | Researching Making at the Aarhus School of Architecture, 2015.

Along with several movies, these kinds of games introduced the public to physics simulation and the conflation of digital and physical worlds that it can give rise to.

Erratic was exhibited twice, first in the solo-exhibition *Erratic* at the Aalto University Digital Design Laboratory (ADD) in Helsinki in 2013, and subsequently in a peer-reviewed exhibition that was part of the conference *Making Research | Researching Making*, organised by Architecture, Design and Art Practice Training-research (ADAPT-r) at the Aarhus School of Architecture in 2015. These two exhibitions presented opportunities to consider the ways in which process and artefacts could be disclosed. At ADD, the 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 exhibited in ADD's gallery space, while all other documentation of the project was displayed in an adjacent room. This meant that visitors first encountered the installation, and later the story of its making, told through drawings, models, and text. In addition to an exhibition opening event ADD, we co-organised a pop-up exhibition and panel discussion around the project at the Helsinki Design Week venue, including panellists Professor Antti Ahlava of Aalto University's Department of Architecture, Professor Tim Anstey of KTH School of Architecture, and ADD director Kivi Sotamaa. We were in addition included as presenters at the design week's official

PechaKucha night, where our talk reached a large, international audience of architects, designers, and the public. At the ADAPT-r conference, our exhibition considered more elaborate alternatives to the problem of disclosing process in design driven research (Norell and Rodhe 2015b). It focused on an extensive selection of process-oriented artefacts behind *Erratic*: models, mock-ups, construction drawings, simulation videos, and customised 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 3.4). Each artefact unlocked an aspect of the project expressed through a specific design medium.

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 audience of architects and designers. In keeping with this attitude, the design work in the thesis has been documented and circulated through published conference papers as well as through lectures and blogs in popular contexts. The exhibition at ADD was presented and promoted at Archinect, an architecture blog with a global reach. These two publications in turn generated several additional features and reposts. Eventually, the project was also published as part of a larger feature in "Sweden Now", a special issue of *Arkitektur, The Swedish Review of Architecture* (Svensson and Bergquist 2017).

Completions

Completions defines and explores a process in which digital survey and fabrication are used to integrate used and broken building elements and materials into a digital workflow and into new assemblies. The unique qualities of such elements and materials, including their dimensions as well as texture and colour, were captured with scanning and transferred onto a new stock through fabrication for the purpose of 'completing', or repairing, the used pieces. The project seeks to expand the register of materialities and effects that digital design can produce, but it does so not by making standardised materials 'misbehave'. Rather, it incorporates the irregularities and grit of extant and nonstandard material into a digital process. Wear, patina and other qualities belonging to such material are mediated through scanning and fabrication, resulting in new ambiguous forms and materialities. The title of the project suggests an approach to material reuse that relies on 'completing' a used entity by bringing the entity into a new state of fulfilment. The project resulted in three full-scale assemblages: a window frame (Figure 3.5), a double door (Figure 3.6), and a mantel piece (Figure 3.7) as well as in imagery, drawings, and written material. For the background and a full



Figure 3.5. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, window frame, 2020. Scanning and CNC-routing are used to design and match a new part (left) that 'completes' a salvaged fragment (right) of a window frame.

documentation of the project, see the second publication (Norell, Rodhe, and Hedlund 2021).

The making of the three assemblages involved multiple steps, from locating and selecting used elements and materials to scanning and postprocessing, modelling and fabrication. These steps amounted to a workflow for digitally enabled reuse, conditioned by a varied set of used entities. The project commenced with a series of stock visits to locate and select three types of elements and materials that correspond to a categorisation commonly used for construction and demolition waste: Stripping, where elements and materials with a value on the market are dismantled and removed prior to demolition; scavenging, where less valuable elements are left separated after demolition in a damaged state; and by-products, which are leftover materials from manufacturing or construction processes.

One half of a door panel with mouldings, stripped from a building at some point, was bought from a reuse market; a sawn-off part of a window frame was scavenged on a demolition site; and a visit to a stone manufacturer gave access to a collection of by-products: fractured cut-offs from marble sheets. While the three



Figure 3.6. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, double door panel, 2020. 3d-scanning and CNC-routing are used to create a replica (right) of an existing double door panel (left), including wear and tear.



Figure 3.7. Daniel Norell, Einar Rodhe, and Karin Hedlund, *Completions*, mantel piece, 2020. Photography, edge tracing, and water jet cutting are used to create a mantel piece by matching and aligning edges of fractured marble sheets.

types of objects covered the three categories of waste material, they also posed different challenges to the subsequent steps of survey and fabrication. The window frame and the door panel had relief, varying colour, and texture, which meant that they lent themselves to scanning with photogrammetry, a process in which many overlapping photographs covering the surface of an object support the construction of a closed, three-dimensional mesh model complete with texture and colour. For the stone sheets, however, it made sense to use a method that concentrated the resources on to certain areas of the piece: the smooth, planar surfaces required less information and the complexity of the fractured edges was recorded through elevational photographs and semi-automatic tracing.

The encounters with these specific used entities, first in the context of the city and then mediated through scanning, spawned a first series of issues for the project. A process that departs from the idiosyncrasies of found materials suggested a workflow that differed substantially from a typical design process where transfer between geometry and standardised material occurs as a last step in an otherwise all-digital process. Migrating idiosyncratic qualities, such as geometric eccentricities and subtle shifts in texture and colour, into the digital realm influenced us as designers. As Maarten Gielen of reuse practice Rotor has noted, such qualities are normally hidden from the gaze of the designer behind "layers of abstraction" of CAD systems (Borasi, Gielen, and Pantazis 2018). Scanning provided a process that gave remote access to hyper real virtual copies of the objects, in all their rugged splendour (Figure 3.10).

Three assemblages were developed based on the window frame, the door panel, and the marble sheets. This was done in a playful manner that departed from their original identity and function, while also adding features and materialities that stemmed from the state of disrepair they were found in. The mutilated window frame was completed by creating a sweeping figure between its sawn-off ends, magically bridging its original profile on one end with fractures and defects on the other (Figure 3.5). The other, missing door panel was added by creating a mirrored replica of the original one that included wear and tear, such as spots of worn off paint (Figure 3.6). The fractured marble pieces were assembled into a mantel piece by matching straight and fractured edges to each other and placing a few strategic cuts that mimicked the topography of the fractured edges so that exact fits between two sheets could be obtained (Figure 3.7). In each case, the geometry, texture, and colour obtained through scanning formed a basis for design and fabrication. The section profiles of the ends of the window frame were defined and used to design and fabricate the completing piece; the mesh geometry of the door panel, including worn-off paint, was used to fabricate the mirrored copy; and the tracing of the fractured edges of the stone sheets were used to place cuts with a waterjet.

The juxtaposition of worn pieces of material, with an authentic materiality, with machined surfaces with a fabricated materiality produced strange effects. The smooth, interpolated surfaces of the completing piece of the window frame were both continuous with and at odds with the rough materiality of the reused piece. The mirrored replica of the door panel, although nearly identical to the reused panel, bore subtle traces of the process of transfer from material to geometry and back again, such as a slight geometric noise that travelled across its smooth, white surfaces, as well as traces from the fabrication process with a CNC router (Figure 1.4). And the doubling of the randomly fractured edges of the marble sheets that

made up the mantel piece seemed to shift their status, from accidental to intentionally designed.

In addition to the previously laid out background and context, *Completions* was a response to broader cultural, disciplinary, and technological currents. Designed and produced during 2019-2020, the project drew from a larger ongoing repositioning of architecture as a 'caring' practice that works through exploration of existing buildings, elements, and materials (e.g., Sample 2016; Borasi, Gielen, and Pantazis 2018). Such practice can be informed by historical examples of reuse in architecture, such as spolia (e.g., Brilliant and Kinney 2011) and adhocism (Jencks and Silver [1972] 2013), as well as by larger disciplinary imaginaries that have emerged with the conceptual construction of Anthropocene and the anxieties of the climate crisis (e.g., Turpin 2013; Iturbe 2019). Melding digital design with reuse practice, the project exploits the increasing availability of scanning and fabrication technologies.

Completions has so far been disseminated through conference participation and as part of several public lectures and presentations delivered by Einar Rodhe and me. In this way, the project has reached an audience of architectural faculty and students, as well as the public. These lectures and presentations have often been part of themed events with several participants that address architectural practice and research considering the ongoing repositioning referred to above. This has meant that the project has been incorporated in a larger narrative of our work and research, as well as in a context of ongoing work internationally. In 2020, at the Umeå School of Architecture, the project was presented in our lecture "Re-presentation and Assemblages" through an invitation from Daniel Movilla Vega, responsible for a studio that considers the built stock of the city as a point of departure for design. At the Department of Architecture at the ETH in Zürich it was part of a lecture and panel in a series titled "Seven Questions", organised by Studio Jan De Vylder, a series that will also result in a forthcoming book. In 2021, at the chair of Architecture + Experimental Design at HafenCity University Hamburg, the project was presented as part of a lecture in "Material Cycles", an event that was organised by Matthias Ballestrem and that also featured lectures by Material Cultures (UK) and the ALICE lab at the EPFL in Lausanne. The project has been part of public lectures we have delivered in 2021 at the Porto Academy at the University of Porto, and in the lecture series at the Department of Architecture at TU Munich. In addition to these presentations in academic contexts, the project was part of two public lectures, first in the series "Material Environment" at the 2021 Rotterdam Architecture Month, organised by Architecture Institute

Rotterdam, and second at Magazin, Space for Contemporary Architecture, in Vienna in 2022.

Implications

In what follows, the implications of *Erratic* and *Completions* will be jointly explored by juxtaposing detailed descriptions of methods used with the theoretical frameworks laid out in Chapter 2. Three implications are developed by positioning simulation and scanning as a means of representation by weaving in and out of the specifics of the two projects and their discursive context. The first explores the notion of a mediated material 'resistance' in relation to more familiar conceptualisations of representation and material practice. The second considers implications of how materials are represented by parsing them into information against more typical means of modelling and survey. Finally, the third looks for other materialities that emerge through the process of mediation and fabrication.

From notations and craft to mediated materials

Both *Erratic* and *Completions* were developed through processes that depart from the specifics of discrete elements or chunks of material: a sack of polyurethan cold foam, and a collection of salvaged building elements and materials. These elements or chunks come with a genesis, such as physical and visual properties that amount to a material history and character. Like an objet trouvé in art, a found object, the *Erratic* and the *Completions* derive their identity from the designation placed upon them by a designer, as well as from their genesis in the world. This genesis may amount to an agency, or a 'resistance' to the designer's intentions. The designer might manipulate an element or chunk of material by subverting or amplifying its genesis, but the resistance is always going to be 'there'.

The resistance exhibited by elements or chunks of material come in different kinds. It might be associated with physical properties, such as the soft flexibility of the pliable polyurethane surface that was used to design and construct *Erratic*. Such properties turn the design process 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. Again, in the case of *Erratic*, the material was polyurethane, commonly known as foam rubber. This material, in its raw state, is not particularly beautiful and its connotations range from yellowed mattresses to featureless insulation material. The way in



Figure 3.8. *Erratic*, Aalto University Digital Design Laboratory, 2013. Installation detail showing constrained polyurethane surface finished with plaster powder.

which we manipulated this material, from constraining it into shape to finishing it with plaster powder, was a way to play with its identity and accompanying associations (Figure 3.8).

The resistance may also be associated with an overall identity of an object that is an assemblage of already shaped materials. The window frame and the door panel that were used in the design of *Completions* were not just chunks of material, but artefacts with an intended function. As such, they came with a wider range of connotations and qualities. Both objects were aged, and they clearly had a genesis and a history. Their design, worn materiality, and detailing gave them a strong identity that evoked curiosity as to their previous whereabouts and to the events that might have shaped them in the past, as well as evoking a sense of nostalgia. Further, the state of incompleteness that they were in begged for action. The window frame had been sawn off during dismantling, and the other half of the door panel was missing. The design of the completions of these objects became a way to both acknowledge and draw from their genesis, as well as to overcome it by bringing them into new states of fulfilment.

In *Erratic* and *Completions,* the process of exploring objects defined through simulation and scanning, respectively, is enabled through a digital modelling interface. The properties of the materials and elements involved are transferred,

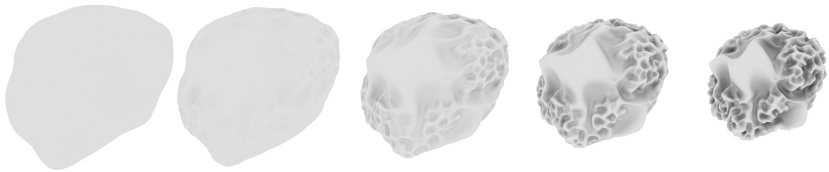


Figure 3.9. *Erratic*, screenshots from animation showing constraining process carried out with physics simulation. A spheroid surface constrained in 200+ points that are moved incrementally towards a centre point.

mediated, and made accessible through these means of representation. This means that some of the 'resistance' offered by the elements and pieces of material will still be 'there', even when accessed through a computer screen. In a regular modelling environment, virtual primitives such as curves, surfaces, and solids as well as the operations that they can be subjected to, offer little or no resistance to manipulation. Primitives are not defined as material entities and can be manipulated and stretched effortlessly and without constraints. The role of lines and edges lie in their ability to graphically outline form. In the simulated environment, however, primitives define entities imbued with properties that make them heavy or light, elastic or rigid, taut, or flaccid, etc. Defining entities through such properties lends a resistance that goes beyond graphical delineation. Once defined, they can be intuitively engaged by the designer in a process that unfolds in real-time (Figure 3.9). The surrounding environment may add further resistance through forces such as gravity, friction, or wind that act on the objects and may cause them to move or deform. Together, objects and their surrounding environment amount to a 'world' that the designer creates and tweaks by tuning their respective properties in relation to each other, a playful conceptualisation of design enacted through physics simulation has been inherited from early on-line computer games (see Norell 2021).

Another aspect of design that takes place through typical modelling software is that it unfolds in a sequence in which abstract wireframe primitives are incrementally refined, detailed, and 'mapped' with materials, something that is often reflected in the switching from wireframe view, to shaded view, to rendered view. The process implies an order where geometry and form precede materiality and colour. Such priorities vanished through the scanning process. The model of an object obtained through scanning collapses the hierarchy between form, texture, and colour that we are accustomed to through modelling software, as all those registers are assigned equal weight (Figure 3.10). And herein lies its 'resistance'. Like its physical counterpart, a model obtained with scanning appears



Figure 3.10. *Completions*, isometric view of three-dimensional geometry of salvaged window frame obtained with photogrammetry (cropped). Closed mesh model with image map.

as an irreducible entity that partially resists the easy transformation that a virtual primitive may be subjected to. Although susceptible to digital manipulation, such models come with an added sense of identity and degree of integrity.

Considered together, these mediated material resistances suggest a different kind of proximity between architect and assemblages or chunks of material with implications for design process and method. A design process that departs from such mediated resistance can be positioned in relation to, and in distinction to, familiar adaptations of notions of 'notation' and 'craft' during the digital turn. It is in retrospect interesting to note that digital design frequently was conceptualised in these somewhat oppositional terms, neither of which categories really fit or describe a practice based on simulation or scanning. In terms of notation, digital design is understood as an allographic practice that targets the reduced description of form. In terms of craft, digital design is understood as an autographic practice where the architect is directly involved with the working of a material.

The popularisation of three-dimensional modelling and fabrication during the digital turn may have introduced a more direct relationship between geometry and material, but discourse at the time still tended to emphasise the abstract registers

of representation. In "Notations + Diagrams", for example, Stan Allen considered the changing nature of drawing after the introduction of digital media through the lens of notations. A drawing, Allen ([2000] 2009b, 41) wrote, works "notationally" and can be "described as a script, a score or a recipe: a set of instructions for realising a building". Although not expressly addressed by Allen, this conceptualisation resonated with a logic of digital design and fabrication in which a virtual model is turned into code that can be fed into a machine that shapes material. In what amounts to a brilliant argument, Allen repeatedly stressed the virtues of the abstraction that pertains to notations and diagrams and the inadequacy of resemblance, mimesis, and simulation as models for architectural representation. The reduced graphic of a "dry, dispassionate form of notation", Allen ([2000] 2009b, 45) argued, gains value and credibility by not attempting to embody the reality of materials and by foregrounding intangible properties such as organisation.

Objects and materials mediated through simulation and scanning might have a more direct appeal in comparison with such conceptualisations of drawing, but because they are accessed through a modelling interface, they still maintain a conceptual distance to the designer. This means that design enacted through these mediums is distinct from equally familiar adaptations of notions of 'craft'. Following Malcolm McCullough's (1996) *Abstracting Craft*, many publications have conceptualised digital design as a 'craft', thereby highlighting that digital design and fabrication has brought architect, material, and making in closer proximity to each other. Adaptations of such notions of digital 'craft' have tended to emphasise an artisanal and tacit knowledge of materials as theorised by Richard Sennett (2008). The craftsperson, or a robotic arm equipped with force feedback, 'feels' the resistance of a piece of material, such as a knot in a piece of wood, and responds accordingly, without the need for an intermediate drawing or "blueprint" (Carpo and Kohler 2014; see also Gramazio and Kohler 2008). This intimacy bypasses representation altogether by collapsing the distance between architect and object or material, often leading to a foregrounding of phenomenal rather than conceptual issues. Drawing from David Pye's ([1968] 1995, 20-24) notion of "workmanship of risk", Kolarevic (2008) defined digital craft in terms of a willingness to accept the risk that the results may not be predetermined through a representation, but instead emerge out of a negotiation between human, machine, and material. While this conceptualisation of fabrication may still seem valid today, it implies a false opposition between representation and material in which representation is understood as a blueprint, a label that suggests something idealised, static, or even obsolete.

When considering simulation and scanning, these oppositions between notations and craft no longer seem tenable. The hybridisation of digital and physical worlds that occur in these mediums appear to rest on principles of mimesis and resemblance. The mediation of visual and physical specificity of materials sets up a mode of communication between subject and representation that is direct and intuitive rather than complex and layered. It is precisely the ability to introduce the grit and the uncertainties of materials and experiments into the realm of representation that makes simulation and scanning distinct from other means of drawing. Moving the representation of objects and materials from idealised geometry towards specificity may seem to favour a less sophisticated mode of viewing in which superficial qualities are foregrounded over underlying geometries, something that will be further interrogated in Chapter 4. Such bias might in turn stem from a lack of disciplinary engagement with simulation and scanning and other recently introduced mediums of design.

Notions such as these are an opportunity to position simulation and scanning as means of design and representation. Neither relying on notations, nor on craft, simulation and scanning set up an alternative, mediated relationship between architect and material. This relationship might be characterised as direct but still conceptual, where the resistance offered by materials as well as their surrounding environment becomes a thickened, virtual medium of design. In what follows, a more detailed and technical account of how simulation and scanning respectively represent materials will be provided, along with some suggestions for such representation.

Models, experiments, and a meticulous gaze

To situate simulation and scanning as means of representation and as means of design, it is necessary to look more closely at their specifics: at how they represent by parsing the world into information, as well as at the operations that they support.

For the design development of *Erratic*, a particle-spring based software was used, in which a surface can be defined as a dense mesh consisting of edges and nodes. To simulate a fabric type material, each edge in the mesh acts as an elastic spring of restricted length (Figure 3.11). Nodes can be fixed in a location by placing constraints on them, and those constraints may in addition be moved. Properties of the surface can be set and tweaked, including elasticity, bending stiffness, thickness, and weight. Similarly, global properties belonging to the surrounding environment, such as gravity, might be set and adjusted. These features were used to set up experiments with the sack-like surface of the installation. Many

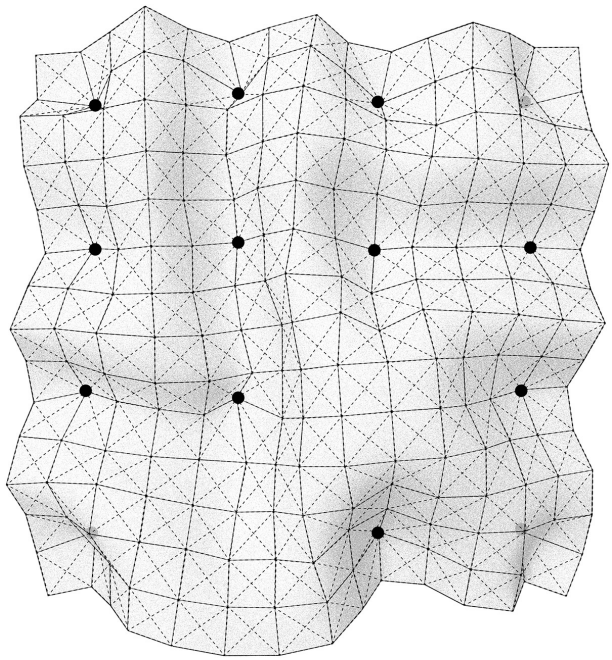


Figure 3.11. *Erratic*, typical particle-spring based simulation mesh with constraining points.

constraining points were placed on the surface, and the locations of these points were moved across a stretch of time so that the distance between each point decreased, causing the surface in-between the points to bulge. Collision detection was used to keep the surface from self-intersecting during this transformation. The simulation could subsequently be played in real-time.

This way of approximating and representing the behaviour of the polyurethan surface targeted both qualitative and quantitative aspects. Physics simulation could be used to receive visual feedback on design variations, as well as to suggest distributions of constraining points. Further, it addressed the problems of modelling pliable surfaces as outlined in Chapter 2. Like subdivision surfaces, it could be used to target the visual results of a process of manipulation, but unlike such surfaces it could keep surface area constant during the transformation. To use subdivision modelling to add a formal feature to a surface, such as bulge, inevitably affects its surface area and its topological resolution. Although the simulation requires keyframe animation to move the constraining points, this animation differs fundamentally from a similar animation of anchor points on a topological surface, a transformation that would stretch rather than redistribute



Figure 3.12. *Erratic*, feedback loops between simulation and material tests: 1:25 scale model created with physics simulation (left), 1:5 scale analogue model (middle), and 1:1 scale mock-up (right).

the surface. Physics simulation, in short, sets up the surface as a discrete piece of material with properties that can be explored across time. While such exploration may be distanced and conceptual in nature, it is at the same time akin to conducting a material experiment. As work on *Erratic* progressed, the visual and dimensional feedback between simulation and material experiment was established incrementally through scale models and mock-ups (Figure 3.12). Over time, these studies gave the simulation 'credentials', as they proved to be accurate enough to act as a stand-in for physical models and mock-ups. As previously noted, this process involved tweaking both the simulation as well as the material specifications.

The design process undertaken for *Erratic* suggests some more general possibilities for physics simulation as a medium of representation. These possibilities can be explored by positioning simulation in relation to the epistemology of architectural models as well as of scientific experiments. In the field of philosophy of science, Eric Winsberg (2010, 136-37) has acknowledged the difficulty of positioning simulation "on the methodological map": is it applied theory, empirical experiment or does it project a third and new type of knowledge? Following philosopher Ian Hacking (1983), Winsberg (2010, 40-42) defines simulation in science as "model building", an activity that straddles theory and experiment (see also Norell 2021). A simulation, Winsberg suggests, represents a physical system but does so in ways that make it possible to use it as a basis for intervening in the real world. Going beyond two-dimensional pictorial representation, a simulation is, to draw a parallel to architecture, less like a drawing and more like a model. This view is corroborated by recent scholarship around the use of models. Models can, as argued by Matthew C. Hunter (2020, 46), be located "in those spaces between theoretical representation and more direct intervention

into the material stuff of the world". Hunter, like Winsberg, departs from Hacking's (1983) discourse on scientific models, and attempts to locate characteristics that such models share with architectural models. Both kinds of models represent, but they can in addition act as mediators that provide insight on material processes. In an architectural model, this can for example happen when it targets conceptual issues while it at the same time is used to approximate forces that traverse it. Physics simulation, it might thus be argued, endows the designer with the projective and descriptive powers that are native to drawing and digital modelling, while at the same time introducing some of the resistance native to modelling with a real and discrete piece of material. In fact, the range of design methods implied by physics simulation are closer to those of the 'live' material experiment, where the designer sets something up to 'see what happens,' than they are to typical modes of drawing and digital design.

For the design development of *Completions*, several means of digital survey were used, from 3d-scanning with photogrammetry, to 2d tracing (see Norell, Rodhe, and Hedlund 2021). A smaller object, such as the window frame, was photographed against a greenscreen and rotated incrementally to arrive at a set of overlapping photographs that covered all its surfaces (Figure 3.13). The green pixels were removed from the images through masking, something that made it possible to produce a complete survey of the object in one session without interference from a background surface. The photographs were subsequentially processed in a photogrammetry software. The software analyses and compares photographs with regards to local areas of pixels that appear similar, and depth is calculated through projection of, and triangulation between, viewpoints (see e.g., Gross and Pfister 2007, 23-30). This process relies on the automated recognition of formal or material features for the pinning down of points in a three-dimensional space. Smooth surfaces lacking these features, such as areas on the door panel or the window frame that were planar and painted white, will be 'underdetermined' and more difficult to detect. Each point detected is assigned an RGB colour value based on the source images. The first output of the photogrammetry process is a point cloud, a dense agglomeration of millions of dimensionless points in space that describes an object. In the final step of the process, the point cloud was processed into a mesh consisting of faces and nodes (Figure 3.14). As part of this process, colour information contained in the points is transferred into a 'texture map', a flat image that is 'wrapped' around the three-dimensional mesh object using projection to give it colour.

This way of representing the salvaged objects through photogrammetry targeted both qualitative and quantitative aspects. The coloured meshes could be



Figure 3.13. *Completions*, photogrammetry scanning process to obtain a closed mesh model. Greenscreen photograph of salvaged window frame.

used for dimensional as well as visual apprehension, for the precise fitting of new parts to the existing objects, as well as for 'completing' the existing objects by transferring their qualities to a new part that extended them. Further, they made it possible to integrate the objects into a digital design workflow and granted remote access to their unique qualities. In this sense, they melded the properties of results typically obtained through a manual survey, such as the measured line drawing and the photograph, into one medium. But unlike the results of a manual survey, these models were not conditioned by prevailing ways of representing geometry, nor by the intentionality of a subject conducting the survey. In a manual survey, to establish a level of detail through the inclusion or omission of forms and materialities for documentation, is a matter of attention and purpose. With scanning, some of these aspects are leveraged to a device that simply captures what it can view from given points in space, with no distinction between what is important or not. Following media theorist Wolfgang Ernst, Zeynep Çelik Alexander (2020b, 74) has referred to this as an ability to "'desemanticize' vision so that seeing was replaced by 'gazing/scanning' without any search of deep meaning". The influence that scanning has on the conception of architecture lies

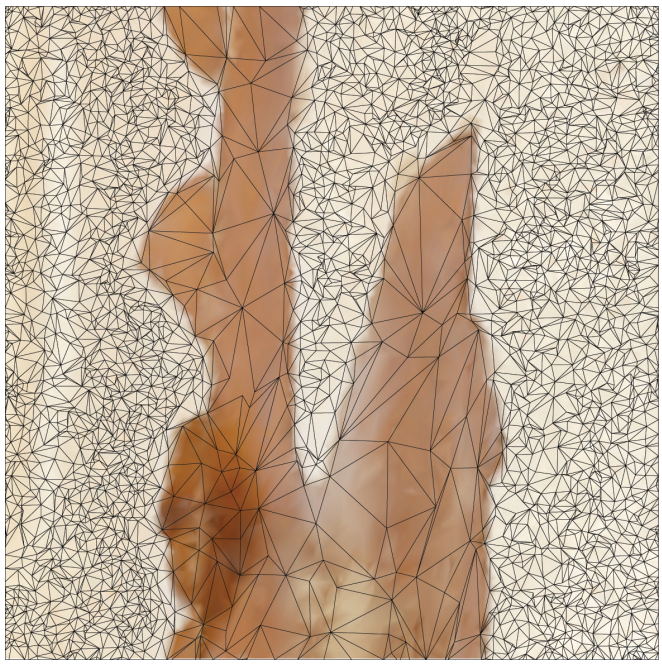


Figure 3.14. *Completions*, detail of reduced coloured mesh with faces and nodes obtained with photogrammetric scanning of door panel.

in this disinterested but meticulous gaze on objects, as well as in the ways it parses objects into information.

This ability to 'see' and represent objects devoid of human preconception resonates with a speculative reuse practice that seeks to explore objects for their existing qualities and go beyond intended use. Targeting reuse through means of representation can in this sense be viewed as an attempt to challenge larger ingrained habits of architectural design. Models obtained with scanning place unique characteristics of objects at the centre of the designer's attention. These means of representation assign as much weight to qualities such as materiality, texture, and colour as they do to overall form or proportion, properties that architectural representations normally foreground.

The work with both *Erratic* and *Completions* should be seen in relation to such a larger discussion on representation. While these projects develop workflows for simulation and scanning in relation to reuse of materials, they in addition aim at furthering a designer 'literacy' towards the use of simulation and scanning as mediums of design. Such literacy can be developed by getting accustomed to the points, meshes, and image maps as means of representation, and as 'cultural

categories'. Pixels are, according to media theorist Katja Kwastek (2015), an historical example of such a cultural category. Kwastek argued that the ability to perceive images as 'pixilated' can be understood through the concept of the "period eye", seminally formulated by art historian Michael Baxandall ([1972] 1988). Baxandall's thesis was that perception is conditioned as much by cultural experience as it is by raw data about for instance light and colour. An image is ultimately read through such a period eye, through an "overlay" of cultural "patterns, categories, habits of inference and analogy" (Baxandall ([1972] 1988, 29). An important part of perceiving the world through simulation or scanning is to come to such cultural terms with the parsing of architectural form into points, meshes, and image maps.

Other materialities

Beyond allowing for a mediated exploration of building elements or chunks of material by parsing them into information, simulation and scanning produced materialities that were shaped by these digital processes. Such materialities can be characterised as being other, as they do not conform to traditional notions of materiality that rest on authenticity and craft. And as Kwastek's discourse on pixels reveals, other materialities may go beyond revealing the limitations and materiality of a digital medium, towards becoming a cultural and aesthetic category.

In the *Completions* project, such materialities emerged in the process of transferring geometry and texture obtained with scanning onto a new stock. A close view of the mirrored and fabricated door panel, for example, revealed the strangeness of the materiality of the scanned copy by juxtaposing it with the authentic materiality of the found door panel (Figure 1.4). The discrepancy between the two nearly identical objects highlighted the spectrum and residual effects of the scanning and fabrication process that the new door panel had gone through, thereby emphasising its distinct materiality. This process had dutifully replicated the exact contour of the spots of worn off paint, for example, but since these spots were CNC-routed from a new stock of massive wood, they did not have the patina that was present on the original panel. Similarly, the process replicated the mouldings, but because of limitations in the transfer between digital and material realms, they were somewhat inexact and ghostly in their reproduction.

In the *Erratic* project, the installation, although the result of a scripted and simulated procedure, did not bear any traces of a digital process. Rather, it was in the realm of the digital simulation that another materiality of this kind was produced. This materiality could be perceived in output that resulted from the simulation, such as the imagery (Figure 3.15) and the 3d-printed scale models

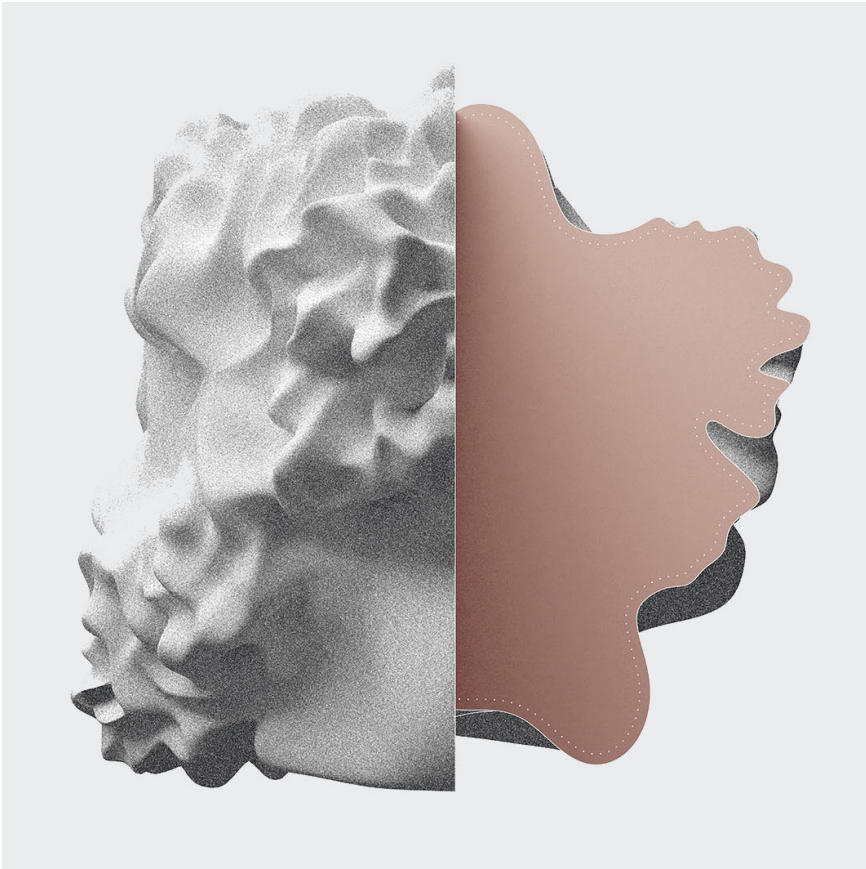


Figure 3.15. *Erratic*, combined elevation and section rendering of massing study created with physics simulation.

(Figure 1.2, 3.2) that featured an almost visceral materiality through their crumpled surfaces. The way in which the material bulged and meandered created a materiality that visually indexed the way in which the surface had been constrained and deformed. While entirely virtual in nature, this kind of materiality induced a sense of the previously discussed material resistance of the surface in a viewing subject.

The materialities in these two examples seemed both related to as well as distinct from some existing conceptualisations of materiality that have been proposed in the field of digital design in architecture. The notion of 'digital materiality', for example, has been used to highlight the impact of digital design

and construction on architecture. While such a notion of materiality acknowledges that the "synthesis of two seemingly distinct worlds – the digital and the material – generates new, self-evident realities" (Gramazio and Kohler 2008, 7), it tends to focus on materiality as a property of programmed architectural systems, such as the establishment of a digitally enabled tectonics that coordinates parts across scales, rather than on the visual and tangible properties of an object or a surface. "Digital materiality" connotes a way of working that "allows the architect to control the manufacturing process through design data" (Gramazio and Kohler 2008, 7), a statement that seems to perpetuate the valuation of form over material through direct transfers of geometry onto inert chunks of material.

The ambiguous materialities featured in *Completions* and *Erratic* can be more productively positioned in relation to Paul's (2015) notion of "neomateriality", as outlined in Chapter 2. To recapitulate, this notion "describes the embeddedness of the digital in the objects, images, and structures we encounter on a daily basis and the way we understand ourselves in relation to them" (Paul 2015, 553). Such embeddedness can for example be visual traces of digital processing that amount to a modified materiality in images or objects. One of Paul's examples is Clement Valla's previously mentioned *Surface Proxy* series. By draping replicas of artefacts in their own image, Valla's work foregrounds the virtuality of materials as understood through digital technology. This highlights the digitally processed materiality as being fabricated rather than authentic – it immediately reveals itself as a thin veneer that has been applied to otherwise mute objects. While this splicing of geometrical and image-based information resonates with the logic of scanning and with the separation of information into digital geometry and image maps, it also produces an effect that relies on the provocation of such a procedural understanding of materiality. The other materiality in *Completions*, in comparison, although equally fabricated, is grafted onto 'real' materials such as wood and stone, and therefore emerges more slowly when viewed in the vicinity of the authentic, original used objects, giving rise to a prolonged moment of ambiguity.

Disciplinary debates

The development of these implications relies on a combination of design explorations and design studies, thus suggesting a dynamic relationship between design and thinking, and between practice and theory building. Within the core of the discipline of architecture, such relationships have been contested and the subject of extensive debates during the past decades. The debates have not so much concerned the general merits of theory or of thinking in architecture but have

rather centred on what theory and thinking are concerned with more specifically, and what relationship with practice they aspire to. In the interest of providing an adequate methodological framing to the explorations and their implications, this section will briefly interrogate some of these debates. The interrogation provides a chronology of discursive developments that partially took place during the years in which the design explorations were carried out, thus affecting the ways in which these explorations resonated with thinking in the field.

In 1990 Sylvia Lavin published an essay provocatively titled "The Uses and Abuses of Theory" where she noted that "something called 'theory' is everywhere" in architecture. Architectural 'theory', Lavin argued, was no longer grounded in the thoughtful process of making buildings but had instead become subsumed in a landscape of literary theory and philosophy. "Kant, Foucault, and Derrida" had "displaced Le Corbusier and the Acropolis" (Lavin 1990, 113). Writing at the apex of a certain brand of critical theory in architecture that had become associated with avantgarde movements such as deconstructivism, Lavin questioned whether such theory could engage with practice, "the domain where the thinking and making of architecture meet, where the ideal and the real collide" (179).

Lavin's essay has been cited as one point of origin (Speaks 2005; Frichot 2009) for a debate that followed throughout the 2000s, with repercussions in the 2010s (e.g., Allen [2000] 2009a; Somol and Whiting 2002; Speaks 2002, 2005; Baird 2004; Martin 2005; Schrijver 2009; Frichot 2009; Stoppani, Ponzo, and Themistokleous 2017). Like Lavin, Robert Somol and Sarah Whiting (2002), as well as Michael Speaks (2002, 2005), positioned "critical theory" as a distinct paradigm of architectural thinking influenced by the neo-Marxist Frankfurt School as well as by French philosophy, one that relied on critique and resistance as modes of operation. Promoted by influential figures in American architecture, such as Peter Eisenman and Michael Hays, critical architecture "required the condition of being 'between' various discursive oppositions", such as those between culture and form, or between kitsch and avantgarde (Somol and Whiting 2002, 72). As a response to Eisenman's and Hays' reliance on dialectical critique, inherited from Colin Rowe and Manfredo Tafuri, Somol and Whiting proposed a "projective" mode of disciplinarity and of architectural practice. The projective moves away from understanding architecture as dialectics, as something removed from external constraints, towards understanding it as a product of a "Doppler effect" – as the result of multiple and interfering "waves" of information that the architect faces. Practice becomes an "adaptive synthesis of architecture's many contingencies", such as "material, program, writing, atmosphere, form, technologies, economics, etc." (Somol and Whiting 2002, 75). As Somol and Whiting pointed out, this

reliance on contingencies should not be understood as a dilution or legitimisation of architecture in relation to other disciplines or market forces:

> The Doppler shifts the understanding of disciplinarity as autonomy to disciplinarity as performance or practice. In the former, knowledge and form are based on shared norms, principles, and traditions. In the latter, a more Foucaultian notion of disciplinarity is advanced in which the discipline is not a fixed datum or entity, but rather an active organism or discursive practice, unplanned and ungovernable.

A less nuanced attack on critical theory was offered by Speaks (2002, 2005), who proclaimed that such theory should be understood as a bracketed period of intellectual history in architecture. In the wake of digital design and information networks, Speaks, like Somol and Whiting, argued for a different and more mutable model of practice, one that continuously synthesises flows of information to stay relevant. Action, or design, was no longer going to be "dependent on the declaration of a set of guiding principles" (Speaks 2005, 74), i.e., theory. Instead, theory was to be superseded by a more fluid relationship between thinking and doing, one that would foster innovation rather than perpetual critique.

In more specific terms, projective, or "post-critical" (Baird 2004) as it was somewhat derogatorily labelled, practice and discourse came to embrace Deleuzian concepts such as atmosphere, affect, and diagrams in lieu of critical tropes inherited from Derrida, such as representation and narrativity. Further, as Somol and Whiting proposed, projective architecture could be characterised as "cool" rather than "hot". Following McLuhan, the critical project implied a 'hot' take on the discipline and on practice, one that prioritised high-definition, delineation, and distinction from the normative, while the projective project was 'cool' in its emphasis on low-definition and participation. "The hot", in the words of Somol and Whiting (2002, 76), "connotes the overly difficult, belabored, worked, complicated", while cool, in contrast, "is relaxed, easy".

The projective approach suggested a model of disciplinarity, of architectural knowledge, and of practice that relied on synthesis and contingencies. It did away with opposition and resistance, two modes of engagement that had become associated with critical theory. It was primarily this crude act of substitution that drew a considerable amount of critique, mainly from George Baird and Reinhold Martin. Both Baird (2004) and Martin (2005) saw lapses in how the projective argument was advanced with regards to disciplinary history, for example in the blunt packaging of Eisenman's and Tafuri's respective positions into "critical theory". Both soberly agreed that architecture still needs theory to navigate

conceptual as well as ethical and social concerns. Notably, Martin (2005, 5), in an otherwise scorching critique of Speaks' as well as Somol's and Whiting's positions, acknowledged that critical work needed to be more projective to be able to intervene in the future, something that could be accomplished by engaging directly in "messy realities". This reasoning was furthered in a remarkable statement that both criticises as well as affirms and develops the projective position: "This also means avoiding the elementary mistake of assuming that reality is entirely real – that is, pre-existent, fixed, and therefore exempt from critical re-imagination" (Martin 2005, 5). The Doppler metaphor, in which waves of contingencies hit an unsuspecting subject, risked, despite Somol's and Whiting's assertions, setting the architect up as someone who merely responds to the real rather than reimagines it.

One of the things that the debate surrounding the projective did was to pave the way for alternative models of practice and theory in architecture and for new ways of conceptualising the relationship between thinking and doing. As noted by Lara Schrijver, it promised to reintegrate practice and theory and implied a shift towards material conditions and constraints. For Schrijver (2009, 124), writing from a more pragmatic European perspective, the projective implied something beyond rather than after the critical, a "recalibration" rather than a dismissal of the critical. Further, following Latour's (2004b) previously mentioned polemic on critique, critical theory assumed a subject that is "outside" rather than 'inside'; it resisted rather than participated. In this sense, the projective was "aimed at incorporating critique and embedding it within the cultural fabric precisely through a sophisticated use of aesthetic qualities" (Schrijver 2009, 124-25).

The reintegration of practice and theory was both foreshadowed by, as well as furthered by, Stan Allen's "Practice vs. Project". In this insightful account of the relationship between practice and theory, Allen ([2000] 2009a, xiii) challenged the view that practice needs a "project", i.e., an overarching narrative that only theory can provide, in favour of an approach that integrates the two:

> Instead of opposing theory and practice, imagine competing categories of practice: one primarily textual, bound up with representation and interpretation: a hermeneutic or discursive practice; and the other concerned with matter, forces, and material change: a material practice. The consequence of this would be to say that there is no fixed category called 'practice' no fixed category called 'theory'. There are only practices: practices of writing, which are primarily critical, discursive, or interpretative, and material practices: activities that

> transform reality by producing new objects or new organisations of matter.

In reviewing this quote, attention must be directed to the implications of some of the terminology. The term 'representation' should here be understood in a general rather than architectural sense. Allen swiftly pointed out that there is no contradiction between understanding architecture as a material practice and the fact that it relies on techniques of representation, such as drawing. Architects engage materials, yet often do so at a distance, through abstract notation. Further, while theory and practice are both considered as 'practices', their vectors point in opposite directions. Theory, being a discursive practice, looks towards the past by critically examining things already made, while material practice projects into the future by bringing new things into being. Together, these perspectives can amount to a practice that is flexible enough to engage the complexity of the real, "yet sufficiently secure in its own technical and theoretical bases to go beyond the simple reflection of the real as given" (Allen [2000] 2009a, xii).

Towards the 2010s, the relationship between practice and theory in architecture received further scrutiny and modification. Against the background of a careful review of some of the debate unfolded above, Hélène Frichot offered a critique of the dismissal of theory that she saw as part of the projective project and proposed a different relationship between theory and practice. Following Deleuze and Foucault, Frichot (2009, 113) argued that

> theory is more useful when it is considered to be a box of tools, and when the 'relay' between theory and practice goes backwards and forwards, so that blockages in one mode of action can be unblocked by the other.

Notably, theory is now cast in a new role: as an instrument in the pursuit of a problem or issue, rather than as a comment on, or critique of, something existing. Theory, or discursive practice, might be a reflection on the past, but it could also, like practice, be "creatively speculative: theory is able to make (sometimes uncoordinated) leaps into the future" (Frichot 2009, 122). While this might be a logical conclusion to the debate, it also raises further concerns.

Locating theory within practice and viewing it as an instrument that can be applied towards an architectural problem might tie it too firmly to the discipline, thus limiting other influences and perspectives. This is one of the issues that have been raised more recently when the relationship between practice and theory has been discussed. In the introduction to *This Thing Called Theory*, the editors

position "theory as a form of architectural practice, a critical voice from within that finds different articulations in the thinking and making of architecture, and opposes the instrumentalization of its use" (Stoppani, Ponzo, and Themistokleous 2017, 2). Thinking in architecture, they continue, cannot be statically located in relation to an inside or an outside. Rather, it is in constant motion, and this motion can, one might assume, as in the case of critical theory, progress from the outside to the inside of the discipline. Or it can, as they are proposing, begin within the discipline and progress towards its boundaries, where it works as a "hinge" that regulates relations to other disciplines. "This paradoxical shifting of positions enables theory to introject ideas within its discourse, thus continuously redefining architecture's disciplinary boundaries" (Stoppani, Ponzo, and Themistokleous 2017, 2). Such probing of the outskirts of the discipline might be the current task of architecture theory, a task that can widen horizons, but that also puts theory at risk of ending up on the outside.

So, what does this most recent model entail for a design driven research practice carried out within the discipline of architecture with the ambition to span design and theory? One example is put forward in *This Thing Called Theory* by Kyle Miller, who reviews and categorises some emerging, mainly American practices. If a previous 'post-critical' generation came to view theory as obsolete and rather aimed to "use speculation to produce innovations that enable architectural design to more directly and aggressively acknowledge and engage the marketplace", this new group of practitioners instead "demonstrate an ability to synthesise thinking and doing without an abandonment of architectural theory" (Miller 2017, 48). This can happen through a "both, and" mindset in which a practice produces work that is often both critical and projective, as well as both disciplinary and instrumental in a wider cultural context. In many cases, design may precede intellection and may amount to a theoretically articulated position over time. Drawing a parallel to the editors' introduction to *This Thing Called Theory*, it can be suggested that the practices reviewed by Miller depart from a position firmly positioned within architecture and proceed to probe the discipline's outskirts. This can happen through the coupling of core architectural concerns such as form, space, aesthetics, or discourse, with the use of unusual materials, mediums, theories, or references located at the fringe of the discipline. Further, it is notable that here this outward, probing motion is not reserved for theory or discourse, it can be propelled by design or theory interchangeably or in tandem.

It now becomes possible to articulate a position that contextualises the approach to method and the design work in this thesis by drawing parallels between the often-interdisciplinary take on method in design driven research and

the disciplinary account of the evolving relationship between practice and theory offered in this section. The research activities pursued in this thesis, such as "for" and "through" design (Frayling 1993), or "exploration" and "studies" (Fallman 2008) suggest a dynamic interplay between design and theory building that draws from projective practice and its later incarnations. The investigative work carried out in the thesis, through design and textual analysis, stresses the importance of artefacts (Wensveen and Matthews 2015), of engaging in material conditions (Somol and Whiting 2002; Schrijver 2009) and of "messy realities" (Martin 2005). Such a tangible engagement with design is deemed crucial, both for intervening in the world as well as in the discipline. The design driven research in the thesis has a "constructive" (Dunne and Raby 2018) ambition: it attempts to reimagine the "real" and engage in the world (Martin 2005; Allen [2000] 2009a; Frichot 2009). In combination with written exploration, it contributes to the discipline from within through "research archetypes" (Wensveen and Matthews 2015) as well as by probing the discipline's boundaries (Stoppani, Ponzo, and Themistokleous 2017).

During the digital turn, the pursuit of technical and formal sophistication frequently trumped the crafting of theoretical argument, something that eventually caused a devaluation of disciplinary knowledge. The advent of the post-critical, and the 'death of theory' that this implied in some interpretations, accelerated that tendency. The situation that resulted suggests something frail and delicate about the architectural discipline: That it was, and perhaps still is, in need of care rather than critique or negation. There is an urgent need to enliven and remodel the relationship to the discipline in ways that establish continuities. The avant-gardism of critical theory promoted a model of such continuity in which the job of a new generation was to study, critique, and defeat the previous one. And while the post-critical generation supposedly did away with such avant-gardism (e.g., Gannon 2009), it was also inscribed in that model through its break with theory (e.g., Speaks 2005). This thesis argues that what architecture as a discipline currently needs is not the generational breaks of critical theory, nor the ill-grounded dilettantism of post-criticality, but new narratives that establish continuities through unexpected links across generations, entrenched 'camps', and local contexts.

4 Agency: Material, representation, technics

Having considered the implications of *Erratic* and *Completions*, a larger issue of agency emerges. The ways in which the use of simulation and scanning expanded the registers of digital design suggested that means of representation that facilitate architectural design have agency, and that these technologies offer a contemporary context in which the effects of such agencies can be productively observed. To assign agency to such means of representation opens an architectural discussion on issues of projection and translation and their role in shaping the architectural imagination, but the discussion also extends beyond such discplinary concerns and into political critique, as representation conditions how we view the world, how we operate in it, and even modifies how we view ourselves. This chapter is an attempt to establish an analytical framework for such discussions through three themes. The first draws from the material turn in philosophy and addresses the notion of 'material agency' in relation to the coding of information that representation through simulation and scanning entails. The second revisits theories of architectural representation that imply that drawings hold agency and interrogates the particularities of simulation and scanning against this disciplinary legacy. The third offers perspectives on the agency of instruments and practices of representation, as well as on the discourse and histories that are spun around them, by taking cues from recent scholarship pursued under the banner of 'technics'. The chapter closes by discussing some current and wider resonances of the adaptation of these three themes towards representation by intentionally conflating architectural and political implications of the term representation.

These themes and the discussion are developed in response to the explorations and their implications, but unlike the previous chapter, the analysis does not engage the specifics of the design work. The ambition is not to provide a broad survey of the issue of agency of means of representation, but rather to engage and widen the discussion of agency in relation to the theoretical and disciplinary premise and context of the thesis, as laid out in Chapters 1 and 2. The analysis of agency pursued here is complemented by the third publication (Norell 2021) that interrogates the agencies of the use of physics simulation in current architectural practice against a disciplinary history of formal analysis and differentiation.

Material agency

A discussion on the agencies of simulation and scanning as means of representation might begin by considering the notion of "material agency", frequently invoked in new materialism and actor-network theory (e.g., Pickering 1995; Latour 1999; Knappett and Malafouris 2008; Coole and Frost 2010). New materialists Coole and Frost suggested that material thinking too often is hampered by idealities that are favoured over materiality, amounting to an "allergy" to the real. Matter, they stated, is never passive or inert, it can possess agency that alters the course of things. In analysing the relations between subjects and objects, Coole and Frost (2010, 37) argued against reduction of materiality to other processes and positioned matter and materiality "outside of the dualism of the material and the ideal". Instead, they called for alternative ways of "conceptualising and investigating material reality" that could address environmental, geopolitical, and economic change (2).

In architecture, this ontological reorientation has often been interpreted in terms of a physical integration of material into the design process. Simply put, for a chunk of material to be able to 'push back', it needs to be present so that the designer can lay hands on it. The resistance exhibited by the material is understood as being literal and it presents itself as a productive limitation in comparison with the wider range of possibilities offered by virtual design media. While this emphasis on unrestricted access to materials explains why adaptations of materialist thinking in architecture tend to be framed by phenomenological concerns and notions of craft or tectonics, it runs counter to an understanding of architecture as a discipline that is dependent on representation. As Latour and Yaneva (2008, 83) argued, materialist thinking can in fact be framed as a problem for architectural representation:

> If there is an injustice in 'materializing' human embodied experience, there is an even greater injustice in reducing matter to what can be drawn. Matter is not 'in' Euclidian space for the excellent reason that Euclidian space is our own way of accessing objects (of knowing and manipulating them) and making them move without transformation (that is, maintaining a certain number of characteristics); it is definitely not the way material entities (wood, steel, space, time, paint, marble, etc.) have to transform themselves to remain extant.

The problem with drawings, they reasoned, is not that they are 'objective' while lived experience is 'subjective'. The problem lies in the assumption that the

conventional reduction of things and materials into drawn form is a good and neutral way of describing a material entity. It is tempting to consider simulation and scanning in the context of such thinking, as apt responses to Latour's and Yaneva's prompt, since both techniques capture material properties in a temporally dependent mode of representation, whether this entails manipulating graphical entities imbued with physical properties in real-time or viewing a model that constitutes a snapshot at a particular moment in time of an extant object or piece of material. However, the point is not that reduction can be avoided altogether. In fact, as Latour and Yaneva highlight, the reduction that takes place by merely transferring an entity into a Euclidian space is substantial. Rather, the merit of these techniques is that they grant the architect access to registers of the world that normally elude architectural representation, and in so doing they 'reveal' and lend agency to aspects and traces of human and material life that would otherwise have gone unaccounted for.

The reduction of material agencies that takes place through representation can be productively related to philosopher Andrew Pickering's (1995) concepts of "the mangle of practice" and "the dance of agency". Scientists, Pickering argued, are human agents that operate in a field of material agency which they continuously try to capture with machines. The "mangle" refers to the continuous tuning that occurs between human, machinic, and material agencies in such scientific practice. The tuning unfolds in a "dance of agency": a process of resistance and accommodation in which humans adopt a shifting role, sometimes as passive monitors of a machine, sometimes as active modellers of reality by modifying a machine or a hypothesis (Pickering 1995, 21-22). An element of discovery and even surprise is integral to this process as that which is captured and observed does not first present itself to the scientist as a 'fact'. Using formulations from actor-network theory, Pickering ultimately suggests that the distinctions between human, machine, and material are dissolved in favour of a field of agencies.

Two adaptations of this thinking towards the field of architecture have been influential in developing a position on the agencies of simulation and scanning in this thesis. In what she refers to as an "ethnographic glance at design", Yaneva (2009a, 14) studied the extensive use of blue foam (Styrofoam) models in early phases of conception at the Office for Metropolitan Architecture (OMA). At OMA, design is typically developed by shaping blocks of foam with a hotwire cutter, a technique that comes with a solid-void logic in which a mass is subtracted. The specifics of the technique, of what Yaneva referred to as the "dance" between designer, cutter, and foam that happens in the moment, continually constrains as well as surprises the designer, whose "thought springs out of the object more

immediately", something that contradicts a conventional view of design as a transfer of ideas onto matter (51-63). Architectural design, Yaneva concluded, cannot be reduced "to an abstract concept of creation or construction", instead it unfolds in the process of making, in "collective rituals, techniques, habits and skills ingrained by training and daily repetition, in reuse of materials and recycling of historical knowledge and foam chunks" (14).

The emphasis on material agency in the "dance" that both Pickering and Yaneva referred to can be understood in opposition to the use of virtual media for architectural representation. Pickering (1995, 6) described how the world is continuously doing "things that bear upon us not as observation statements upon disembodied intellects but as forces upon material beings", and Yaneva (2009a, 57) stressed the significance of the resistance inherent in the physical act of making models. More abstract means of representation, it seems, come burdened by baggage that make them unlikely allies in discussions of material agency. Drawings and virtual models tend to establish a distance between subject and object through orthographic projection and Euclidian space, and they disembody physical entities through notations and diagrams.

In some interpretations, the numerical representation of the world that digital design generally relies on can further the division between drawing and material agency. Following Pickering, Jonathan Hale (2012, 521-25) has described transfers between representation and material in terms of "dematerialisation" and "rematerialisation". Writing towards the end of the digital turn, Hale critically interrogated the digitisation of the process of designing and constructing buildings that had taken place. The dematerialisation, or "coding", of material entities that occurs in transfers from physical materials to digital design media risks reducing material constraints to the point where the "dance of agency" is avoided altogether, something that in turn affects the designed outcome negatively when representations are "decoded" into material form. The disembodiment inherent in digital design media allows for easier manipulation without material constraints, but it also begs the question of "how much of the world is trapped or lost in these passages through the digital bottleneck?" (Hale 2012, 523). For Hale, this sense of loss proceeds from a decouple he perceives between the participation of the hand and the body in actions of digital design and the phenomenal quality of the physical material that digital design acts upon. Although optimistic with regards to the greater integration with the material world promised by techniques such as fabrication and environmental simulation, he remains hesitant to endorse a fully mediated materiality.

Models defined through simulation and scanning arguably allow some of the 'dance' of material agency to continue in the virtual realm by lessening the dematerialisation that typically occurs in the transfer from material to representation. By allowing a different and extended spectrum of visual and physical properties of a chunk of material to enter the virtual realm they make some of the agency of the chunk accessible to the designer in absentia. This mediation of material agency is one aspect that gives virtual models defined through scanning or simulation a particular agency as mediums of representation and design.

The material agency captured in a virtual model through simulation or scanning may easily be decoded into physical form through fabrication. But as a medium, such a virtual model remains highly codified. Apart from mechanical movements of the mouse when viewing and manipulating it, its appeal to the material world is limited to visual effects on a screen. Rather than bemoaning this fact or anticipating a future in which the virtual experience of materials might address all senses and become fully immersive, the projects that have constructed discourse in this thesis acknowledge the agency that rests with a visual and therefore conceptually oriented understanding of material agency. The sensations that may arise from watching a physics simulation unfold or from being immersed in the rich textures of a scanned scene suggests that purely visual stimuli might, in fact, give rise to more visceral insights. As one cultural critic's account of the current internet phenomenon ASMR (autonomous sensory meridian response) made clear, visual content such as artist Andreas Wannerstedt's digital animations, based on real-world physics, can trigger a "satisfying" physical "tingle" in a viewing subject even though they occur exclusively onscreen (Watson 2021). Linking ASMR to architectural representation, Mark Morris (2018, 55) has recently remarked that unlike synaesthesia, ASMR "requires more than just a given stimulant to induce a head- or spine-tingling response; it involves a psychological stance – paying attention" – to a drawing, or the making of a drawing, for example. Such remarks indicate that the visual manifestation of material agency through simulation or scanning may expand architecture's repertoire of representation by introducing new modes of perception.

Representation and visibility

It is important to remember that the coding of information is an intrinsic faculty, not just of digitisation, but of architecture as a discipline. Representations such as drawings rely on graphic reduction, symbols, and projection that in and of themselves establish a distance between the designer and the world. In the context

of architectural representation, material agency must thus be understood as coded and mediated, rather than direct or tectonic. When Louis Kahn in 1971 famously told his students to ask their materials for advice, he appealed to their material agency from a tectonic point of view. In Kahn's story, an architect engages a brick in a conversation (Kahn 2003):

> You say to brick, 'What do you want, brick?' And brick says to you, 'I like an arch.' And if you say to brick, 'Look, arches are expensive, and I can use a concrete lintel over you. What do you think of that, brick?' Brick says: 'I like an arch.'

The purpose of such a conversation, according to Kahn, was to give the material, the brick, "presence" through the design of appropriate tectonic articulation (Kahn 2003). But the conversation is in addition predicated on another kind of simultaneous presence: that of the architect and of the brick as a physical entity, a situation in which representation is bypassed.

The idea that means of representation hold agency in the design process by conditioning such a conversation is implied in theories of representation in the architectural discipline. Robin Evans ([1989] 1997, 199) once framed this in terms of "visibility":

> Architectural drawing affects what might be called the architect's field of visibility. It makes possible to see some things more clearly by suppressing other things: something gained, something lost.

This play between making visible and supressing is fundamentally what gives drawing its 'agency'. A drawing "is not a neutral vehicle transporting conceptions into objects, but a medium that carries and distributes information in a particular mode" (Evans [1989] 1997, 199). Although Evans asserted that drawings have a "strong influence" on a designer, he was hesitant to attribute "instrumental effects" to them, as drawings must be understood through a set of related practices (200). Like Allen after him, Evans was ultimately prone to assign drawings power based on the gap that they establish to material reality – on the idea that they remain abstract and distinct from what they represent.

Such disciplinary legacies of 'abstract notations' may, as implied in Chapter 3, seem to be at odds with the realism of practices that rely on simulating and scanning. But the gap that a drawing establishes to reality is not just dependent on its often-reduced language of lines. As Evans ([1989] 1997) pointed out, the projective nature of orthographic drawings means that they always provide a

partial view of their subject, as the representation of the entirety of the exterior or an interior of a building is spliced across several facades or sections. Spinning, panning, and zooming in a virtual three-dimensional model through a graphic interface tends to provide a different and more comprehensive view of an object of design, without sacrificing the powers of orthographic projection. This tendency towards more all-encompassing representation is developed and furthered by practices of simulating and scanning, that both tend to construct 'complete' objects or worlds. The notion of a world, consisting of objects that interact with a surrounding environment over time, is implied in the use of simulation. Scanning, whether directed towards an object or environment, reconstructs not just architectural surfaces, but also the impact and traces of the surrounding world left on those surfaces post construction. Facing such realism and completeness of representation, the question of agency, to follow up Evans' prompt on 'visibility', becomes: What, in these modes of representation, is supressed or downplayed?

One aspect to interrogate might be resolution. Practices that rely on simulating and scanning are conditioned by resolution in ways that are distinct from analogue as well as digital drawing that rely on lines or curves that connect or pass-through points in a coordinate system. This reliance on vector geometry is what makes a typical drawing or virtual model 'idealised': its appearance is independent of scale or zoom. In contrast, models defined through simulating and scanning have a 'materiality', just as raster images composed of pixels do. Point clouds, particle systems, and meshes are dependent on resolution and sampling. Zooming in will inevitably reveal that what appear to be continuous surfaces are in fact constructed from discrete building blocks such as voxels or planar faces and edges. And as William Mitchell (1990) has suggested, this, in turn, affects their 'workability', the kinds of operations and transformations that they afford as a medium. Differences become apparent if one considers the "line worlds" and "surface worlds" of regular vector models next to the "point worlds" of raster images and point clouds (Mitchell 1990). A vector model is typically constructed from geometric primitives that can be subjected to a vast number of geometric transformations through manipulation of the points that lock it into position, such as the corner points of a cube, or the centre point and radius of a sphere. A point cloud, however, like a raster image, is unstructured and often composed of millions of points that do not directly correlate to the delimitations of the objects that they depict. The boundary, edge, or line that architectural drawing takes for granted as the separator of one object, element, or surface from another dissolves as it becomes dependent on a discrete number of points. And just like a raster image, an object described

through a point cloud can be sampled, filtered, and segmented, rather than subjected to typical geometric transformations.

Another aspect of the notion of 'visibility' worth considering in relation to agencies of simulating and scanning has to do with what Evans (1989, 29) referred to as the construction of "after-effect" in architectural representation. Having studied Bertrand's *Shadows Cast by a Tuscan Capital* (1817; Figure 4.1), a combined plan and elevation drawing depicting a detail of a column, executed with outlines in black ink and grey washed shadows, Evans noted that while some earlier architectural drawings had featured shadows, these shadows had been drawn through human observation and intuitive sketching. Bertrand's drawing, in contrast, featured shadows that had been constructed through descriptive geometry, as evidenced in parallel lines indicating rays of light that were mapped from the plan to the elevation. The effects of this pioneering use of 'automatic' shadow projection, or sciagraphy, were addressed by Evans (1989, 29) as follows:

> It might be argued that the play of sunlight on stone is not materially affected by the way we draw it. Unlike the design of the classical orders themselves, it is merely a simulation of what might happen after something is built. This, however, is the reason these drawings are so interesting. The after-effect is more vividly portrayed than the shape of the capital itself.

Two aspects of Evans' remarkable study are of relevance here. The first thing to note is that the invention of the process of shadow projection through descriptive geometry marks a shift of agency, away from human perception towards a drawing instrument. With the formalisation of systems of orthogonal projection in the late 1700s by Gaspard Monge and perspectival projection in the early 1800s by Victor Poncelet, a given geometry could be represented from any angle, independently of the position of an actual observer (Evans 1989, 28-29; see also Perez-Gomez 1982, 3-4). The drawing was no longer conceptualised as an intermediate filter between a subject and the world. Rather, as Latour (1986, 25-26) has suggested, it became a constructed and internalised world in which objects could be viewed, moved, or transformed without the need of manual survey. With these descriptive powers, representation in architectural design in a certain sense became 'idealised' and 'abstract' as it lost a link to material reality previously provided through human observation. Scanning has actualised this link between (now machine-based) observation and representation through direct transfer of some aspects of physical objects in real space into the Euclidian space of today's modelling software interfaces.

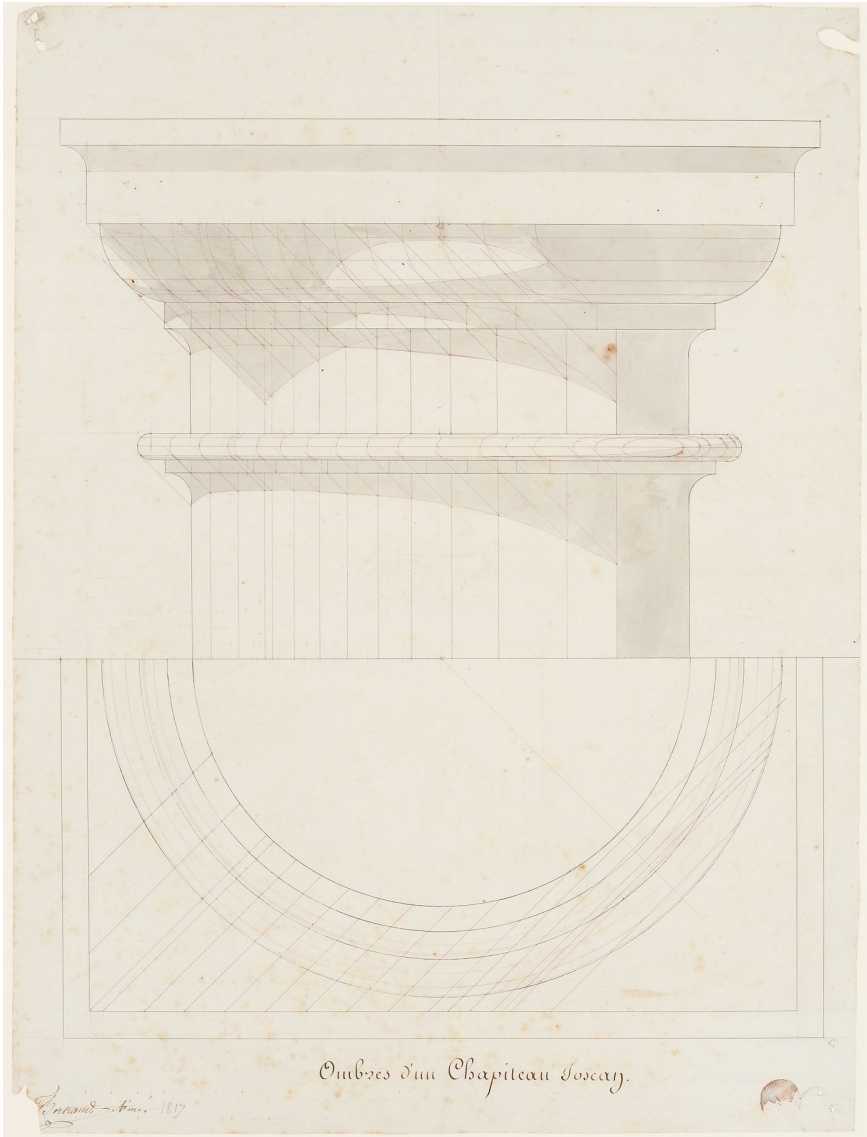


Figure 4.1. F. Ainé Bertrand, *Shadows Cast by a Tuscan Capital*, 1817. Pen and black and red inks with grey watercolour wash over graphite, 58.6 x 43.8 cm. Canadian Centre for Architecture.

The second thing to note is that the shadows, drawn with mechanical precision by Bertrand, may be fleeting and impermanent in comparison with the stable geometries of the capital, but they still end up visually dissolving the structural

form of the capital. This, in Evans' (1989, 30) phrasing, is the "revenge" of the shadow on the column. To address after-effects of architectural representation is to anticipate or document events that will occur or have occurred after what has been designed has been released into the world. In more mundane cases, such as structural calculations, this anticipation is pursued to assure that the architecture remains unimpacted by the forces of the surrounding world after construction (and thus does not crumble). Representing after-effects is often done in the service of eliminating them, to make sure that what is designed stays the way it was designed. The agencies of simulating and scanning lie in the ability to render such after-effects, from deformation to the interplay of light and materiality, visible in the design process, sometimes to the extent that they visually overpower more abstract and geometrical qualities belonging to the underlying architectural object. By capturing the ways in which matter responds to or soaks up its environment, they push the idealised and abstract towards a simulated experience, thereby recasting the architectural imagination.

Technics and medium

A discussion on the agencies of means of representation in the design process must in part revolve around the relationship between architect and drawing instrument. As the previous sections have argued, such relationships may centre on human perception, in which a means of representation can be understood as a reduction of an otherwise unimpeded access to the world through the senses. Alternatively, they can centre on technical processes of capturing objects that to a certain extent remain unaffected by human perception, in which a means of representation reveals or constructs a world with relative independence from human observation. The relationship between subject and instrument may, as previous chapters have made clear, be interrogated from the point of view of direction and influence: representations allow us to act in the world, but they also act on us by shaping the ways in which we understand the world. These concerns are addressed in new materialism and actor-network theory that challenge the impulse to place humans at the centre of the discussion by suggesting that agency is distributed across networks of humans as well as technological objects.

Such thinking resonates with recent scholarship that examines the relationship between architecture and technology by establishing a 'middle' between user and instrument. In her introduction to the recent *Design Technics* anthology, co-edited with John May, Zeynep Çelik Alexander (2020a, x) articulates an alternative position that nuances the human-instrument dichotomy:

> […] it quickly became clear that analysing artifacts used by designers (from the T-square and the French curve to the various kinds of software used today) would be a strategy that would as much duplicate as invert historical sciences' tendency to rest all agency with subjects – in the case of architectural history, for example, with individual designers. Prioritizing the subject or the object conformed too readily to a master-and-slave dialectic familiar from Enlightenment discourses: if humans were the master, instruments were nothing but neutral, passive tools, applying human intentions to a compliant nature. Similarly, if instruments were to be seen as the master, they acquired godlike powers. It was in an attempt to avoid such intractable antinomies that the scholars who contributed to this volume decided to focus on the middle between the object and the subject and between the instrument and its user.

The word 'technics' shifts the attention, from material or representation, towards a more inclusive and multifaceted understanding of design and technology. "Technics", similar to the word "Technik" in German, Alexander (2020a, xii) explains, connotes both "technology", as in artefact, and "technique", as in procedure, thus mending a split between the meaning of the two words. Examining design through the lens of technics implies examining it as a product of "gerunds" carried out in daily practice, such as rendering, modelling, and scanning (xi). These seemingly mundane operations are not just technological, Alexander argues. They are ontologically established through concrete habits of use as well as through developmental histories of often anonymous technologies. 'Scanning', for example, should thus be understood as an operation that has been incrementally defined and modified over time through an interplay between the technical development of instruments and the reading and conceptualisation of form in the arts and architecture (Alexander 2020b). What first appear as minor technicalities, such as differences in the mechanics of how two early scanners, or "reading machines", recognised letters, can in fact be associated with the development of positions in important art historical debates that unfolded in parallel, such as those surrounding Gestalt theory (Alexander 2020b).

The notion of 'technics', as well as the reciprocal relationship between technology and practice suggested through the gerunds, partially draws from media theorist Bernhard Siegert's (2015a) notion of "cultural technique". To understand design as a cultural technique, Siegert (2015b, 121) writes, differs from understanding it as an unfettered act of creation by instead analysing it in relation to "discursive, technical, and institutional practices". This suggests that the ways

in which we read, understand, and conceptualise architecture are produced as much in practices of representation as they are in sensuous apprehension: "space does not exist independently of cultural techniques for surveying and administering space" (Siegert 2007, 30; quoted in Alexander 2020a, x). Similar conclusions have been reached in a broad stream of contemporary analysis in architectural history and theory that posits that architecture cannot be understood separately from the forms of mediation – newspapers, public debate, trade magazines, advertising photography – which surround it (e.g., Arrhenius 2012; Hvattum and Hultzsch 2018). Scanning is a perfect example of such mutual relationships between representation and conceptualisation. A model obtained with photogrammetric scanning performs in a process of backward projection: it turns light that emanates from objects into information. But even when used towards non-speculative ends, it shapes our understanding of space. It constructs space as much as it documents it. Evans (1989, 20) once asked: "Yet is there not, in fact, a constant interplay between the passive portrayal and the active remodelling of reality?" Yes, practitioners of scanning would answer.

The recent discourse surrounding the notion of technics in architecture suggests two facets of agency in relation to simulation and scanning as contemporary mediums of representation. Design unfolds under influence of both the technicalities that underpin simulating and scanning as operations and the histories and discourse that are constructed around them. Opening up such agencies to the gaze can uncover hidden technological agencies as well as provide for a richer and more speculative practice.

To consider the agencies of simulating and scanning from the point of view of technics does not necessarily imply an engagement with these technologies as mediums of design. Such an engagement carries some implications that might further be framed through the changing notions of 'medium' in the arts. In the wake of the digital turn and the proliferation of technologies that followed, some scholars and practitioners have begun to address the issue of medium from an architectural point of view (e.g., Lavin 2011; Meredith 2013; Bair et al. 2018). As Rosalind Krauss (1999, 5) once stated, an interpretation of 'medium' invokes "the relationship between a technical (or material) support and the conventions with which a particular genre operates or articulates or works on that support". Criticising Clement Greenberg's mid-century definition of medium as material support, such as paint and canvas, Krauss (1999; 2011) argued that the arts had entered a "post-medium condition" in which artists invent new mediums by discovering the conventions of new technical supports, or 'apparatuses'. Mediums used by artists, such as film, are characterised by an apparatus (i.e., a combination

of celluloid, camera, projector, etc.), as well as by concepts and "rules" of use that are defined over time (Krauss 1999, 26). A new medium thus springs from the specifics of a technical support, as well as from a "memory" of pre-existing mediums (Krauss 2011). In this sense, simulation and scanning can be viewed as new mediums of architectural design rather than as neutral means of analysis or verification. Following Krauss, this involves exploring how they modify existing conventions of architectural representation in relation to a design practice. The exploration evolves from histories of other mediums of representation, as well as from finding new logics of use.

Towards a politics of representation

An unexpected result of actor-network theory's desire to break down assumptions about scientific discovery or creation in design, by pointing out the extent to which those activities happen in an environment in which all sorts of actors and actants effect its presuppositions and conclusions, was to create a view that lifted away from human actors something of their political responsibility. In suggesting that human agency was not central to the shaping of certain kinds of endeavour, the conclusion might be drawn that the political dimension of that agency was of less importance. Focussing on the space between the instrument and human agent avoids some of this risk as the political responsibility of human agency cannot be shed. If nothing else, all instruments are themselves designed and thus result from processes in which human and material agencies interact. What they play up or down is as much defined by what their designers have prioritised, as by the nature of the materials of which they are constructed.

An analysis of the agencies of current means of representation should stay wary of such problems of political responsibility. Agency, it has been argued by the fiercest critics of the concept of material agency, is a property that is inseparable from intentionality. Scholar and environmental activist Andreas Malm ([2018] 2020, 92-97), whose thinking has recently laid the foundation for new imaginaries in architecture (e.g., Iturbe 2019), distinguishes between a human agent that acts intentionally in a situation and a mindless object that merely makes a difference in the same situation, without any possibility of acting according to an agenda. The climate crisis, Malm argues, might be caused by both humans and coal as "difference-makers", but we cannot assign agency, that is intentionality, to the coal, and the responsibility for the crisis must therefore be understood as being exclusively human. Such critique, although somewhat commonsensical, evidences a dilemma that comes into focus as soon as material agency is discussed in connection with a politically charged situation. For what happens if we begin to

assign responsibility to non-human entities? Yet, directing focus to a network of human and non-human agencies does suggest the possibility that human agency, and thus intention, might be inscribed in an instrument through its design, and that this instrument in turn influences further human action. This view is implied in an analysis of design that draws from actor-network theory by Yaneva (2009b, 277):

> [Artefacts] can mould the decisions we make, influence the effects of our actions and change the way we move through the world. By so doing, they play an important role in mediating human relationships, even prescribing morality, ethics and politics.

Thinking of instruments of representation as mediators between a designer and the world is affiliated with Evans' conceptualisation of representation as a selective field of visibility. As mediums of design, drawings and models may productively constrain the designer in the act of creation, but their agency extends beyond such immediacies. As mediators, they modify the way one relates to the world, a point memorably made by John Berger (1972, 18) in *Ways of Seeing* with regards to how "the invention of the camera changed the way men saw". To see through the mediation of representation is to reveal and make sense of the world in ways that condition how one acts in it, a point that has been raised repeatedly in recent years. Dalibor Vesely ([2004] 2006, 18) has at length argued that representation can grant access to "the depths and plenitudes" of an otherwise "inaccessible" material reality, and Orit Halpern (2014, 23) has stated that while "vision" connotes the cognitive apparatus of seeing, it "operates metaphorically as a term organising how we know about and represent the world; a metaphor for knowledge, and for the command over the world beyond or outside subjective experience".

'Visibility', 'seeing', and 'vision' constitute notions against which some of the political agencies of simulation, and in particular scanning, can be framed. If representing an entity, phenomenon, or activity, equals assigning importance to it, knowing about it, or even commanding it, then the question of what is included or excluded in architectural representations acquires political significance. The ability of simulation and scanning to incorporate registers of objects and environments that elude conventional modes of architectural representation should be seen in this light. To represent an entity or environment through scanning captures traces of material and social events that have left imprints on its surfaces. Following the philosophy of Siegfried Kracauer ([1927] 1995), artist Hito Steyerl (2017, 201) has argued that this "superficiality" and "unconscious nature" in the representation of surfaces through scanning may be an asset. A direct

inversion of the traditional view that that in the shallowness of the surface lies a possibility of deception as 'appearances can be deceiving', Steyerl claims that the scanned surface "folds in subjects, objects, and vectors of motion, affect, and action, thus removing the artificial epistemological separation between them" (201). As Steyerl points out, there are always aspects that escape even the meticulous gaze of the scanning process, such as "blind spots" (197) that remain obscured from the view of a scanner or camera or alternatively features that remain indistinct due to limits in resolution. The political significance of such 'blind spots' has been interrogated by architect Eyal Weizman (2018) through recent work carried out with the research practice *Forensic Architecture*. Yet, the presence of such exceptions these practitioners regard as interpretive lacunae to be exploited, rather than inherently disabling. The reach and resolution of imaging and scanning technologies used in architecture and urban design, such as satellite imagery and map applications, establish a threshold at which humans and objects can be identified and tracked, for good or for ill.

Framing the political agencies of simulation and scanning through these notions of visibility consolidates two aspects of the word 'representation' that are rarely addressed in tandem in architectural discourse. On one hand, following authors such as Evans, Perez-Gomez and Pelletier, and Allen, representation can be thought of as a disciplinary problem of translation, projection, and codification that pertains to drawing and virtual modelling. On the other hand, representation in a societal context connotes something that shapes a wider audience's understanding of an issue of political significance, such as identity, gender, and ethnicity. As Hanna Fenichel Pitkin ([1967] 1972, 241) stated in a classic study of political representation, to represent means "to make present or manifest or to present again", which in a societal context equals to render voices and opinions of citizens visible and politically effective. The potentiality of a technique such as scanning lies in the collapsing of these two interpretations of 'representation': in its promise of lending agency to otherwise neglected materials and events by representing them in ways that make them accessible to a wider audience, thereby making them effective in the world.

This reorientation of architectural representation considering practices of scanning and simulation emphasises the role of such representations as intermediaries. They can 'speak' on behalf of specific chunks of materials or building elements because they can appropriately 'portray' certain characteristics that belong to them. Latour (2005) has addressed this dynamic between speaking on behalf of and of portraying "things" and "issues" in the context of political philosophy. To represent an issue is both to assemble people that represent others

and to use science to present, or rather, represent the issue at stake to the assembly. "Realism" in representation, Latour (2005, 6) reasoned, is achieved when "the same degree of attention is be given to the two aspects of what it is to represent an issue". Notably, such realism does not imply that representation can be bypassed, nor that representation can be "total, complete, and transparent" (28). In fact, the opposite is true according to Latour: There simply is "no representation without re-presentation" (16). A realist acknowledges that such all-encompassing (political) representation can never be faithful as it cannot absorb the diversity of a globalized society. This is an important reminder to practitioners of scanning and simulation. The merit of these techniques is not their sense of direct and objective disclosure, but their ability to represent an expanded and varied set of elements and chunks of material.

If representation conditions 'seeing' and how we relate to and act in the world, then it might also influence how we construct ourselves as subjects. This is what Jonathan Crary argued in his often-cited *Techniques of the Observer*, a study of the role of technological inventions such as the camera obscura in the shaping of the modern subject in the 19th century. Although mainly concerned with this distant period, Crary (1990, 1-2) contextualised his analysis in relation to how then emerging computer techniques such as CAD created "fabricated visual 'spaces'" that relocate "vision to a plane severed from a human observer", potentially contributing to a recasting of a contemporary subject. This account foreshadows some of the impact of simulation and scanning and establishes links to critical discourse that examines the use of technology in architectural production today. A subject is known in the tech industry as a 'user' and instruments and software are typically created with a particular bias towards a certain kind of user. Such reasoning begs the question of what kind of subject, user, or indeed architectural practice, that 'seeing' through simulation or scanning can produce? In other words, if these technologies modify 'seeing', can they also modify the persona of the architect?

To begin to address this question, one can revisit the discourse on "translation" in architectural representation, laid out by Evans ([1986] 1997), Perez-Gomez and Pelletier (1997), and Allen ([2000] 2009b) during the first half of the digital turn. By examining the translation that happens between two-dimensional orthographic drawings and three-dimensional form, or indeed between such drawings and building, these authors ultimately emphasised drawing as an intellectual pursuit. The abstraction that pertains to line drawing sets up a productive tension between material reality and representation that works as an intellectual lubricant, as something that appeals to the mind to fill in the notational

gap that it establishes. This might be one of the reasons why these authors tended to assign increasing disciplinary weight to modes of representation that establish a wide gap between drawing and building, such as Allen's ([2000] 2009b) conceptualisation of drawings as reduced "notations" and "diagrams". As I argue in the third appended publication (Norell 2021), such biases were already present in the emphasis on underlying geometric syntax over 'superficial' appearance in the influential mid-century work of Colin Rowe (1947), pursued under the banner of 'analytic formalism'. Adopting Rowe's habit of formal analysis, Peter Eisenman (2016), in a recent brief for a course at Yale School of Architecture titled "Theories of Authority: Seeing as an Architect," stated that "an architect must learn to see beyond the facts of perception. An architect must see as an expert, as different from the average user." The proportional analysis employed by Rowe and later by Eisenman, involves the enticement of uncovering a hidden agenda through graphic reduction, thereby setting up an expert way of reading architecture that reinforces the authority of the architect. This is but one example of a legacy of architects increasing their authority through use of visual representation and its mechanisms of drawing and projection as a rhetorical tool aimed at an expert audience (Anstey 2007, 20-21).

Implicit in Rowe's and Eisenman's discourse on seeing in architecture is the construction of a subject that diligently interprets architecture's hidden geometrical layers through "close reading" (Eisenman 2016). This mode of seeing, and, by extension, of architectural conception, relied on a whole set of disciplinary conventions tied to orthographic drawing. It should by now have become clear that part of the political charge of simulation and of scanning as means of representation lie in their ability to capture other, more obvious, and surface-oriented qualities, such as the ageing of materials or traces of events that have occurred post-occupancy and display those qualities in ways that make them intuitively perceivable. They intensify and dislodge the ability of the human gaze to 'scan' material reality, with all its erratic peculiarities, rather than searching for hidden disciplinary codes. In so doing, they may widen architecture's audiences by subverting some of the traditional authority of the architect and hold the promise of setting up alternative ways of reading and conceiving architecture that may in turn be a step towards reconstructing the persona of the architect.

5 Conclusions

In exploring the relationship between design, technology, and theory, this thesis has selectively charted developments in the field of digital design since the digital turn in architecture in the early 2010s. It has traced how the field since its inception has relied on an ambiguous interdependence of technology and discourse, as well as how attempts to reinvigorate the field in the wake of the digital turn have implicitly relied on links to materialist and post-digital thinking. Tying actor-network theory and new materialism to architectural representation and materialisation, the thesis has attempted to go beyond a general reappraisal of architecture as a material practice. By similarly drawing links to post-digital theory, it has explored alternative and non-positivist narratives for the 'digital' in architecture that do not rely on a rhetoric of innovation and technological progress. This has implications for the relationship between representation and material reality in projective design work as well as in theory building. Thus, the thesis' (modest) aim is to change both theory and design practice in architecture, suggesting that matters of representation and materialisation in discourse and techniques of representation and materialisation cannot really be separated.

Developments in the field since the digital turn have in addition been framed through the specifics of transfers between architectural representation and material, or the other way around. As technology during the 1990s and 2000s increasingly automated geometrical projection and materialisation through digital design and fabrication, a string of authors and publications highlighted that such 'translations' are neither neutral nor transparent and that architectural design is always underwritten by the bias of tools of representation and materialisation. As some of these authors argued, the bias is present even when information is transferred backward rather than forward, as in for example a study of an existing building. By centring on projects that explore such transfers rather than treating them as mere expediencies, the thesis contributes to a critical understanding the role of technologies and techniques in the conception and production of architecture. By combining transfers in either direction between material and representation, the thesis further contributes to a substantial shift in research focus for digital design: Rather than using modelling and fabrication processes to overcome the limitations of a standardised stock of materials such as sheets, lumber, or bricks, the work included combines simulation or scanning with

fabrication in order to integrate and explore the unique qualities of used and nonstandard building elements and materials into a digital process.

In pursuing design and theory in parallel, the methods used in the thesis have been contextualised in relation to the interdisciplinary field of design driven research, as well as in relation to disciplinary debates surrounding the relationship between design practice and theory. This approach highlights how artefacts can fulfil several purposes depending on their research context: As speculations that construct alternative realities, as 'archetypes' that contribute to the discipline by embodying new concepts, and as generators of alternative processes and workflows that can be documented and disseminated. Similarly, an approach with regards to the relationship between design and disciplinary discourse has been outlined, in which the research practice couples core architectural concerns with materials or theories located at its fringe. Considered together, these approaches can support an engaged, thoughtful, and 'caring' relationship between design research and architecture as well as between the practices of design and of theory.

The design projects *Erratic* and *Completions* embody this outlook and have made disciplinary concepts and techniques developed in the thesis visible in a larger landscape of design culture and research. The production of artefacts has been central to these projects, and each of them have provided opportunities to engage with simulation and scanning as mediums of representation. *Erratic* contributes to a reconceptualization of design in which geometrical control in fabrication processes is ceded in favour of material agency, and where such agencies can be channelled into a digital design process through physics simulation. Similarly, *Completions* makes a case for how reuse and repair in architecture can be reframed as a problem of representation, and where photogrammetric scanning is used to 'see' and integrate atypical aspects of extant material into a digital workflow.

The thesis has argued that the realistic mediation of building elements and chunks of materials that simulation and scanning entails is ill-suited to existing notions of design as being enacted through 'notations', as notations rest on principles of abstraction. This mediation introduces the uncertainty and temporality of the material world into representations and stands in contrast to a widespread view of representation as something idealised, static, or even antiquated, a view that has been popularised through notions such as 'digital craft'. For simulation practices, the specifics of the mediation suggest a new epistemology of representation, situated in-between concept and direct, material intervention. For scanning practices, the specifics of the mediation amount to a different way of 'seeing' architecture that is detached from human preconceptions. Both practices

can produce 'other' materialities that are shaped by processes of mediation and transfer and that differ from both notions of authentic materiality and from more recent conceptualisations of digitally informed materiality.

These accounts of the design works, point to a larger issue of the agency of means of representation. By drawing from the notion of 'material agency' the thesis has argued that simulation and scanning diminish the dematerialisation that typically occurs in the transfer from material reality to digital representation, something that to a certain extent allows a designer to access such material agencies in absentia. In architectural discourse on representation, the idea that representation 'makes visible' by channelling some registers of an object into a drawing while subverting others, also allows certain agencies to be explored remotely. The agencies of simulation and of scanning, it has been argued, can be approached via this characteristic of disciplinary discourse in architecture and make untypical registers of our material world intuitively accessible and manipulable. Taking cues from recent discourse surrounding the 'technics' of the instruments of representation, the thesis suggests that design is conditioned by the technicalities of such instruments, as well as by the histories and narratives that we construct around them.

Finally, outside these rather disciplinary themes, this line of thinking begins to encounter what might be called a politics of representation. Broadly speaking, representation is a way to know about the world and to operate in it. What is included or excluded in representations has political implications. The architectural understanding of the term as a way to translate, project, and codify information, cannot escape the term's political implications as a way to render voices of citizens visible and effective. Conversely, the thesis has argued that the wider potentiality of simulation and scanning as means of representation lie in their ability to re-present, or portray, qualities that belong to building elements or chunks of material, thereby making them effective in the world – in one way enfranchising such qualities. As in the ideal of just political representation, which aims to allow the marginalised, neglected or overlooked to impact on political processes, practices of simulation and scanning challenge existing material hierarchies in design perception, allowing new kinds of composition. They do so through principles of realism and resemblance rather than through the abstraction of typical drawings. Jettisoning abstraction might in turn subvert some of the traditional intellectual authority of the architect as an expert who in their mind can bridge the wide gap between representation and material reality. This might ultimately be a step towards widening architecture's audiences as well as reconstructing the persona of the architect.

The coupling of design oriented and analytical perspectives on technology offered by the thesis carries multiple opportunities for further research. While such opportunities may appear to be rooted in either design or theory building, it remains crucial to commit to this double perspective. The varied contexts in which the publications included in the thesis have been presented, ranging from technology to theory, reflects this. In what follows, three trajectories for further research are suggested.

First, the thesis implies that sustainable design and building practice can be reframed as a problem of representation. Today, the reuse of extant material still tends to be exceptional rather than systemic, despite the abundance of such material and despite recent policy making (Norell, Rodhe, and Hedlund 2021). A major challenge in handling used or wasted elements or materials is integrating them into a digital workflow through means of survey. In targeting this issue through use of scanning and fabrication, the thesis shows how such workflows can be set up, suggesting alternative models for practice. Melding approaches from digitally enabled reuse and experimental preservation, this model is based on the act of repairing, adjusting, and assembling as well as of establishing a formal and material vocabulary that can handle patina, fractures, breakage, and other imperfections. Further research is however required to explore how principles of reuse outlined in the thesis can be applied in more systemic ways. Creating larger assemblies of used elements and materials presents practical and representational challenges, including the establishment of processes for assessing structural capacities of such elements, logistics for storage and transport, and the development of more robust workflows for scanning and fabrication that could support the development of extensive virtual catalogues of used elements and materials that designers could interact with remotely.

Second, beyond establishing an analytical framework for discussing the agencies of simulation and scanning as means of representation, the thesis suggests that other agencies can be similarly uncovered through scholarship focussing on the link between practices and means of representation. Such scholarship can build from the technicalities and mathematical underpinnings that are at work behind the interfaces of today's digital design platforms (Norell 2021). Principles that govern routinely applied operations, such as the construction of geometry through basic components or techniques for the rendering of geometry, can in turn shape design practice and theory building. To design increasingly means to be confronted with an assortment of geometrical primitives, with the manipulation of vertices, or with the interactive exploration of forces, as well as with the algorithms that control the illumination of a scene or with the mapping of two-

dimensional texture maps onto three-dimensional geometries. Human bias can be inscribed in such operations that, admittingly or not, tend to be constructed with a particular purpose and user in mind. By linking design practice to scholarship of 'technics', such research can critically uncover the influence that current software and hardware platforms silently exert over design practice, as well as speculatively construct alternative concepts and approaches based on such operations and platforms. These concepts and approaches have the potential to quickly become operative in design practice.

Third, the thesis implies a specific approach to technology within design driven research and scholarship in architecture. Research on technology in architecture tends to be defined in terms of 'building technology': as ways of using technology to manufacture building elements and orchestrate the construction of buildings. While this take on technology in architecture is valid and even urgent, it nevertheless risks losing a connection to concerns that spring from disciplinary as well as interdisciplinary discourses on representation and its agencies. In contrast, the work presented here positions technology as 'architectural technology', as technics, and as technique: as ways of exploring mediums of representation that enable the design process and shape the architectural imagination. And as the thesis has argued, this positioning does not imply a withdrawal from the material realities of the world, since new means of representation increasingly can apprehend material agencies. Rather, it acknowledges that technologies of representation always already constitute ways of making sense of the world and of acting in it.

Lastly, a reflection. The double commitment to design practice and theory building that the thesis relies on is not just a deliberate response to a specific set of issues or research opportunities. It is also something that is inscribed in the rich legacy of combining speculative design work and discourse that surround representation in architecture. Representation in architecture is never solely an expedient means to construction, it is always also a medium of design and of thinking design, and the transfer between representation and material reality, whether it occurs in the mind or through an instrument, whether direct or indirect, will always remain 'a problem' worthy of consideration. This is especially important in times when habitual use tends to make digital technology invisible.

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