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Interface/Ornament: Enabling Engagement Through Digital Design and Fabrication

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Enabling Engagement Through Digital Design and Fabrication

by

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Abstract

Along with a renewed interest in the use of pattern and ornament in architecture, there is a growing body of research into how cognitive processes shape the experience of the built environment and an increasing awareness that embodied experiences of making can deepen the level of critical engagement with concepts related to technology and society. The intersection between the fields of design and production of architectural ornament and the study of the perception and experience of the built environment provides a rich territory for design research and innovation. Digital tools and processes such as robotic fabrication have added a range of new possibilities in terms of precision, dexterity and human/machine collaboration in bringing digital design into physical space. These tools and processes offer the potential to democratize the design and production of the built environment.

Preface

The impetus for this thesis stems from the intersection of my interest in public sculpture, architectural ornament and digital design and fabrication. I first became interested in these subjects while studying sculpture and the history of craft in my undergraduate degree. It was fascinating to learn that the field of ornament has been a source of creative exploration and critical discourse on the intersections between structure, geometry, aesthetics, perception and psychology of space and form. I was particularly drawn to conversations around concepts of mechanical production of art and craft. My curiosity was sparked by what seemed like a very different perspective than the one provided by the traditional art historical canon.

Pursuing a degree in architecture reinforced the potency of these ideas and their continued relevance in the digital age. An interest in technique and craft in relation to architecture led me to deepen my knowledge of digital craft and its applications in physical material processes. The convergence of the digital and material enabled by digital design and fabrication offers a path for designers to participate in the process of making and building. Exploring the evolution of architectural ornament has led me to realize that the built environment communicates in an unwritten language that speaks directly to our senses on multiple perceptual levels. This research represents some of what I have learned from engaging in this conversation.

Acknowledgements

I wish to express my sincere gratitude and appreciation to the many people who have played a role in helping me complete this project. Particularly I want to thank my parents, who have made everything possible for me. I also want to thank my closest friends, Adam, Devan, Sol, Khalid, Neal, my coach, Anderson and my jiu-jitsu family, and the students and instructors in the Faculty of Environmental Design. I would like to thank Del Geist, Patricia Leighton and Taewook Cha for their guidance and mentorship. Lastly I would particularly like to thank the research assistants in the Laboratory for Integrative Design, who have taught me so much, as well as Josh Taron, and Jason Johnson, my supervisor.

Dedication

To my parents. Thanks for always encouraging me to follow my dreams.

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Epigraph

"It is clear that machines will eventually have to make good all the misery they have caused, and atone for the atrocities they have committed... They produce beautiful things and ugly things indiscriminately. But the mighty power of their iron arms will produce beautiful things as soon as they are governed by beauty."

Henry Van De Velde

Säuberung der Kunst, 1894

Chapter One: **INTRODUCTION**

1.1 Ornament as an Interface with Buildings and Cities

Figure 1. Triassic Towers, Del Geist, Calgary, 2017

In April, 2017, "Triassic Towers," designed by Del Geist and built on the Trans-Canada Highway at the new Bowfort interchange was unveiled to Calgarians (figure 1). The four towers, each measuring fifteen meters tall, built from weathering steel tube supporting slabs of stone were to be the first half of a collaborative artwork forming the western gateway to the city. According to the artist, the work is intended to celebrate the natural geology that has shaped the local landscape by elevating Rundle "specimen" stones selected from a local quarry. They are intentionally positioned so that their form and texture can be read and understood even at the speed of a car on a freeway, asking the viewer to consider the speed of modern life next to geologic time scales. Writing about Geist's long-running fascination with geology in his work, Heartney notes: "Because of the vast times involved, human history shrinks into insignificance in comparison to the

rate of geologic change. As a result, geology demands the surrender of our sense of human importance and an acceptance of forces larger than ourselves." [1]

Soon after it's unveiling, media began reporting that the work had provoked condemnation and outrage over the cost, perceived cultural insensitivity and lack of public consultation. On social media, members of the public compared the work to piles driven in at a partially completed construction site, and news articles put images of the work side by side with images of traditional Blackfoot burial platforms. It was suggested that the work, located on land identified as being significant to local indigenous groups, had appropriated culturally sensitive imagery without permission. The artist was inundated with hate mail, and was asked by city council not to speak publicly about the work. The controversy eventually resulted in the cancellation of the proposed second stage of the project and the suspension the entire public art program to allow for consultation on how improve the process for engaging the public in decision-making around public art.[2]

"Triassic Towers" demonstrates some of the challenges involved with designing for the public realm. It also shows how easy it can be to form either positive or negative associations with symbolic or ornamental objects inserted into public spaces. Often, designers want their work to be open to various interpretations. In this case, the artist and the city argued that the work had been misinterpreted and that any cultural references were unintentional.

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[1] (Heartney, 2018, p3)
[2] (Gerson, 2017)

The towers were the latest in a string of contentious public artworks in Calgary, which has a policy of putting 1% of public infrastructure spending towards public art projects. Many cities are struggling with issues around public space and perception. Throughout the western world, controversies have emerged around new public works and various groups have called for the removal of existing works and the renaming of public spaces as a way of addressing historic injustices. When individuals or groups feel alienated by the narratives encoded in the public realm, the ornamentation of public space can reinforce their perception of the underlying forces of prejudice and oppression within societies. There are many examples, both recently and throughout history, of movements who have sought to remove, replace or amend what they perceive as symbols of injustice in the public realm. These examples underline a divide that exists between design intention and viewer's perception, and the potential for readings to shift over time. The increasingly polarized debate over public space raises a number of issues, including the representation of history, the appropriation of iconic or culturally significant symbols and images, and the need to accommodate diverse communities.

Public spaces play an important role in contributing to a sense of identity and enhancing the social integration and sustainability of cities. Their formal qualities, including public sculpture and architectural ornament condition how we experience these spaces. Designers, administrators and the public all have a role to play in the production of urban environments which respond to their broader context and reflect the diversity of our contemporary society. "Triassic Towers" represents one approach to the problem of how to provide a sense of identity to generic urban spaces. Like many large scale public sculpture projects, the artist's proposal was selected by a public art committee through a competition process. The city worked with the artist team to facilitate public

consultation and to address design, fabrication, installation and preservation challenges. This process was followed by a public unveiling of the finished work. The controversy surrounding the project demonstrates the importance of involving the public early in the process and communicating a clear narrative. As cities become more diverse and integrated, perhaps we need to look for new ways of democratizing public space by bringing members the public into the design and planning process so that they can contribute to and take ownership of work that exists in the public realm.

The challenge of how to facilitate diverse, meaningful participation in the planning and design of public spaces can be extremely difficult, and it is impossible to please everyone. It is much easier to criticize a work once it is completed than to get involved in the consultation process. For some, any taxpayer-funded artwork represents a needless waste of public money. Some politicians and commentators recognize that public sculpture in particular can act as a lightning rod that can be exploited in order to capture popular attention and galvanize public opinion.

1.2 Digital Design and Fabrication of Architectural Ornament

This work attempts to connect ideas around the democratization of design and manufacturing with contemporary approaches to architectural ornament. Bringing these topics together raises questions including: how are advances in technology changing how we design, manufacture and experience architectural ornament? What are the implications of these changes for urban environments and the individuals and groups who experience and inhabit them? Research into the relationship between pattern recognition and subjective perception of the built environment provides opportunities for

insight into these questions. Yannick Joye has reviewed a series of studies which suggest that humans are attracted to ambiguous and complex stimuli, and facades, streetscapes and skylines with a degree of complexity have the potential to engage our interest. Joye writes: "As the mind seems innately attuned to natural form, building in fractal-like forms can please and "nourish" the human mind. Although research appears to hint at the positive psychological effects of non-representational fractal patterns, it remains to be established whether fractal architectural patterns can have similar effects."[3] This research, which will be discussed in further detail in chapter 2.5, raises questions about the potential for complex patterns to be used as a way of tuning individual and collective perception of the built environment.

In order to adapt to changes in design and production technologies, designers have had to shift their thinking and shed some of the traditional preconceptions about practice. These changes have a empowered design teams by providing access to new resources and tools, allowing them to connect and work globally. Robots and AI are becoming collaborative tools in the materialization of digital design. Digital Craft, critical making and design-build activities provide opportunities for the democratization of design. By learning through engaging in a hands-on way with these new technologies it is possible to gain a better understanding of the range of possibilities provided by computational design and digital fabrication.

This work hopes to examine how contemporary approaches to the production of architectural ornament at a variety of scales may provide a means of facilitating a greater level of interconnectivity and participation between users and the built environment.

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[3] (Joye, 2011, p. 825)

1.3 Engagement

This thesis attempts to understand how digitally designed and fabricated architectural ornament can engage different user groups. The word "engage" has a range of meanings. These include:

Engage. a: to hold the attention of: Engross; (her work engages her completely). b: to induce to participate (engaged the shy boy in conversation). Additionally: to bind (someone, such as oneself) to do something. To attract and hold by influence or power. To offer (something such as one's life or word) as backing to a cause or aim. To interlock with.[4]

In public art and architecture, "public engagement" is used to describe the process by which members of the public are informed and consulted with prior to the design and development of projects which will have a direct bearing on their lives. Public engagement can sometimes take the form of a presentation of plans and renderings in a community center, or can involve surveys and charrettes, where people are invited to share aspects of communities and what makes them unique so that these descriptions can be incorporated into a design.

This thesis is more interested in alternative approaches to engaging users by providing opportunities to involve them in the design, production and experience of architectural ornament. To this end, the most relevant definitions of the word engage involve attraction, interaction and participation. When we are engaged by something, it attracts

[4] https://www.merriam-webster.com/dictionary/engage

our attention, holds it and induces some form of participation. All of these elements are key aspects of the function and power of ornament. As Antoine Picon has suggested, one of the functions of ornament is communication and the transfer of knowledge.

"Ornament presents us with a kind of mirror. In this mirror, we see ourselves as we believe we are and as we would like to be. Ornament is inextricably about knowledge and illusion. Although tainted with dreams (but is this not always the case with what is in our mind?), the knowledge component appears essential"[5]

Contemporary examples of ornament have the capacity to attract and hold our attention, inducing a response. We interact with ornament as we move through architecture and experience it at multiple resolutions both visually and through our sense of touch. Ornament encourages us to consider what it represents and its relationship to the broader material and cultural context and makes us more aware of our perceptual systems, our bodies and their relationship to the environments we inhabit.

In the case studies presented in this paper I will try to quantify levels of engagement and develop a methodology to measure how works of ornament engage viewers, makers and designers in a continuous feedback loop. I will ask how digitally designed and fabricated ornament can attract our attention, and encourage interaction and participation with the built environment.

1.4 Research Statement

[5] (Picon, 2013. p27)

The overall intent of this thesis is to gain an understanding and develop a framework for using digitally designed and fabricated architectural ornament to engage users, makers and designers of the built environment.

1.5 Research Objectives

This research sets out the following objectives within an evolving conversation focused on architecture's relationship with machine-produced ornament.

- To analyse the historical presence of machine-made ornament and its definition in contemporary society.
- To create an exhibition based on a series of full-scale prototypes which demonstrate the feasibility of fabrication processes focused on contemporary ornamentation.
- To create a catalogue that illustrates the process of creating engaging contemporary ornament.
- SECONDARY OBJECTIVE: to develop a business strategy for a venture that accommodates the primary objectives

1.6 Contributions

- This work furthers the discussion around digital and robotic fabrication within architecture.
- This work demonstrates the viability of an approach which merges critical thinking with physical making as an academic endeavor, and which situates design-build as an effective means of engaging with aspects of architectural history and theory.
- This work demonstrates the effectiveness of creating a user experience immersed in both digital and physical artifacts as communicative devices

1.7 Methodology

The methodology for the research consists of the following components: a literature review, interviews and case studies of alternative practitioners, case studies involving design/build projects and the development of an exhibition of prototypes:

-Digital Design processes used:– grasshopper, Silkworm, HAL, RAPID

-Physical prototyping - robotic fabrication, CNC/Waterjet cutting, 3d printing, analog fabrication techniques

-Surveys/analysis -computer vision – google image searches – community engagement surveys

1.8 Logic of Inquiry

Chapter 2 investigates existing literature on machine production of architectural ornament, modern architecture and ornament, contemporary forms of architectural ornament, perception of patterns of decoration and articulation in the built environment, and digital craft and critical making as they relate to hybrid digital/analog production of architectural ornament

Chapter 3 presents interviews with alternative practitioners and examines case studies including business models based around computational design, digital fabrication and architectural ornament.

Chapter 4 presents project case studies that form a personal ethnography and source material for design principals for the production of digital ornament

Chapter 5 presents case studies investigating the development of custom G code and robotic toolpaths.

Chapter 6 concludes by reflecting on the objectives, contributions and limitations of this work, providing insight into how the speculative forms produced within this research

relate to larger architectural agendas and investigating the future role of ornament within an increasingly digitally augmented architecture.

Chapter Two: **MACHINIC ORNAMENT: A BRIEF HISTORY**

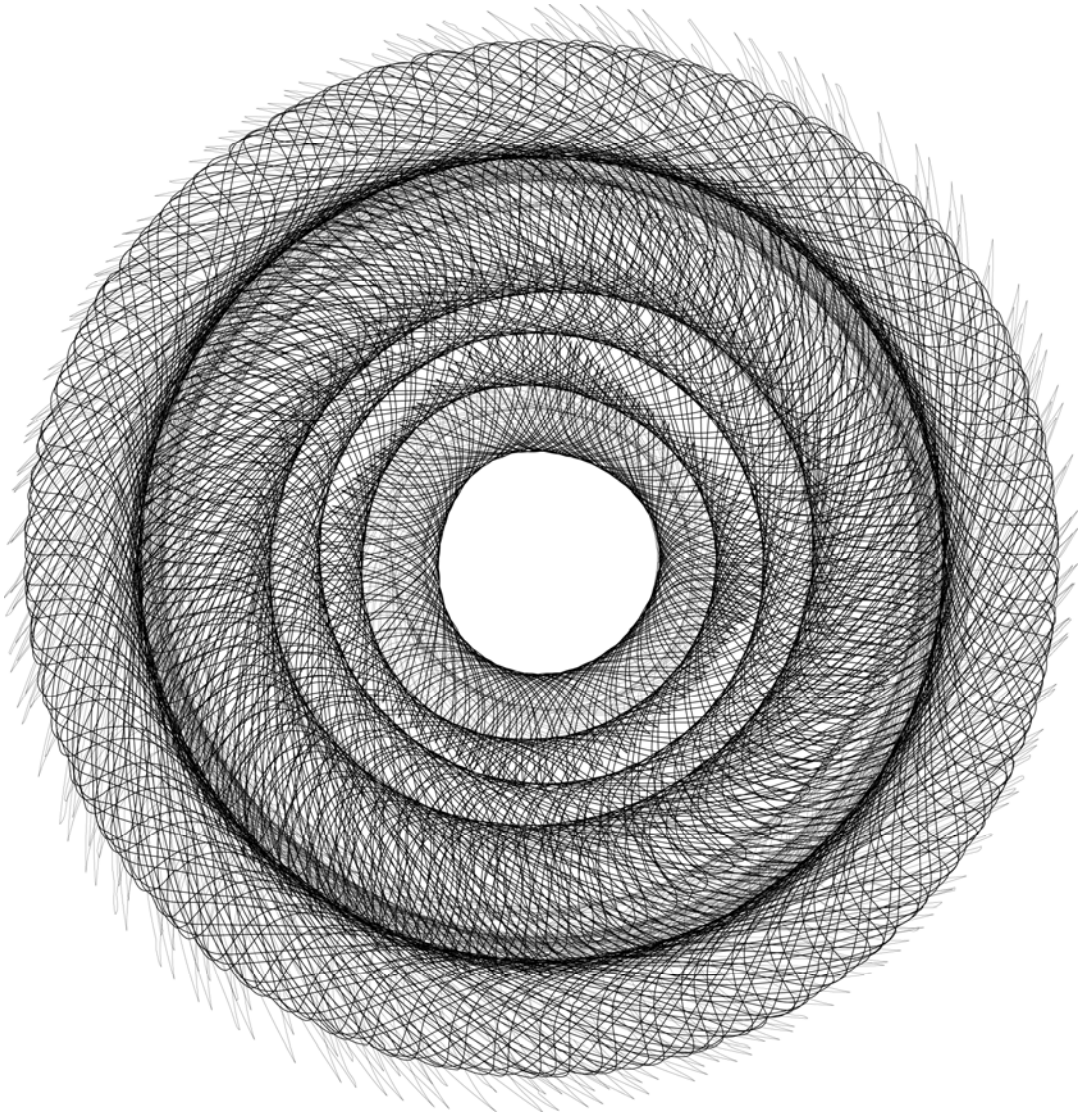

Figure 2. Guilloche Pattern Inspired by the Geometric Lathe Engravings of Cyrus Durand

2.1 Introduction

Ornament has a rich history in architectural discourse. In contemporary practice the definition of the term has become less clear as it has become more integrated with elements such as structure or aperture. Mechanization and digital technologies have profoundly influenced the design, production and experience of architectural ornamentation. While there have been significant changes in technology, culture and

society, historical debates that emerged during the first industrial revolution can inform contemporary discussions involving emerging production technologies, craftsmanship and our perception of the built environment. By tracing the arguments of designers and theorists regarding the increasingly widespread industrial production of architectural ornament in the 19th and early 20th centuries, we can shed light on contemporary discussions around the digital production of ornament.

2.2 Ornament and Authenticity

The Oxford English Dictionary defines "ornament" as: "any adjunct or accessory (primarily for use, but not excluding decoration or embellishment); equipment, furniture, attire; or something employed to adorn, beautify, or embellish, or that naturally does this."[6] The etymology of the word ornament is derived from the Latin "Ornatus", and originally was used in the context of rhetoric, the art of persuasion through writing and speech. Ornament referred to the embellishment of rhetoric using style and techniques such as alliteration, analogy, simile and metaphor. Architectural ornament historically fulfilled a similar function by providing a set of defining rules for embellishing, enhancing and expressing the content of buildings.[7]

Beginning with Vitruvius, the classical view was that ornament should express propriety and "decorum," helping to reinforce social norms. Over time, ornament came to be used as a form of self-expression, as well as a means of commemoration and

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[6] Dictionary, O. E. (n.d.). "ornament, n.". Retrieved from http://www.oed.com/view/Entry/132624

[7] (Frank, Is the Term Ornament Still Relevant Today?, 2008, p. 19;00)

memorialization.[8] Ornamentation of buildings frequently took the form of an embedded or inscribed layer of human-scaled, representational forms produced with the same building materials and construction techniques as the building.[9] Traditionally, architectural ornament functioned as a "self-referential sign;" a stylized formal language that allowed the architect to elaborate on design choices in a non-verbal form of communication.[10]

The industrial revolution had a major impact on ornament, both through the development of new processes for mass production as well as the appearance of novel patterns and forms of decoration on everything from domestic objects to buildings. These changes had a number of side effects, including changes in labor conditions for workers involved in the decorative arts and crafts, as well as aesthetic changes to the character of objects, buildings and cities. Industrialized mass-production of decorative arts and crafts resulted in an eclectic mixture of styles based on a range of influences. In response, design theorists began debating the function of ornament, its relation to craftsmanship, and how it should be meaningfully integrated and deployed, putting forward sets of rules for how ornament and decoration should be designed, made and applied. These theories form a body of literature that emerged between the late 18th and early 20th centuries as a response to "new forms and types of objects" resulting from new industrial materials and methods.[11] These historical texts concerned with aesthetic theories of decorative art and craft continue to inform and enrich contemporary discourse.

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[8] (Picon, 2016, p. 12)
[9] (Payne, 2012, p. 8)
[10] (Payne, 2012, p. 24)
[11] (Frank, Introduction: The History of the Theory of Decorative Art, 2000, p. 1)

While the majority of these debates were occurring in Europe, eventually American designers would make their own contributions to the conversations. One of the early contributors was Louis Sullivan. Sullivan's theories regarding architectural aesthetics influenced generations of designers and theorists. His architecture is exceptional in part because of his ornamental design, and his writing demonstrates how many designers of this era were concerned with the function of ornament. Sullivan's theories can be seen as a bridge between the ideas of John Ruskin, who believed that ornament and decoration were an integral part of architecture, and modernists like Adolph Loos, who would argue for an undecorated architecture. Sullivan saw the role of ornament as communicating the 'spiritual' aspects of architecture. He speculated that a contemporary approach to ornament required a break with the styles of the past and the development of a new approach.[12] In "Ornament In Architecture", written in 1892, Sullivan argues that perhaps architects should stop using ornament in favor of a simpler approach to massing and proportion. If ornament were to be used, he argued, it should be integrated with the design of the building in a holistic way. Ornament should emerge organically from form, rather than being stuck on.[13] A great building, Sullivan argues, has a unique individual character, and if the rational and emotional qualities that make a building great are applied to its ornamentation, it will "raise it at once from the level of triviality to the heights of dramatic expression." [14]

For Sullivan and many of his contemporaries, the question of authenticity was a key aspect of the debate around ornament. The question arose in part due to the impact of new industrial materials, equipment and techniques on the decorative arts. Could mass-

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[12] (Frank, Materials and Techniques of the Decorative Arts, 2000, p. 248)
[13](Sullivan, 2000, p. 284)
[14] (Sullivan, 2000, p. 287)

produced, machine-made ornament communicate the "spiritual" qualities that Sullivan attributed to "great" works of architecture? Could it denote authenticity in the same way as hand-crafted ornament? This debate began to take shape well before Sullivan began thinking about how or even if ornament should be applied. On one side of this debate, Ruskin and William Morris worried about the rapid proliferation of indiscriminately applied industrially-produced ornamentation on objects and buildings and the demise of manual production. Ruskin was particularly interested in the role of the craftsman in the production of ornament, and approached the subject of ornamentation by examining the relationships between production, perception and emotional response.[15] In "The Seven Lamps of Architecture," written in 1849, Ruskin proposes that the craftsman's pleasure in the making of decorative forms could be transmitted through those forms to users[16]. The role of the craftsman in conveying authenticity was particularly important to Ruskin, who believed that evidence of workmanship contributed to our perception of beauty. He argued that there should be a relationship between the status of an object or space and the quality, level of detail, workmanship and materiality of its ornamentation, and that certain patterns and motifs are appropriate to specific use conditions[17].

For Ruskin, Gothic architecture and its ornament in particular demonstrated how the free creative expression of individual artisans could contribute to a greater cause. The evidence of this individuality and freedom can be seen in the roughness and slight imperfections that reveal the hand of the maker.[18] Picon suggests that Ruskin's emphasis

[15](Frank, Introduction: The History of the Theory of Decorative Art, 2000, p. 247)
[16] (Frank, Introduction: The History of the Theory of Decorative Art, 2000, p. 132)
[17] (Frank, Introduction: The History of the Theory of Decorative Art, 2000, p. 7)
[18] (Picon, 2016, p. 13)

the hand-crafted authenticity of imperfection and roughness was an idea that would later influence Corbusier's development of his rough textured, "brutal" concrete.[19]

Ruskin's ideas also influenced William Morris, founder of the Arts and Crafts movement, who, like Ruskin, was concerned with production of the decorative arts and with the role of the craftsman. Morris proposed that in order for ornament to bring meaning and pleasure, it must be produced with dignity and humanity[20]. The focus of much of Morris' writing involves the ideas that the decorative arts are inherently democratic, that handcraft has an enduring value to society and that art is a collaborative practice[21].

Like Ruskin, Morris was disturbed by what he saw as soul-less mass-produced ornament and its negative effects on craftsmanship and labor conditions. At the same time, Morris recognized the potential benefits of machine production for workers[22]. Morris opposed the increasing division of labor between designers and industrial workers, and the disappearance of the role of craftsman. He speculated about a future in which monotonous physical labour could be taken over by machines, freeing workers to pursue their own creativity, and allowing for a renewed interest in hand-made arts and crafts under a revival of the collaborative and interdisciplinary forms of practice of the medieval guild system.[23]

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[19] (Picon, 2016, p. 13)
[20] (Frank, 2000, p. 9)
[21] (Frank, 2000, p. 9)
[22] (Frank, 2000 p. 133)
[23] (Frank, 2000, p. 9)

While Morris' anti-industrial argument found a great deal of traction, a growing number of designers were more open to the potential benefits of industrial production. In 1895, Pedro Rioux de Maillou wrote about the potential for machine production to act as a force for social mobility and progress that allows workers the opportunity to become designers. Maillou's writing demonstrates an early attempt to imagine a machine aesthetic.[24] Maillou acknowledges the arguments of Ruskin, Morris and others that the hand of the craftsman transmits a unique quality, but he proposes that the machine is also capable of can translating the intent of the designer into an "abstract beauty" that emerges from a synthesis of the designer's intent and its material expression.[25]

Maillou's idea of a machine-made "abstract beauty" echoes descriptions of the intricate ornamental patterns produced by the geometric lathe, invented in the 1820's by Cyrus Durand. Durand, like many 19th century decorative artists was interested in exploring the unique qualities of machine production[26]. He developed the geometric lathe along with various other machines to produce and decorate portable, domestic objects[27]. The machine-engraved patterns were initially used to decorate boxes, watches and other personal items, but eventually came to be used to combat the counterfeiting of banknotes. The precision of the engraving technique and the perfect symmetry of the composition could not be reproduced by hand-engraving and the underlying geometric code generating the pattern was virtually impossible to duplicate. The engraving process allowed for the propagation of a run of notes, and then the destruction of the production tools to prevent further production. The engraver developed each unique pattern by adjusting a set of interlocking cams into combinations resulting in compositions of line-

[24] (Frank, 2000, p. 134)
[25] (Maillou, 2000, p. 191)
[26] (Roberts, 2016, p. 319)
[27] (Roberts, 2016, p. 319)

work which could not be predetermined. A tiny adjustment would result in a completely new pattern, and unless an exact record of the configuration was kept, it would be impossible to repeat the pattern[28].

The line-work used the formal language of traditional engraving, where the tool is held still against a plate which is rotated. The ornamental patterns demonstrate a combination of fluid, animate and mechanically precise aesthetic qualities. The tension between geometrical precision and indeterminacy of the mechanical process creates a space which traps the viewer's attention in the intricacy of the line-work[29]. Arguing that the superhuman symmetry, uninterrupted regularity and precision of the line-work was immediately perceptible to the human eye, writers of the time suggested that these machine-made ornamental patterns represented a progressive, universal and "self-authenticating" form of visual language[30].

Early examples of machine-made decorative art such as the ornamental patterns produced by the geometric lathe showed that machine–production could transmit a unique form of beauty and authenticity. This allowed theorists to begin to build an opposing argument to the views of Ruskin and Morris that authenticity was the domain of hand-craft. Machine-made ornament posed many of the same questions around objectivity and authenticity as lithography, photography and other intricate reproductive technologies being developed in the 19th Century.[31]

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[28] (Roberts, 2016, p. 311)
[29] (Roberts, 2016, p. 317)
[30] (Roberts, 2016, p. 313)
[31] (Roberts, 2016, p. 313)

The relationship between our perception of authenticity, indeterminacy and reproduction would later become a concern of Walter Benjamin. In his essay, The Work of Art in the Age of Mechanical Reproduction, written in 1936, Benjamin argues that mechanical production has disrupted the "aura" of tradition. He writes: "What is really jeopardized when the historical testimony is affected is the authority of the object, the weight it derives from tradition…What withers in the age of technological reproducibility of the work of art is the…aura."[32] For Benjamin, the freeing of works of art from the bounds of tradition so that they could become more widely available was revolutionary.

Throughout the 19th Century, theorists debated which style or aesthetic would most appropriately communicate the spirit of the time, and to what extent this aesthetic should express the new forms, materials and techniques made possible by industrial production. One example was Austrian Architect Georg Heuser's "articulation style" which combined newly emerging techniques from the discipline of engineering with traditional techniques from armor and iron-working. Heuser sought to produce "a style in harmony with the body and the technology of contemporary industry, and thus an ideal representation of contemporary zeitgeist." [33]

The vibrant debates over style and ornament in the decorative arts and architecture during the 19th century were heavily influenced by a number of figures both within and outside of the architectural discourse. Ernst Kapp brought forward the concept of organ projection which imagined technological instruments as subconscious extensions of our bodies' sensory systems and functions[34]. Similarly, The Empathy theory of Aesthetics,

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[32] (Benjamin, 2008, p. 22)
[33] (Payne, 2012)
[34] (Payne, 2012)

developed by Heinrich Wolfflin, proposes that the way in which we understand and interpret form is intrinsically related to our physical bodies, and our physical experiences of, for example, gravity and proportions, allow us to identify with the objects and spaces that make up our environments.[35]

2.3 Machine Aesthetics

The rapid industrialization of construction, particularly apparent in the United States at the turn of the 20th century resulted in an increase in the machine-production of building components. Debates about the value of hand-crafted versus machine produced ornament became less relevant. The increasing efficiency and precision of industrial processes led designers to seek new ways of adapting the design of ornamentation to suit mechanized production, or to discard it altogether.

"In "The Art and Craft of the Machine," Frank Lloyd Wright acknowledges that machine production has "dealt a deathblow to art in the grand tradition of art"[36]. As an early proponent of the machine aesthetic, Wright responded to Ruskin and Morris' arguments against machine production by asking "what can we learn from the machine? His response is that we can learn about "simplicity" about the truth of materials, their natural beauty arising from their material properties:

"*The machine with its wonderful cutting, shaping smoothing and repetitive capacity has made it possible to so use it without waste that the poor as well as the rich may enjoy today beautiful surface treatments of*

[35] (Hellberg, 2017)
[36] (Wright, 2000, p. 202)

strong, clean forms that the branch veneers of Sheraton and Chippendale only hinted at with dire extravagance which the middle ages utterly ignored"[37]

Wright's embrace of the simple beauty of materials as expressed by the machine was gaining traction. With the rise of modernism, ornament was increasingly considered frivolous and superficial. Decorative art became less relevant to the practice of architecture. According to Frank, "the story of Modernism is the story of the final dismemberment of the concept of decorative art."[38]

A key proponent of this dismemberment was Viennese architect, Adolf Loos. Loos' "Ornament and Crime" called for modern architects to repress the urge to decorate, or at least subordinate it to other considerations. According to Loos, ornament was subject to changing tastes and trends and could quickly become dated, resulting in wasted labor and expense in its production. Adolph Loos' famous manifesto, "Ornament and Crime", characterized the urge to ornament as a basic human impulse, associated with feminine, childish or criminal tendencies that should be repressed by the "modern" man[39]. Loos' vision of undecorated, pure form became emblematic of the Modern aesthetic. Beginning with Loos, modernism developed the sense that in contemporary, industrialized society, the impulse to ornament was associated with "forms of childhood behavior that prefigured criminality," and the modern architect should restrain such urges in favor of a rational approach to design.[40]

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[37] (Wright, 2000, p. 206)
[38] (Frank, 2000, p. 13)
[39] (Loos, 2000)
[40] (Picon, 2016, p. 16)

Historian Alina Payne argues that 3 factors created the conditions for the rise of a modern machine aesthetic:

- The increasing influence of museums and academic institutions with a focus on decorative arts, craft, ornament, anthropology, art history and allied fields.
- The Great Exhibition of 1851, and subsequent exhibits, which brought together objects from around the world and put them on display for mass public consumption.
- A greater public interest in applied arts and crafts and the objects of daily use.[41]

As Modern architects moved away from ornament and decoration, they increasingly began to experiment with the design and integration of mass-produced household implements, furniture and other objects of daily use. Payne argues that this was a moment of paradigm shift, in which architecture came to embrace the potential for small, portable and hand-held objects to become culturally significant.[42] This paradigm envisioned architecture as "The art of daily life," a series of layers expanding outwards from the body to include clothing, objects, the house and the city.[43]

Rather than disappearing completely with the rise of the undecorated machine aesthetic, a number of critics have argued that architectural ornamentation found a new form of expression with modernism. Modern Architecture's focus on industrial production processes, truth to materials, purity and functionalism demonstrated the power of simplicity and how a single object or a collection of objects within a space can become symbolically charged with meaning, and how the interplay of light, texture and material qualities can in themselves become an expressive form of ornamentation. Historian Robin Schulenfrei points out thatthis new approach appears in Loos' work as well as other early German modernists including Hermann Muthesius and Mies van der Rohe,

[41] (Payne, 2012, p. 204)
[42] (Payne, 2012, p. 196)
[43] (Payne, 2012, p. 201)

who argued for a rejection of ornate forms of decoration in favor of a more straightforward, practical approach to machine-generated production of material and form.[44]

While later forms of international modernism became preoccupied with abstracting materiality into flat, pure form, early modernists like Loos and Mies exploited material qualities for decorative effects. This idea is illustrated in works such as the Barcelona Pavilion, which deploys the complex veining patterns of marble to offset the pavilion's minimal geometric form.[45]

The luxurious qualities of materials such as Marble or Onyx, showcased in the Barcelona Pavilion, were expressed through the high level of polish applied to their surfaces, and the intentional use of patterning techniques such as book-matching.[46] In work of early German Modernists, the concept of ornamentation was reinterpreted through the use of luxurious materials, and rather than being attached or applied, it was expressed as a combination of form and surface. This approach manifested itself in the form of "clean lines….purity of proportions, the taut tension of flat or curved surfaces, the colorfulness of paints and varnishes, the sparkling sheen of finishes."[47]

These ideas of geometric simplicity of form and luxurious materiality influenced a generation of designers coming out of the Bauhaus. Payne and Schulenfrei both point out that while the objects produced by Mies and students at the Bauhaus attempted to

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[44] (Schulenfrei, 2016, p. 334)
[45] (Kolarevic & Klinger, 2008, p. 11)
[46] (Schulenfrei, 2016, p. 340)
[47] (Schulenfrei, 2016, p. 340)

hide the hand of the maker and appeared to be mass-produced using automated industrial tools, they were in fact almost all hand-crafted using luxury materials.[48]

In contemporary discourse, Loos' writing receives a great deal of attention for his views on ornament. However, Le Corbusier's work demonstrated for a much wider audience how ornament would be transformed with the rise of modernism. In the publication which accompanied his Pavilion de L'esprit Nouveau at the exposition of decorative arts in 1925, Corbusier stated: "The decorated arts of today are no longer decorated." Payne proposes that L'esprit Nouveau pavilion and the carefully curated paintings, furniture pieces and other objects which it contained were Corbusier's architectural manifesto regarding of the newfound relevance of domestic objects as "vehicles for meaning" in the emerging Modern architecture movement.[49]

According to Payne, Corbusier's ideas were influenced by Loos, Muthesius and other early German Modernists, as well as by the widespread debates regarding ornament, the decorative arts and the objects of everyday life which had taken place predominantly in German speaking countries in the second half of the 19th century.[50] By translating and adapting these ideas, he made them more widely accessible to an international audience, popularizing the emerging aesthetic and conceptual vision of Modernism.[51]

Corbusier's interest in the relationship between the body and the objects of everyday life can be seen in both his paintings and in his architecture. The paintings are still-life compositions of anonymous, mass-produced industrial objects stripped from their

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[48] (Payne, 2012, p. 234)
[49] (Payne, 2012, p. 9)
[50] (Payne, 2012, p. 138)
[51] (Payne, 2012, p. 262)

contexts; in a style he called 'Purism". Payne argues that Corbusier's obsession with light, portable industrial objects and pieces of furniture informed his idea of the house as a lightweight, portable industrial object. Corbusier referred to them as "limb-objects," and the way in which he describes them can be seen as a translation of the concept of empathy theory developed by Kapp.[52]

There is widespread consensus among theorists that the traditional function of architectural ornament was permanently disrupted by the modern movement. Without ornament, Modern architecture needed a new means of communicating. In L'esprit Nouveau, Corbusier demonstrated how this need could be fulfilled by the objects of everyday life. Rather than relying on a layer of ornamentation attached to the surface of the building, architecture could now be interpreted through the objects it contained and brought into contact with the bodies of its users.[53]

The industrial revolution placed the machine at the center of design, and Modern Architecture celebrated industrialized forms of mass production, rather than the handmade. The intricate, small-scale, hand-crafted qualities common to both objects and ornament were no longer a focus of architectural discourse. As a result of a more mechanized worldview, ideas around the human body and how it interacts with form and space began to shift.[54] The rise of the Machine Aesthetic brought a new set of concerns to the forefront of architecture; efficiency, simplicity, truth to materials and a celebration of the instruments of modern daily life.[55]

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[52] (Payne, 2012, p. 262)
[53] (Payne, 2012, p. 9)
[54] (Payne, 2012, p. 16)
[55] (Payne, 2012, p. 14)

Whether ornament died out or was transformed, the rise of international modernism coincided with a long period in which ornament was relegated to obscurity within the study of architecture. With a decline in interest in decorative art in general, and ornament in particular, it has been argued that critical discourse on material culture lost sight of the connection between ornament aesthetics and perception.[56]

2.4 Complexity, Ambiguity and Patterns

The ideals of International Modernism dominated architectural discourse for much of the 20th century, but in the 1970s and early 1980s , designers and theorists began to question some of the rhetoric, providing an opportunity to revisit concepts related to image, pattern, and meaning within architecture. At the same time, new media and computational technologies for information processing were being developed and would soon have a dramatic impact on architectural design, paving the way for ornament to re-emerge as a topic of discourse within the discipline.

At the forefront of the critique of Modernism, Robert Venturi, Denise Scott-Brown and Steven Izenour began looking for alternative models for thinking about how architecture communicates. In "Learning from Las Vegas," 1972, based on their observations of the Las Vegas strip and its buildings as bill-boards, the authors put forward the argument that at its most basic level, architecture communicates meaning through image.[57]

The increasing prominence of theories complexity in philosophy and the natural sciences provided a framework for this criticism. The exclusivity of notions of purity,

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[56] (Frank, Introduction: The History of the Theory of Decorative Art, 2000, p. 15)
[57] (Sarkis, 2016, p. 37)

architectural order, symmetry, and harmony championed by orthodox modern architects was challenged in Venturi's "Complexity and Contradiction in Architecture." Arguing that architecture communicates through the use of iconography, symbolism and ornament, and that intentionally deployed ambiguity allows for a more rich and meaningful architecture, Venturi cites a number of case studies whose resonance arises from the underlying tension and inherent contradiction between form, program and ornamentation.[58]

According to Bernard Tschumi, the power of ambiguity as a design tool lies in its ability to make us reassess what we take for granted and to look at the familiar objects of everyday life with a fresh set of eyes. In the first of his "Six Concepts," Tschumi calls for architects to understand and exploit the potential of emerging media and information technologies to "defamiliarize" as a strategy for slowing down perception and breaking out of habitual ways of experiencing contemporary urban reality.[59]

Ernst Gombrich notes that designers of ornament have deployed ambiguity for centuries. He points to the Grotesque as a style which continuously developed new effects and techniques to elicit psychological responses in viewers, through the production of "…unfocused forms mainly serving to enhance the focused center. They thus provided an ideal vehicle for the grotesque, for the free play of inventiveness of the decorator's imagination"[60]

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[58] (Venturi, 1966)
[59] (Tschumi, 1996)
[60] Gombrich, 282

Postmodern Architecture embraced pattern and ornament as opportunities to develop ambiguity, complexity and contradiction and to reference historical and symbolic content. As Tschumi and others began to leverage newly emerging information processing technologies, they were able to deploy increasingly complex and sophisticated patterns in their designs.

Pattern and ornament can be seen as distinct but related terms which overlap within architectural design discourse. Patterns are systems with recurring elements that exist throughout the natural and built environments at all scales. Branko Kolarevic and Kevin Klinger argue that "It its only when a particular pattern is recognized and represented in some physical manifestation, such as a decoration, for example, that it becomes a cultural artifact – an ornament."[61]

In A Pattern Language, written in 1977, Christopher Alexander put forward his own approach to addressing ambiguity and complexity within the built environment. Alexander wanted to provide template patterns which could be used to solve problems across all scales of environmental design, from the scale of city and landscape planning to the layout of furniture in a room. He writes:

"…No pattern is an isolated entity. Each pattern can exist in the world, only to the extent that it is supported by other patterns: The larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded within it."[62]

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[61] (Kolarevic & Klinger, 2008, p. 20)
[62] (Alexander, Ishikawa, & Silverstein, 1977, p. xii)

Paul Andersen and David Salomon characterize Alexander's approach to patterns as one which prioritizes traditions and patterns of use in which forms and images are repeated again and again, allowing Alexander to characterize certain patterns as foundational laws or principles.[63] They contrast this approach with that of Gyorgy Kepes, who studied natural patterns at a variety of different scales, imagining pattern as dynamic and temporary. Kepes argued for "pattern seeing," which involves looking for relationships rather than objects.[64]

2.5 Fractals and Pareidolia

One example of a type of complex natural and synthetic pattern which drew the attention of researchers and theoreticians is the Fractal Pattern. The term 'Fractal' was introduced in 1975 by Benoit Mandelbrot to describe self-similar geometric structures that exist at multiple scales. Fractal patterns appear in the built and natural environment, and have been present in architecture throughout history.[65] In the 80s and 90s, emerging computational technologies allowed architects to address complexity at multiple scales and levels of resolution, and fractal patterns provided a novel means of formally representing these ideas. These patterns were free of the cultural baggage of more traditionally iconographic pattern and ornament. A number of architects including Stephen Holl, Asymptote, Peter Eisenman, Coop Himmelblau and Charles Jencks were interested in complexity theories in general and began to experiment with fractal patterns in their designs. The mainstream popularity of fractal architecture was short-lived; by

[63] (Andersen & Salomon, 2010, p. 46)
[64] (Andersen & Salomon, 2010, p. 48)
[65] (Joye, 2011)

the mid 90's, critics were describing fractals as a "kitsch" style, but they have continued to be a source of interest to some researchers.[66]

Through case studies which illustrate how fractals have been deployed within architecture, Carl Bovil proposes that fractal patterns have been an important part of architecture throughout history, helping to condition our visual experience of form and texture. He speculates about why they are compelling, especially within specific ranges of complexity, and introduces techniques for analyzing fractals in architecture, including methods for calculating fractal dimension. Fractal dimension represents a way of measuring visual texture by quantifying the amount of detail visible at different viewing resolutions, and can be measured using techniques including line-length measurement or the box-counting method. [67] For Bovil, the value of fractals in architecture is that they provide a way of analyzing and calibrating the "cascade of detail" which an architectural composition should provide in order to maintain a sense of visual interest.[68] He claims that the lack of progressive change in detail at different scales resulting from the flat, abstract qualities which characterized the International Modernist style is part of what contributed to its alienating qualities.[69] Bovil proposes that Tschumi's winning proposal for the Parc de la Villete competition is suggestive of the indefinite, ambiguous and complex qualities of fractal patterns.[70] Bovil imagines that an understanding of fractal patterns would allow a contemporary reintroduction of the rich visual texture present in classical architectural ornament and detailing.[71]

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[66] (Mutica, 2016)
[67] (Bovill, 1996, p. 23)
[68] (Bovill, 1996, p. 5)
[69] (Bovill, 1996, p. 6)
[70] (Bovill, 1996, p. 176)
[71] (Bovill, 1996, p. 185)

Figure 3. Boxcounting method applied to Limenitis Wall reveals a fractal dimension of approximately D1.3

Bovil's ideas about the ability of fractal patterns to improve the aesthetic experience of architecture by negotiating texture and detail across scales has been supported by subsequent research. Joye presents findings that suggest that fractal patterns in architecture may "lead to positive aesthetic responses and…reduce psychological and physiological stress in humans"[72]. Richard Taylor et al have shown that most people have a preference for images containing fractal patterns, especially when they fall within a fractal dimension range of d 1.3-1.5 (Figure 3.) This range is closely related to fractal dimensions found in nature, and has been found to have a stress-reducing effect on test subjects. [73] The perception of fractal dimensions within the built environment forms the basis of Stephan Chalup and Michael Ostwald's theory of "Contextual fractal fit," which

[72] (Joye, 2011)
[73] (Taylor, Spehar, Van Donkelaar, & Hagerhall, 2011)

proposes that humans find cityscapes more appealing when the fractal dimension of the skyline correlates with the fractal dimension of the natural environment.[74]

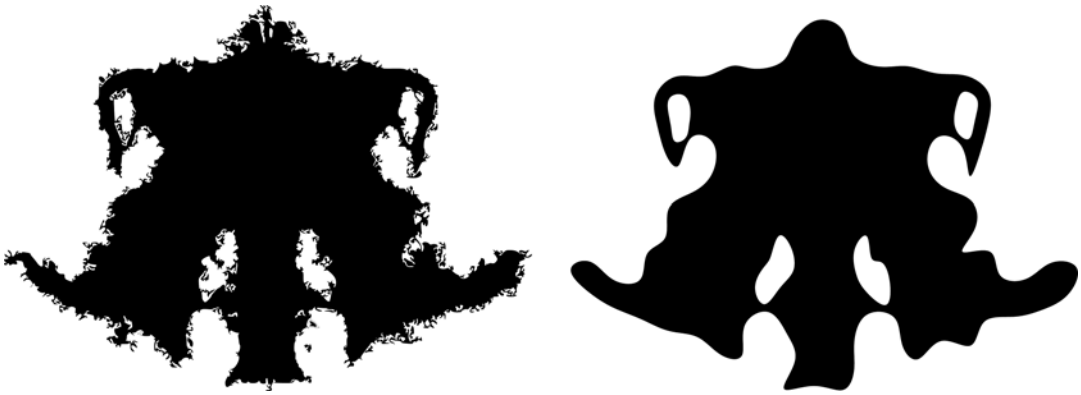

Figure 4. Rorschach-style inkblot (left) with fractal edge removed (right).

Fractal patterns have been found to be connected with the phenomenon of pareidolia. Pareidolia is a psychological phenomenon defined as the process of perceiving meaningful patterns in vague or ambiguous stimuli, and is exemplified by seeing animals or faces in the clouds, or the man in the moon, etc.[75] Zusne and Jones describe the experience of pareidolia as the foundation of the famous Rorschach inkblot test, a psychiatric assessment tool developed in 1921 by Swiss psychoanalyst Hermann Rorschach.[76] The test involves 10 cards, with inkblots on them, 5 black and white and 5 colour. The symmetrical blots were carefully designed by Rorschach, who worked through numerous drafts to remove evidence of how they were made, seeking a balance between detail and abstraction which would generate the most revealing responses.[77]

Gombrich recognized and wrote about the similarities between the Rorschach test and many examples of ornament. Both have the ability to elicit associative imagery in the

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[74] (Challup & Ostwald, 2014)
[75] (Pareidolia, n.d).
[76] (Zusne & Jones, 2014)
[77] (Searls, 2017)

minds of viewers. Gombrich proposes that symmetry is a key part of this equation. It provides "cohesion," or an underlying sense order which attracts our attention and encourages the mind to perceive a seemingly random shape as a recognizable object.[78]

Recent studies have suggested that Rorschach's inkblots are able to promote the generation of associative imagery in the minds of subjects at least in part due to the fractal complexity of their edges (Figure 4). There is an optimal bandwidth of fractal pattern at which subjects are most likely to see the most imagery, and it may be possible to "tune" how much people see in inkblots by adjusting the level of fractal complexity of the blots.[79] The Rorschach test continues to be a subject of research, and remains relevant so many years after its creation partly because of its ability to reveal an important aspect of human cognition which applies to both the experience of looking at inkblots the and the way in which we experience the built environment. The majority of our thoughts are based on unconscious associations.[80] One of the most common tendencies involved with pareidolia is the perception of faces within ambiguous patterns. The broad tendency to attribute human qualities to nonhuman objects is referred to as Anthropomorphism. This tendency arises from the fact that the human body is our main frame of reference for evaluating the world around us.[81] The capacity for face recognition and processing is a highly evolved component of the human brain that develops early in life, occupies a significant area of the brain, and extends to an innate aesthetic predisposition towards bilateral symmetry around the vertical axis.[82]

Gombrich recognized that ornament can play off of the viewer's tendency to see faces in any pattern which seems to contain eyes and other facial features. The process of

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[78] Gombrich, 158
[79] (Taylor, et al., 2017)
[80] (Goldhagen, 2017, p. xxx)
[81] (Hellberg, 2017)
[82] (Sussman & Hollander, 2014, p. 120)

searching for recognizable elements can provide a means of of "animating" image and form. "…*We easily succeed in making sense of some of the lines and accept others for what they are, mere flourishes. But the more intently we look the more we may also find that the image dissolves and recomposes itself according to various possible readings. In other words, we are engaged in a constant process of animation which can never quite come to a standstill"* [83]

Recently, fMRI testing supports the idea that we process inanimate face-like objects in the same way as human faces, and that objects resembling faces engage us emotionally. Our subconscious emotional response to faces and face-like objects has been recognized and exploited in art, design and marketing, and can be seen in everything from the design of car grilles to the design of buildings facades.[84]

Non-conscious cognitive processes such as fractal dimension perception, face detection and edge detection all play a role in how we perceive and relate to our environment and have an impact on conscious thoughts and emotions. For example, research has shown that some architectural façades trigger emotional responses in observers which may be related to the unconscious perception of facial expressions of emotion via pareidolia. [85] This unconscious emotional response may play a role in our feelings about the design of streetscapes and buildings. [86] Research into human cognition and perception can inform the design of the urban environments, allowing designers to incorporate associations and emotional responses as design parameters. The potential for digital design and fabrication tools to translate data and inscribe complex patterns onto surfaces and forms allows designers to leverage the tendency to augment and project associations onto

[83] Gombrich, 264
[84] (Sussman & Hollander, 2014, p. 70)
[85] (Chalup, Hong, & Ostwald, 2010)
[86] (Chalup, Hong, & Ostwald, 2010)

pattern in order to use pareidolia as a communicative tool to add richness and subjective meaning to the urban realm.[87]

2.6 Perception and Embodiment

Investigations into the perception of fractals and other complex patterns in our surroundings are a small portion of a growing body of research into how cognitive processes shape our experience of the built environment. This research suggests that by understanding how users perceive and process complex stimuli in the built environment, it may be possible to help them identify and engage with their urban context.

The basic building blocks of perception include the orientation of contours and edges, motion of patterns or the relationships between colours. Arguing for a greater consideration for how design influences mental health, Thomas Albright proposes that it is possible to understand the relevance of neuroscience to design by thinking of the brain as a visual information processing device. [88]

Humans rely on patterns to organize and provide order and meaning to the built environment. At the same time, they are stimulated by variation and differentiation. "Patterned complexity" satisfies the need for both ordered patterns and complex cognitive stimuli.[89] Overly repetitive patterns contribute to a lack of visual stimulation in urban environments. Humans are unconsciously repelled from environments which are perceived as either too monotonous or too busy and are conditioned to seek a balance

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[87] (Johnson & Gardner, 2017)
[88] (Albright, 2015, p. 204)
[89] (Goldhagen, 2017, p. 236)

between complexity and order. This idea was originally put forward by Gombrich, who proposed that ornamentation arose as a result of the human mind's underlying need to balance order and complexity in its surroundings.[90] Albright argues that recent findings of neuroscience support this hypothesis, and that the human perceptual system organizes visual information according to patterns, and seeks a balance between regular structures and complex formations.[91] Albright suggests that the built environment reflects human visual perceptual systems, and that an "optimized environment" contains varying levels of easily processed patterns which produce an underlying sense of order juxtaposed with novel, complex elements.[92] The mind's attraction to certain designs relates to how easily they are read and understood.[93]

In order to understand how we relate both consciously and non-consciously to our surroundings, it is important to understand that our thoughts and emotions are influenced by our body's sensory perception systems. According to critic Sarah Williams Goldhagen, the paradigm of Embodied Cognition proposes that cognitive processes arise from 3 factors: the mind, the body and the environment it inhabits.[94] The human body interacts with and perceives the built environment on multiple levels, via what has been described as "cross-modal stimulation" of motor and visual sensory neurons, a phenomenon where visual perception of a surface or object sparks a sense of tactile engagement.[95] Goldhagen proposes that, due to the way in which we process "surface-

[90] (Kolarevic & Klinger, 2008, p. 20)
[91] (Albright, 2015, p. 210)
[92] (Albright, 2015, p. 212)
[93] (Albright, 2015, p. 209)
[94] (Goldhagen, 2017, p. 46)
[95] (Goldhagen, 2017, p. 111)

based cues such as texture, density, color, pattern…" that surfaces in particular are more likely to stimulate memories, activate our senses and cause us to respond emotionally. [96]

2.7 Affect

The growing attention to how we perceive, interpret and respond to patterns and stimuli in the built environment has paralleled a widespread transition towards digital design and fabrication processes within architecture. Computation has extended architecture's ability to generate complex material effects capable of affecting viewer's subjective responses.

Within the context of architectural discourse, the terms "effect" and "affect" have become intertwined with digital design and fabrication. In recent years, a number of theorists have proposed that contemporary ornament operates through affect. In order to understand the development of the terms, Vittoria Di Palma refers to historic examples which attempted to mimic the way that landscape can trigger an emotional response in order to produce an architectural effect. Di Palma characterizes effect as "Eighteenth century architecture's most powerful communicative tool," a one-way form of communication, in which a building produces a predetermined sensation in an individual viewer.[97] In contrast, Di Palma proposes that contemporary architectural surfaces produce affects through field conditions which are not intended to communicate meaning, but rather to express a new type of relationship between objects and subjects.[98]

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[96] (Goldhagen, 2017, p. 158)
[97] (Di Palma , 2016, p. 32)
[98] (Di Palma , 2016, p. 33)

Kolarevic and Klinger propose that effect and affect can be thought of in terms of material. The way in which material is crafted with consideration to its appearance, performance, function or meaning produces an *effect* while the emotional or subjective responses that arise as a result of engaging with material effects are what *affect* perception and experience.[99] They suggest that an attention to the complex and inter-related emotional and sensorial qualities of user experience will allow ornament to return to place of importance within architectural theory.[100]

For Picon, an understanding of affect emphasizes contemporary architecture's focus on the skin or surface. Arguing that contemporary ornament is surface based, can be inscribed or tattooed, and can extend beyond the visual experience to include tactile effects, as in the example of Herzog and Demeuron's De Young Museum, Picon notes that contemporary architecture employs pattern to create immersive environments capable of generating "hypnotic" sensory affects. [101]

The idea that digitally produced effects generated through ornamental texture and pattern applied to buildings could affect users emerged in architectural discourse in the early 21st century. In "The Function of Ornament," Farshad Moussavi examines a number of buildings that exemplify a contemporary reinterpretation of ornament and which communicate through sensation and affect.[102] Moussavi argues that these examples, in which ornamentation has been pushed out to the skin of the building, demonstrate how new production techniques have opened up possibilities for

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[99] (Kolarevic & Klinger, 2008, p. 11)
[100] (Kolarevic & Klinger, 2008, p. 20)
[101] (Picon, 2016, p. 16)
[102] (Moussavi & Kubo, 2006, p. 7)

differentiation and customization. The ornament cannot be separated from its material and expresses the forces which formed it. In this new way of understanding ornamentation, buildings "produce affects that seem to grow directly from matter itself."[103]

Moussavi echoed Venturi's critique of modernism and its preoccupation with qualities such as transparency, but suggests that one of the flaws of Postmodern discourse was its interpretation of culture through symbol. This interpretation eventually led to Postmodernism's obsolescence due to the limitations of semiotics as cross-cultural forms of communication. Moussavi points to affect as a more universal form of communication which operates directly on the senses.[104] Di Palma highlights Moussavi's contention that contemporary ornament relies on affect to allow architecture to communicate more universally. This universality stands in contrast to postmodern ornament's focus on culturally specific hidden meanings produced through semiotics and symbolic imagery. [105]

Anderson and Solomon argue that contemporary approaches to the use of decorative and ornamental patterns within architecture are able to draw on a variety of methodologies to merge performative and aesthetic design qualities. This is partly because contemporary practice, with its focus on variation and variety, is a synthesis of modernism, with its interest in progress and post-modernism, with its focus on meaning.

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[103] (Moussavi & Kubo, 2006, p. 11)
[104] (Moussavi & Kubo, 2006, p. 8)
[105] (Di Palma , 2016, p. 31)

"The recent re-emergence of patterns in contemporary architecture can partly be understood as a re-assessment of the isolationist tendencies present in both modern and post-modern theories of architecture. Many of those theories denied the generalist potential of architecture. In typically paradoxical fashion, a new understanding of architectural patterns maintains an emphasis on performance and aesthetic coherence found in modernism, while incorporating the indexicality, hybridity, and ambiguity of post-modernism." [106]

The affective potential of emerging digital technologies continues to remain a topic of discussion and research in contemporary architectural discourse. Behnaz Farahi has explored how digitally designed and dynamically actuated objects with ornamental qualities can both evoke and respond to human emotion through her works such as Opale and Mesolite. These works demonstrate how material assemblies can act as an "emotional interface."[107] Using computer vision and facial recognition to both detect and provoke user emotions and translate emotional cues into dynamic physical responses such as color and shape changes, Farahi's work deploys interactive and responsive articulation in wearable garments and objects to condition social interactions, and to develop emotional connections between users and objects via what she describes as an "affective loop". [108]

2.8 Digital Design of Ornamental Patterns

[106] (Andersen & Salomon, 2010, p. 67)
[107] (Farahi, 2018, p. 213)
[108] (Farahi, 2018, p. 213)

There is a consensus amongst theoreticians including Di Palma, Picon, Schumacher, Kolarevic and Klinger,and Moussavi that the traditional definition of ornament has changed, that contemporary ornament operates through the production of affect, and that the return of ornament to a place of prominence in 21st century architecture has been enabled in part through the rapid dissemination of digital design and production technologies.

The rise of computation in architecture has enabled the design of complex formal and surface patterns and the widespread availability of additive manufacturing and CNC equipment has allowed those designs to be translated into intricate material assemblies.[109] Along with these changes, the rules which traditionally governed the use of ornament in architecture changed drastically as a result of the modern movement, and ornament has been redefined in recent years, according to what Picon identifies as three important factors. First, there has been a shift from the way that traditional ornament was concentrated in specific areas to its dispersal across the entire surface of a building. It has also gone from being a superficial element which revealed a building's underlying order, to being actually integral to the form and structure, as in the example of the Bird's Nest building by Herzog and de Meuron. Lastly, contemporary practitioners have sought to disassociate their work from the use of decoration in Post-modern architecture by avoiding symbolic associations.[110]

At the convergence of theorists' ideas around ornament and digital fabrication is the suggestion that machinic processes are uniquely positioned to enhance the affective qualities of ornament. Kolarevic and Kligner and Patrick Schumacher both point to designer Bernard Cache's "Objectiles" as early examples of how customized toolpaths

[109] (Picon, 2016, p. 25)
[110] (Picon, 2016, p. 10)

can produce patterned surfaces with ornamental qualities by leveraging traces of the CNC machining process.[111] The tectonic qualities of the "Objectiles" are a direct result of their production technique. They embrace the potential of mass-customization while referencing the ideals of early modernists to express a machine aesthetic through the interaction between a material's inherent properties and an industrial process. [112]

According to Mark Garcia, understanding the affective qualities of ornament and how it could be deployed to enhance environments is contingent on understanding the relationship between technology and pattern. Garcia notes that contemporary ornament is intrinsically related to pattern, and that instead of being hand-crafted, or even mass produced, contemporary architectural ornament is mass customized, digitally designed and fabricated, expressed through form, materiality, pattern, and articulation. New technologies are allowing for new types of spatial patterns and new possibilities for the integration of structure, ornament and space, as well as endless possible configurations.[113]

The rise of new software and scripting techniques and the increasing availability of fabrication equipment in the 21st century have made the materialization of digital design possible, but it is still a work in progress. The process of developing and adapting fabrication tools and techniques for the mass-customization of variable architectural assemblies has been a long and challenging process. Prior to the re-emergence of ornamental patterns of articulation in building skins in the early 2000's, Kolarevic and Klinger note that architects working with digital technologies were more interested in

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[111] (Schumacher & Garcia, Parametric Patterns, 2009, p. 33)
[112] (Kolarevic & Klinger, 2008, p. 18)
[113] (Garcia, 2009)

the production of geometries consisting of smooth, continuous surfaces with hidden connection details, exemplified by the work of firms such as Future Systems. [114]

Many of these projects relied on parametric design techniques which combined scripting and associative modeling. Parametricism developed into a style with important implications for architecture's understanding of pattern. Parametric patterning is defined by Schumacher as the use of datasets to differentiate and amplify patterns, surfaces and spaces. Differentiation is created through correlations between geometry and spatial organization. Sophisticated patterns should be able to accommodate multiple datasets regarding occupation, environment, furniture, aperture and other parameters.[115]

Schumacher suggests that parametric patterning can activate ornamentation by incorporating parameters derived from users in order to animate architectural forms and surfaces. This sense of animation can be enhanced through what he describes as "parametric figuration," a form of articulation that extends beyond visual effects to trigger shifts in the perception of the order or the atmospheric qualities of a space: "The notion of parametric figuration implies that figures tentatively crystallize from the continuous field conditions they remain embedded within by parametric manipulations, including by shifting observer positions."[116]

Parametric tools continue to shape the development of new types of architectural forms and surfaces. Increasingly, these tools are being used not only to produce design and fabrication files for CNC machines, but are also being integrated into processes which

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[114] (Kolarevic & Klinger, 2008, p. 13)
[115] (Schumacher & Garcia, Parametric Patterns, 2009)
[116] (Schumacher P. , 2011)

deploy robotics, sensors and AI to respond in real time to variability in materials and production environments. These workflows, which incorporate "real-time making," disrupt the traditional roles of designer and craftsperson, and allow for new possibilities in terms of surface articulation and ornamentation. [117]

Schumacher argues that Parametricism has entered a new phase of "Tectonism" related to the development of new methods of materializing digital architecture, including robotic fabrication. He defines this phase the "stylistic heightening of engineering and fabrication based form-finding processes." This "style" is characterized by a greater attention to material and logics of fabrication. Aesthetically, this results in a greater level of variety, texture, articulation and the expression of joints and the translation of construction processes into ornament. Schumacher argues that this allows for a greater level of communication, and for the development of information rich environments which make cities more understandable.[118]

2.9 Conclusion

Ornament has been and continues to be a lens through which we can critically reflect on meaning in architecture and its broader role in culture. Numerous theorists and historians have pointed out the important role that ornament and pattern have played in architecture throughout history by enhancing, embellishing and expressing buildings and cities. Ornament serves to amplify, accentuate, and adorn, and provides a way of reading and understanding space. There is also widespread consensus that the traditional functions of ornament were disrupted by Modernism and its focus of simplicity and function.

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[117] (Daas & Wit, 2018, p. 34)
[118] (Schumacher P. , Tectonism , 2017)

Discourse around decorative and ornamental patterns within architecture has varied widely in the last century, from romantic idealization of craftsmanship to an embrace of the machine aesthetic and its "superhuman intricacy". Modern architects prioritized purity, functionalism and truth to material. Postmodernists turned to signs and symbols, complexity and ambiguity. Throughout these shifts, architects have been engaging viewers through form and pattern. Digital design and fabrication technologies have allowed for a renewed integration of the functional and aesthetic qualities of architecture through the direct manipulation of material at multiple scales along with an ability to augment form with layers of information.

Contemporary theorists argue that the reintroduction of ornament and pattern into architecture thanks to the possibilities for mass customization, precision, and intricacy provided by digital tools can allow architectural ornament to once again have a deeper impact on our experience of the built environment. Discoveries from neuroscience and environmental psychology about perception and embodied experience have important implications for environmental design in general, and particularly for the design of surface articulation and architectural ornament.

Among the trends that emerge from this review include an understanding that ornament and decorative patterns of articulation have taken different forms and styles but have remained important aspects of architecture, providing a means of communicating and conditioning how the body experiences the spaces it occupies. Throughout the literature, there is a continuing obsession with craftsmanship and the mark of the maker, beginning with the work of Ruskin, then continuing through Le Corbusier, and re-emerging via the

concept of digital craft and in traces of the machinic processes in the work of designers including Bernard Cache. New real-time production workflows which leverage robotics are once again requiring a re-evaluation of the relationship between designer and maker. An underlying theme in these developments is the way that ornament conditions the relationship between the human body and the built environment and how advances in technology are providing new avenues to understand that relationship.

Gombrich predicted that the computer would have a profound effect on the production of ornament. He saw the emergence of digital design as a continuation of the sequence of styles which have made their mark on the history of art and architecture. The final paragraph of "A Sense of Order" continues to be pertinent in trying to understand the role of digitally augmented ornament in architecture and culture:

"The study of the pattern – makers craft no less than the study of any other art suggests that what we need is patience. It takes time for a system of conventions to crystallize till every subtle variation counts. Maybe we would be more likely to achieve a new language of form if we were less obsessed with novelty and with change If we overload the system we lose support of the our sense of order."

The next chapters will examine ornament's potential to operate as an interface to enhance engagement in the design, production and experience of objects and environments.

Chapter Three: **ENGAGING WITH ORNAMENT THROUGH DIGITAL CRAFT AND CRITICAL MAKING**

3.1 Introduction

The previous chapter examined how machine-produced ornament has evolved and come to be associated with a wide variety of objects, surfaces and patterns of articulation in the built environment. Investigating the continuing relevance of ornament can help us understand the interrelations between craft, advances in production technologies and the perception and cognition of objects, spaces, buildings and cities. If, as some theorists have argued, ornament is once again playing an important role in architecture, perhaps it can also provide a means of understanding the role of experimentation and improvisation through digital craft within the expanding field of contemporary architectural practice. This chapter seeks to understand how technologically augmented forms of production are allowing for new avenues of experimentation with ornament and pattern across a variety of scales.

3.2 Machinic Interfaces and Digital Craft

The evolution of parametric and computational design has paralleled advances in digital fabrication technologies, allowing for greater flexibility, variation and mass customization in the production of the built ream. According to Fabio Grammazio and Matthias Kohler, robotic fabrication represents a new paradigm in which the materialization of digital architecture can have a much broader impact on society.[119] They point to several examples including their project series titled "Procedural Landscapes" as evidence of a newly emerging approach to building with robots. The computational and fabrication workflow adapts the precise movements of industrial

[119] (Kohler, Gramazio, & Willman, 2014)

robots to account for the unpredictable way in which "soft" materials such as sand particles perform. In order to make the necessary real-time adaptations, live data is gathered from the building material as it is being manipulated, creating a feedback loop which allows the fabrication process to evolve as it unfolds.[120]

Grammazio and Kohler contrast Ruskin's notion of handcraft, which privileges the experience and skill of the craftsman, with the contemporary idea of digital craft. Ruskin's stance against industrialized society in general and machine production in particular, argued that craft arose from a combination of the skill of artisans and the inherent properties and potentials of their materials. Handcraft can be thought of as an interface between the craftsman and the building material. In the case of robotic fabrication, the robot functions as a "machinic interface," providing a new way of linking maker and material, and of reinterpreting traditional craft processes.[121]

Defining an interface as a connection point between something that has been designed and its surrounding natural environment, Steele suggests that the digital revolution has resulted in fundamental changes to the practice of architecture, and architects have become "Machinic Interfaces." In the digital age, architects are a connection point between the existing world and the network of tools, techniques, software, and information processing languages involved in the production of the built environment.[122] The popular image of the architect as a solitary creative genius has been superseded as a result of how digital technologies have been incorporated within the profession, and instead of trying to preserve that image, Steel proposes that architecture students,

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[120] (Kohler, Gramazio, & Willman, 2014, p. 18)
[121] (Kohler, Gramazio, & Willman, 2014, p. 189)
[122] (Steele, 2003, p. 432)

teachers and professionals should adopt a new digitally networked and highly collaborative approach to practice. As an example of how this approach has already taken hold, he describes the open-sourced, collaborative, networked methods of working that evolved in the Architectural Association Design Research Lab (AADRL) as students were encouraged to experiment with new forms of digital technology in a hands-on way. [123] For Steele, the digital evolution of the practice of architecture has blurred the boundaries between various disciplines, processes, clients and users, and has transformed architects into "cyborgs" whose function is to act as an interface between the digital and physical worlds.[124]

Malcolm McCullough elaborates on the idea of the digital extension of human culture from the perspective of craft, describing the narrative of the "abstraction of craft" as the story of the industrialization of labor leading to the death of artisanal and hand-crafted production, and eventually to the development of CAD/CAM technologies.[125] These technologies can be seen as another layer separating people from the tactile experience of handcraft, but they also offer the potential for new types of artistic improvisation and creativity, and provide a new way of understanding how technology-enabled craft can extend human abilities.[126] Examining craft through the lens of digital production, McCullough argues that a digital artifact, for example a CAD model, is a composition resulting from procedural actions requiring knowledge, skill and experience in its production, and can be considered a crafted object. As with other crafted objects, the production of a CAD model requires the use of tools and techniques, in this case CAD software, to shape it. Its formal qualities and the way it was created are unique to the

[123] (Steele, 2003, p. 423)
[124] (Steele, 2003, p. 434)
[125] (McCullough, 1996, p. 70)
[126] (McCullough, 1996, p. 189)

designer. Digital craft describes the creative use of digital technologies which draws on aspects of traditional craft, such as repetitious, skillful mechanical actions. A digitally crafted object, McCullough argues, has a unique structure resulting from the composition of direct and indirect actions, internal relationships and ways in which information is formatted within the design space. [127] McCullough's definition of digital craft has been influential across a number of disciplines, including in architecture, where it helps to contextualize digital design and fabrication processes such as designing and translating digital models into numerical code for CNC machines, as part of a continuum of production techniques developed by designers and makers over the course of human history.

Figure 5. Designer as machinic interface: students in 'Introduction to Robotic Fabrication for Architects, EVDS, 2018'

McCullough published his argument in the mid-nineties, at a time when parametric modelling and CAM processes were still in their early development, but a number of observations and predictions have proven accurate. He proposed that as these technologies advanced they had the potential to inform each other by using the optimization of fabrication processes as a design parameter to drive variation. According

[127] (McCullough, 1996, p. 166)

to McCullough, "Tightening the loop between conception and execution has the potential to reconcile some of the separation of design and fabrication that industrialization has imposed on craft."[128] The increasing availability of fabrication tools such as rapid prototyping equipment in parallel with improvements in software represented a new set of opportunities for improvisation and creative expression in physical space. [129]

For McCullough, connecting digital modelling and digital fabrication is another step in the process of extending the human capacity for craftsmanship. Acknowledging the argument that these technologies are part of an ongoing process of industrial mechanization which has disconnected the human hand from the act of making, *Abstracting Craft* is optimistic that computational design and digital fabrication processes provide a new and fertile ground for a renewed exploration of craft in the digital age.[130]

3.3 Critical Making

In order for designers to adapt to the disciplinary changes described by Steele, Grammazio and Kohler, McCullough, and others, they have needed to develop the capacity to quickly become proficient with new software, hardware, design languages, fabrication equipment and working arrangements. This has required changes in pedagogy, a mental shift that embraces digital craft, and a willingness to critically engage with technology through hands-on forms of production and experimentation. The

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[128] (McCullough, 1996, p. 178)
[129] (McCullough, 1996, p. 188)
[130] (McCullough, 1996, p. 189)

subject of how to develop digital craft skills in designers, makers and even users is of interest to many contemporary researchers and educators. One of the terms that is used to describe the process of hands-on forms of learning through making, often involving digital technology is "critical making."

Critical making is a term coined by Matt Ratto describing a way of engaging with ideas around technology and society through hands-on forms of production. Ratto defines the term as "a practice-based engagement with pragmatic and theoretical issues," where the act of making is more important than the final result.[131] Ratto produced a series of workshops in which groups of participants designed and produced physical prototypes and then shared their experiences within a framework of "design oriented research." [132] Ratto's hypothesis is that people make a deeper connection with the concepts being communicated when the object they were making reinforced those concepts. The physical act of making augments and deepens the level of critical thinking around topics related to technology and society.[133]

Critical making offers the potential to provide designers, users and makers with opportunities to consider the broader implications of how emerging technologies for the production of the built environment are influencing the production and perception ornament. By providing a framework which prioritizes the shared act of making over the constructed prototype, critical making highlights the importance of open-sourced, collaborative, networked methods of working (such as those described by Steele) in contemporary design environments. As technologies such as robotic fabrication continue

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[131] (Ratto, 2011, p. 253)
[132] (Ratto, 2011, p. 245)
[133] (Ratto, 2011, p. 254)

to gain prominence within design and production, collaborative activities such as critical making workshops and design-build projects involving the digital production of ornament provide a way of gaining a deeper understanding of the implications of these technologies. These activities potentially offer a more embodied form of conceptual engagement by connecting the digital and physical aspects of production, providing opportunities to experiment with real-time collaborative production workflows, improvisation and creative expression in physical space, and the digital extension of craft.

3.4 Merging Roles

Previous sections have described how digital technologies have enabled a renewed interest in craftsmanship. This has helped shift our understanding of the meaning and function of ornament. As we have seen, theorists have argued that contemporary ornament seeks to avoid overt symbolism and direct associations with specific cultural references in order to achieve a greater level of universality.[134] Contemporary examples of ornament are often not only decorative but are also functional, operating as integral components of a building.[135]

[134] Moussavi & Kubo, 2006, p.8 and Di Palma, 2016, p 31
[135] Kolarevic & Klinger, 2008, p. 18 and Picon, 2016 p. 10

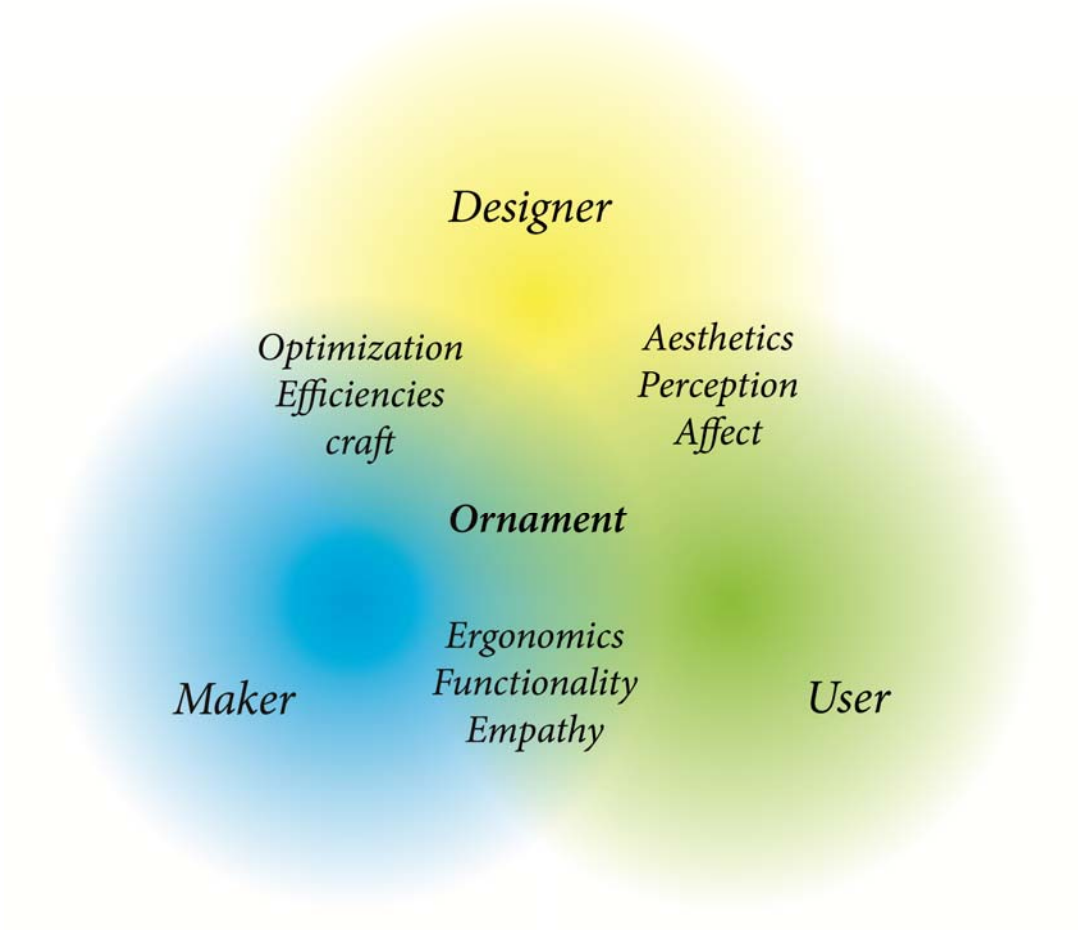

Figure 6. Overlapping Relationships

In addition to disrupting the historical functions, digital approaches to ornamentation are also changing the traditional role of the architect, blurred boundaries between disciplines and provided new opportunities for collaboration and creativity. Alternative forms of practice focused on digital craft and ornament have emerged to occupy a hybrid territory between design, research, fabrication and art (this will be explored further in the next chapter). Michael Szivos of SOFTLab argues that operating outside the traditional

bounds of architecture provides opportunities to iteratively experiment and engage with users through built work at a variety of scales.[136]

Picon identifies three established categories of users who have traditionally interacted with ornament in specific ways: its designers, makers and users.[137] The category of "makers" includes decorative artists and skilled craftspeople. The users and recipients of architectural ornament range from the casual observers passing by and through buildings to clients who use ornament as a way of customizing their spaces and a means of self-expression, commissioning architecture as a form of autobiography.[138]

Analyzing contemporary ornament through the lens of these user groups, Picon suggests that users, designers and makers are merging into a single entity: "….the different individuals and their complex interplay, which architecture addressed in the past, are apparently becoming reduced to a single generic individual swimming in a fluid stream of patterns and affect."[139]

Along with increasing access to manufacturing technologies in academia and in practice, there has been an increasing proliferation of non-standard, experimental architectural pavilions, installations and prototypes developed by teams of digitally enabled designer/fabricators. Picon speculates about whether contemporary approaches to ornamentation are allowing designers to reinterpret ideas involving hand-craft. He cites Gramazio and Kohler as examples of technologically enabled designers overtaking the domain of the artisan in the production of mass customized, precise and cost-effective

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[136] (Szivos, 2011)
[137] (Picon, 2016, p. 12)
[138] (Picon, 2016, p. 14)
[139] (Picon, 2016, p. 18)

ornamentation.[140] Gramazio and Kohler have written that their notion of a robotically-enabled digital craft is not intended to revive Ruskin's romantic idealization of the craftsperson by translating craft processes into robotic movements. Instead, they propose that robotic fabrication provides a 'machinic interface' which opens up new opportunities to incorporate technique and individuality into robotic movements and constructed objects.[141]

For Picon, the disruption of traditional boundaries and classifications is related to the influence of globalization and the internet age. By shifting focus from individual experience to the interconnected network of relationships between users, future developments in contemporary ornamentation present new opportunities for designers to communicate meaning and express mutual experience.[142]

3.5 Conclusion

This chapter has investigated how contemporary notions of ornament have changed the relationships between different user groups. New fabrication-optimized design and production tools and newly emerging robotic fabrication workflows have fundamentally altered the role of the designer, requiring a digitally networked and highly collaborative approach to practice which blurs the boundaries between disciplines, processes, clients and users.

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[140] (Picon, 2016, p. 17)
[141] (Kohler, Gramazio, & Willman, 2014, p. 189)
[142] (Picon, 2016)

These technologies can potentially be seen as a layer of separation between the maker and the embodied, tactile connection to material and technique associated with handcraft. At the same time, they have opened up new possibilities for the development of digital craftsmanship enabled by access to digital tools and technologies for design and production and the potential for creative expression and improvisation in both physical and digital space. From this perspective, these technologies are providing interfaces and platforms which link designers, users, makers and environments. At the same time, they are generating data which informs further research into the perceptual and cognitive aspects of user experience. The act of making provides designers with an embodied experience allowing for a deeper understanding of the cultural implications of emerging design and production technology.

Expanding on these observations, I propose that by allowing users, makers and designers greater freedom to tune and customize their own environments, digitally designed and fabricated ornament can function as an interface to enable engagement between users and across scales of material culture.

In order to investigate this proposal, I have conducted research on a set of existing practices and interviewed practitioners. In the next chapter I will present these case studies and recorded observations.

Chapter Four: **ALTERNATIVE FORMS OF PRACTICE**

4.1 Introduction

Previous chapters have examined the evolution of contemporary architectural ornament, the introduction of machinic production and the implications for perception and craft. This chapter will explore how designers and makers are incorporating these ideas into practice, and bringing them into the public realm.

There are many examples of design and research studios and collectives whose work operates in a hybrid space between ornament, object and architecture, and who are concerned both with designing and making using digital tools. I have chosen to focus on three examples of collaborative design practices who work in the public realm. They fall within a spectrum of experimental forms of aesthetic practice involving ornament, material exploration, perception and production. Some of these practices are highly dependent on computation and technology while others take a more traditional approach. In some cases, they engage with the built environment as both designers and makers, using a mixture of digital and analog processes. They share a common focus on the production of models, mockups, prototypes and built works that exemplify, to varying degrees, both digital and traditional craftsmanship.

These design practices demonstrate how pattern, form and material can engage user's perception through public works that challenge our idea of what contemporary architectural ornament and public sculpture mean. They also show how networks and interfaces between the digital and physical worlds are allowing the roles of designer, maker and user to begin to merge.

To support the objectives of this research, I conducted interviews with practitioners working in the field of architectural ornament and public space. These interviews helped to shed light on what is involved with developing a successful business model within this space.

I was interested in learning:

- What types of specializations has the practice developed.
- What role does digital design and fabrication play in the practice, and what digital tools and processes (software, or processes like 3d printing, CNC, robotics) are employed most frequently and why?
- How has the role of digital design and fabrication tools within the practice evolved over time, and where is it going in the future?
- Does the practice engage with making by building its own work or producing mockups and prototypes as part of the design process?
- How does digital technology influence the design process or the conceptual content of the work?
- How does engaging with digital design and fabrication processes change how the practice interacts with its clients, subcontractors and consultants?

In the interview summaries, I have organized my lines of inquiry under the following headings:

- Overview
- Origin
- Specializations
- Design and business evolution
- Craft and the Design process
- Collaboration
- Engagement

4.2 CASE STUDY 1: GEIST/LEIGHTON/CHA

OVERVIEW

I had the opportunity to work with this artist team as a local artist mentee during the fabrication and install of the Triassic Towers project in 2016-17. I also travelled to New York to conduct studio visits with the team and to learn about their respective roles. During this time, I was able to speak extensively with each of the team members and gain a good understanding of their practice.

ORIGIN

The team is composed of three members who are based in New York: Del Geist, Patricia Leighton and Taewook Cha. Del and Patricia have collaborated for more than 20 years on a number of environmental artworks in the public realm around the world. Cha began collaborating with Geist and Leighton more recently, after having initially worked as a consultant on one of their projects.

SPECIALIZATIONS

Patricia, Del and Taewook each bring their own unique skillsets but share a common love for landscape and the environment and sensitivity to the unique conditions of a particular site. Patricia Leighton, who grew up in Scotland, has been working with earth as a medium for almost 3 decades. Her best known work is “Sawtooth Ramps,” occupying a 95acre site located between Edinburgh and Glasgow. It is one of several large-scale, permanent commissions she has completed worldwide, which relate to the history of a given site and its environmental and ecological conditions. Describing the apparently simple yet timeless landforms that she produces, Patricia notes “Each project

brings a new set of parameters, the history of the site, its people the geology. The scale of the site, its energy and form are starting points for the development of a site-sculpture."[143] Many of Patricia's site-sculptures involve transportation and infrastructure, often utilizing excess soil from excavations and creating work at a scale that can be seen and experienced from the air or from freeways. The works typically require collaborations across a set of diverse fields with ecologists, engineers, architects and landscape architects.

Figure 7. Fabrication of Triassic Towers, Del Geist, 2017

[143] (Henry, 2002)

Del Geist has been producing art for the public realm for more than 30 years. Drawing his inspiration from geology, he has developed several major site-specific artworks throughout North America and Europe. His largest projects have been collaborations with Patricia, including “Barum Stenning” in Barnstaple, England, and “Passage,” located at the Roosville Canada/US Border Station, Montana. “Passage” featured five 25-ton boulders set on steel supports, spread out across a 1000ft field. Del says he came by his love of geology as a boy growing up in North Dakota on a farm located on a glacial moraine, where he collected rocks. He went on to study geology, architecture and environmental art. Del’s sculptures raise selected pieces of local natural stone into the air using fabricated steel support structures. The works aren’t representational, their aim is to elevate and honor the natural world that lies beneath our feet.

Taewook Cha is a graduate of the Harvard Graduate School of Design, a registered Landscape Architect and founding principal of Supermass Studio. He has previously worked for Hargreaves and Associates, and Field Operations, and was involved in the design of the Highline Park in New York City. Supermass’ most recent project is “Concourse Park,” an indoor landscape in the new terminal of LaGuardia Airport, New York.

Taewook began working as a consultant with Patricia on a project for Charlotte, North Carolina which was never built. Having gained previous experience working with Mechanically Stabilized Earth (MSE) in a number of landscape architecture projects, he was able to provide expertise in the design and planning of large earthworks. They decided to form a partnership and have gone on to collaborate on other public art projects, including their project in Calgary.

A 2002 installation of Patricia's work in the Vanderbilt Hall of Grand Central Station was titled "Monuments to Nature." This name encapsulates the scale, materiality and tone of the work that this artist team produces.

As a team, Geist, Leighton and Cha are primarily focused on entering international design competitions for large scale public sculpture. Their primary area of expertise is in working with large-scale earthworks and stone sculpture. They have worked extensively with MSE, quarried stone and fabricated metal structures. Their role in projects is typically to produce concept designs in the form of models and maquettes, drawings, renderings and other graphics and then, if selected, to work with consultants, administrators and subcontractors to produce detailed construction documentation and to manage the project. They are also heavily involved with managing the production process, spending time on site and in production facilities overseeing the work. Within this process, each team member has their own specific roles. Del and Patricia describe Taewook as an excellent project manager with a gift for organization and coordination of people and tasks. Del and Patricia both acknowledge that Taewook has a very "level-headed" approach, while they can occasionally let their frustrations with the challenges involved in managing projects boil over. According to Taewook, Del and Patricia have a unique way seeing and understanding the world which comes from the fact that they are true artists.

DESIGN AND BUSINESS EVOLUTION

Throughout each of the team member's careers, a focus on scale, site specificity, landscape and ecology have been common themes. Since they began working together,

their collaboration has allowed the team to take on larger and more complex projects. At the same time, it hasn't been a guarantee of success. They have now had a number of projects which have been halted in the design phase. They also acknowledge that the constraints and challenges of public art projects mean that even if they do successfully make it to completion, they are difficult to justify financially. "I think we are a great team," says Del, "but I'll tell you, we need to figure out how to make some money." According to Taewook, the challenges of running a landscape architecture practice are insignificant compared with the challenges of running a public art practice. "I thought I was in the wrong business, but now I think my mom was right – she didn't want me to become an artist."

Figure 8. Del Geist and Patricia Leighton in her studio

Each project brings a different set of challenges and constraints. For example, the contract for their public art project in Calgary was quite different from other contracts they have previously worked with. According to the team, there was less clarity and less leeway in the artists' contract fee. The team was surprised how much of the budget has been taken up by engineering. This was due mostly to revisions and additional requests

for information required by the City, which usually generated at least as much if not more work for the artist team, in terms of project management, than for the engineers, but was not billable due to the fixed nature of the artists' fee. Del says he was "shocked" at how much the engineering has cost. According to Taewook, "If I had known that the engineering was going to be such a significant portion, I would have asked for a higher fee." In past projects for other jurisdictions, there was always an incentive to be efficient. Taewook says: "I was naively thinking that if we can finish the project for less than the budget, we would keep the rest... I guess on the other hand, if we are over budget, it's the owner's problem, although according to the contract, we are responsible for delivering the project on time and on budget."

Figure 9. Triassic Towers, Installation, 2017.

According to Patricia, the issue of ongoing conservation and maintenance of public artworks has become a major factor which artist teams and administrators need to address, and it can sometimes kill projects. In the case of their project in Calgary, the city's conservation consultant released a report highlighting a number of concerns with

their work which added additional design and engineering revisions when they thought they had already completed the detailed design. In addition, it was difficult to find a contractor who would take responsibility for providing a fixed price to maintain the earthwork portion of the project.

These factors mean that even for an established artist team with a track record of completed projects in the public realm, the challenge of turning a public art practice into a viable business model is still a work in progress. Fortunately, besides working as a collective, the members also all have individual practices which sustain them. Their individual work ranges from public art and landscape design to drawings, prints and small scale sculptural objects for exhibitions or private collections. According to Del and Patricia, "if you don't do site specific work, if you make objects, or "plop art,' you can make money."

CRAFT AND THE DESIGN PROCESS

Digital design has played an increasingly important role in the team's work. It has become an expectation in public art projects that the artist team should provide renderings and CAD drawings. Bringing in Cha as a team member has expanded the team's abilities in this area, as it is a required skill-set for his landscape architectural practice. Cha produces the majority of CAD drawings, digital models and renderings. As a team they all work both digitally and physically, producing models, sketches, drawings and renderings.

For their project in Calgary, the team employed a mixture of digital and analog processes for design and fabrication. They produced renderings of the project, which

Patricia would augment with traditional hand drawing and watercolour techniques. These images were used as communication devices to explain the project to the selection jury. They also became artifacts serving to document the design process in an expressive way by communicating not only the intended shape and form, but also the more intangible aspects of the project such as the experience of moving past the works at different speeds and in different seasons.

Figure 10. Triassic Towers, model, L and stone selection at Kamenka Quarry, R, 2017.

The team also produced digital and physical scale models of the various aspects of the project. For the towers, Geist produced a hand-built scale model of the work. He then worked with a draftsperson to reproduce the model in Rhinoceros3d. When the team visited Kamenka Quarry near Canmore to select stones, their selections were accurately measured and photographed, and the digital model was updated. This allowed the braces and supports for the stones to be precisely located in the digital model. The locations of the supports determined from the digital model were transferred to the stones and were drilled using a diamond hole-saw at Amico Stone Supply, a local stone shop. This allowed the stones to be hoisted by a crane and set onto their supports. The exact

placement of the supports was left until the stones were installed on the towers on-site, allowing for any required adjustments.

The artists were also expected to provide extensive technical drawings and engineering details for the works. They worked with RJC engineers to structurally detail the towers and their footings, and a number of subcontractors, including Metalfab, a local metal fabricator and Tensar/Nylex, a MSE consultant located in Calgary who provided a detailed design for the earthworks portion of the proposal.

COLLABORATION

Delivering large-scale public art projects requires significant collaboration, both within the design team and with the many levels of administrators, consultants and stakeholders. As each team member has their own specialties and strengths, they rely on each other throughout the design and project management phases of the project. Del and Patricia live together and have studios across the hall from each other, which means they are able to continuously discuss projects and bounce ideas off each other. Their working methods and the way in which they approach their individual practices are very different. In the studio, Del is very hands on, making models, welding, drilling stone and arranging objects, while Patricia has a more conceptual approach based on drawing, painting and writing. When they collaborate, their styles balance each other. They note that Taewook brings a great deal of diligence, pragmatism and skill when it comes to project management, organization and communication. For Taewook, working with Patricia and Del provides a different way of designing and creating based on intuition. Their approach to understanding and interpreting a site has in turn been influential on his landscape architecture practice.

The use of physical and digital models allows the design team to communicate the intent of the project to the various subcontractors and consultants involved in their projects. For example, in the case of Triassic Towers, the physical and digital models were used as explanatory aids in communications with the engineering team, the city and the fabricators throughout the bidding and construction phases of the project. Visiting the metal fabricator, Del would pull out the model, compare the as-built structure and ensure that the drawings had been executed properly. He did actually find an error in the framing that the fabricator was able to fix before the final welding was completed. On site, as the stones were being placed, the model again proved useful as Del stood on the opposite side of the Trans-Canada highway from the site, giving instructions to the crane operator and welding team about the specific placement and angle of the stones over a cell phone.

The team acknowledges that collaboration can be difficult, especially when there are large committees of administrators and stakeholders involved, as is often the case in public projects. They brought up several examples where projects which had been negotiated for months and were almost completely designed, were eventually canceled due to a lack of coordination, sometimes through the unilateral actions of a single administrator. Public art is contentious, and ego and competing interests can play into decision. Often, the team is left to speculate about the final outcomes, with no way of really knowing the true motivations behind them.

ENGAGEMENT

While their projects aren't directly driven by public engagement, the team seeks to learn as much as possible about the local site in developing their designs. In the case of their project in Calgary, the team met with local consultants referred to them by the city administration. These experts included an indigenous elder and a historian who walked the site with the team, bringing them to significant landmarks nearby, including a glacial erratic located within the green space of the Paskapoo Slopes. In addition to these consultants, they also drew heavily on the expertise of local quarry owner Louis Kamenka, who provided insight on local geology and on the character of stones used in the work. They also engaged with the public after the unveiling of the work, responding to letters and giving media interviews. In responding to the controversy over the work, Del says, "I would prefer not to speak, and instead to have the city speak on my behalf, but for the artist not to talk at all does not work, I believe. I remember the controversy about Richard Serra's Tilted Arc…Serra would not address the people. People considered him aloof, and he caught no empathy. That sculpture is gone. It was, at the time, the best artwork in NYC."

Figure 11. Triassic Towers, installation, 2017

4.3 CASE STUDY 2: PROJECTONE STUDIO

Figure 12. Extess, Project One Studio, Muncie, IN, 2016

OVERVIEW

I had the opportunity to visit Kyle and Adam from Projectone in March of 2017. During my visit I was able to conduct an interview in order to gain an understanding of their practice and learn about their respective roles. When I spoke to the team they were in the process of moving from their long-time shop in Muncie, Indiana to a larger space in Indianapolis so they can scale up their business and take on larger commissions.

ORIGIN

Projectone started in 2009 as a collaborative architecture thesis project between Kyle Perry, Adam Buente, Elizabeth Boone and Eric Brockmeyer, who at the time were Architecture students at Ball State University. The goal of the thesis was to develop a business informed by the tools and techniques they had learned in architecture school and launch it while they were still finishing their studies. It started out as a series of industrial design experiments and mockups that could be scaled up to building scale

projects. The team branded themselves as a business rather than a school project from the outset in order to legitimize their work. The commissions they received while still in school laid the groundwork for their next projects after graduation. Today, Kyle and Adam are the two remaining partners in the business.

SPECIALIZATIONS

Early on in their studies and at the outset of launching their business, digital craft was an important concern for Projectone. The team uses scripting tools including Grasshopper3d in a way that they describe as "post-digital". Software is just another tool to speed up workflows and iterate through design options. They note that form has proved challenging, and that for them, shape is less of a priority than fabrication and patterning systems and novel combinations of material and technique. They don't use digital processes for their own sake, or to show off. They extensively rely on flat-cut production processes employing CNC cutting of sheet goods, including aluminum, plywood, acrylic and composite materials. Often their designs require a considerable amount of intricate assembly work, and use tabs and tags to connect component parts and assemblies.

The two partners work side by side, collaborating intensively on all of their projects. Their desks sit directly next to each other in their office, and they both have the ability to use Rhinoceros, Grasshopper and the range of fabrication equipment in their shop, including their 3 axis CNC table with automatic tool changing ability (figure 14). This collaborative partnership allows them to solve problems, make decisions and change course rapidly if necessary. This type of collaboration requires a relinquishing of individual agency to some degree - neither team member has a greater sense of

authorship over various designs than the other, and when they get too attached to ideas, they can help each other see the larger picture.

DESIGN/BUSINESS EVOLUTION

Their work is primarily focused on two channels. They actively seek out public art projects, and seek to network with other design firms including architects who can contract them for interior and exterior installations and sculptures for clients. Often the public art projects are more financially constrained, but offer a greater chance to increase their profile, while the work for clients can be more financially lucrative.

They note that an important lesson they have learned is that, while it is difficult to turn down work, sometimes saying no is better than taking a job and losing money, or missing out on a better opportunity.

Digital design has played a key role in Projectone since their inception. It is part of their brand, and it allows them to differentiate their work from other competitors in their field. As they develop more projects, their workflows become more streamlined and integrated. Adam and Kyle noted that one of the first lessons they learned in business was the importance of real-world timelines. Projects are often delayed, so the team needed the ability to shift focus, and move one project on to the back burner for a while to seek other opportunities. Renderings, models, diagrams and CAD are critical to their process of responding for calls for submission and design competitions. However, according to Kyle, what really sets their work apart from others working in the public art realm in terms of its content is the fact that "We think like architects." They see their work as a service for a client, rather than as an ideological expression. Their work brings

some of the ideas around technology and culture that have been developing in architecture since the digital revolution out into the community and into mainstream public consciousness. Working at the scale of urban ornament allows them to move through projects with more speed than if they were doing traditional architectural design.

They note the importance of differentiating what they do from what others are doing, of not copying other's work, even when clients ask them to, and of not repeating their own work. Each project has to have enough novelty to make it interesting for them, and in each project they find ways to make it their own, and to take pride in the details and the execution.

DIGITAL/ANALOG CRAFT and DESIGN PROCESS

In their design process, Kyle and Adam go back and forth between digital and physical space. Over time, they have developed techniques and specialties as a function of the equipment they have available. They note that some of this equipment, such as CNC machines which were originally developed for mass manufacturing, have been re-purposed by small entities like themselves to be used in new and innovative ways. According to Adam, "There's a million ways you can interrogate a tool to do so many different things." Access to these tools brings freedom and flexibility as well as constraints, and in the end, every job is a combination of both digital and manual production. "everything produced by a machine still has to meet up with something in the real world that was made by someone's hand and was measured and cut... sometimes wrong."

Kyle and Adam test their ideas using mockups and prototypes. They also fabricate and install their own work. They occasionally sub out some aspects of the production such as paint, but often will try to do as much as possible themselves. This requires them to constantly learn new skills and procedures.

"Being a fabricator, designer and installer allows you to create different working relationships with people. It opens the floodgates for a better understanding of the entire process, which makes the quality and craft of the project better. Understanding things like machine tolerances or material properties allows the designer to account for those variables early in the design process. This is particularly critical in the case of installations. Being the person who is going to install the work makes you think about installation early on in the design." Designing the work in a parametric environment and fabricating it themselves allows the team to produce efficient design to fabrication workflows as there is less need for layers of communication and translation. Dialog and self-reflection throughout the design and production process is what allows the team-members to be flexible and to find opportunities and efficiencies within each project.

DIGITAL COLLABORATION

Designing, making and installing their own work provides Projectone with opportunities to learn about all aspects of the process and take that knowledge forward into future projects. This creates different working relationships with fabricators and clients. Digital production helps the team to save material, time and effort while allowing them to engage with complexity. It allows for visualization of the completed work as a communicative device. It helps the team members to communicate with each other, rotating models and iterating through design options rapidly.

ENGAGEMENT

Adam and Kyle note that they don't start projects with community outreach, and engagement is not part of their design process. They want to projects to speak for themselves. This is one of the factors that sets their work apart from more traditional public sculpture practices. Their engagement strategy is to make work which is engaging, and which is different from the rest of the public art projects out there. They note that this is partially due to their size and location, hidden away in a small town. When they scale up and move to a larger center, their approach may need to change, but for now they have little interest in art activism. They leave what they see as the "visionary" work of initiating public projects, getting the public on board and finding funding to those who are better suited for that role, and instead concentrate on making and doing. "Our focus is on how we take a project and make it the best thing it can be for us and for the users and the site."

While they have created interactive, responsive works which are augmented with digital technologies such as sensors and actuators, Adam and Kyle are currently more interested in creating a layered experience of space where users encounter multiple levels of complexity at different scales. This complexity can be created through detailing, colour and pattern, and a mix of global and local variation. In the case of their recent work for the town plaza in Muncie, they created a colourful triangulated wall out of aluminum nodes and struts. The form and colour grab the viewer's attention, drawing them in. As the viewer moves around the work towards the back, the edges of the triangulated apertures align with a point of view looking towards the historic town hall. The struts and nodes disappear momentarily as the eye shifts from the foreground to the

background plane, creating a tromp l'oielle effect. Kyle and Adam argue that this type of experience of static space, form and pattern can be as engaging and interactive as a digitally responsive installation involving video or kinetic components. They believe that users find varying levels of complexity at multiple scales engaging. The trick is to find right blend of simplicity and complexity, where a project isn't a one liner but at the same time doesn't have too many variables, to the point where it is out of control. "We're always questioning; is this enough, or can we push this further?"

Figure 13. Kyle Perry and Adam Buente in their studio in Muncie, IN

4.4 CASE STUDY 3: THEVERYMANY

OVERVIEW

I had the opportunity to visit and interview Marc Fornes from Theverymany at his studio in Brooklyn in 2017. During the interview I asked Marc about his team, their practice and their respective roles. Theverymany's work focuses on computational design of self-supporting shell structures composed of strips of thin-gage aluminum woven and riveted together. Each project is larger and more robust than the last, and represents a trajectory of research into the optimization and discretization of meshes capable of generating

aesthetic and ornamental effects. These structures operate as installations, sculptures, amphitheaters, and urban ornaments for clients ranging from municipal governments to developers to cruise liners to fashion designers. They extensively rely on flat-cut production processes employing CNC cutting of sheet goods, including aluminum, plywood and other materials. Often their designs require a considerable amount of intricate assembly work, and use tabs and tags to connect component parts and assemblies.

ORIGIN

Theverymany started in the early 2000's, as a way to explore notions of space and the craft of building outside of an academic context. According to Fornes, at that time, being interested in fabricating your own work meant that you needed to use analog processes like sculpting in plaster and making fiberglass molds. Digital tools were still in their infancy, software was extremely expensive and slow, and often required a team of programmers to troubleshoot problems. As a way of responding to these challenges, Fornes founded Theverymany to begin to experiment with scripting techniques for describing and rationalizing complex form.

At the time, digital modeling software such as Rhino3d was very limited, with no rendering capabilities and no plugins, just simple NURBS surface modeling. Through their early experiments, Theverymany realized they could overcome the software's limitations by accessing its underlying language, known as Rhinoscript and writing their own routines and procedures to automate tasks in order to address greater levels of complexity. Theverymany published the scripts they developed along with documentation of the results in a blog, and exhibited the works, which Fornes describes

as “proofs of concept.” These exhibitions led to more opportunities, and the projects increased in scale from objects to installations. Often these temporary installation projects were paid for through arts funding. As the scale and complexity of the projects continued to grow, the team began to look for opportunities to fund and develop larger and more permanent works. Moving in to the public art field provided a means of supporting these larger and more ambitious projects. Marc says this jump in scale took approximately 5 years.

SPECIALIZATIONS

According to Fornes, Theverymany’s work can be boiled down to 3 major themes.

1: descriptive geometry of complex curvature with flat panels, linear and non-linear strips

2: Ultra-thin self-supported geometries which leverage double-curved geometries to generate space, structure envelope.

3: Computationally driven coloration systems which accentuate or disrupt part to part relationships and create global effects

Through focusing on these 3 discrete research problems in all their work, Theverymany has produced spaces which play with user’s perception and experience of space and form, bringing them outside of the typical experience of daily life and into continuous, edgeless, curving environments augmented with light and colour.

Each work is an iterative experiment. For Fornes, this is something that has not been adequately addressed by digital design researchers. “We’ve always said that you can do the nicest model in the world, (but) at the end you can’t prove your concept, you can’t

test it, let it be understood through someone's experience, understand by someone else, and feedback your research. So in the interest of growing in scale, I was really interested to be able to say: hey, I envision that, I need to test it."

DESIGN/BUSINESS EVOLUTION

Fornes notes that he never woke up one day with the intention of doing public art, because it was never really a model of practice that previously existed for architects. Theverymany moved into the space as a result of their process of iterative problem solving. Working in the public art realm has allowed them to continue the "slow, gentle growth," that allowed them to jump in scale from temporary installations to permanent pavilions and amphitheaters. Each built project is also a means of building trust with clients and the public. Fornes states that the field of public art isn't a destination, but at the moment it is an ideal space for experimentation. At the same time, it comes with its own set of complications. Fornes describes his approach as "practicing at the edge, but staying on your side of the border." He doesn't claim to be an artist, and is aware that many artists don't think of his work as Art. While they are competing against artists in public art competitions, they are trained as architects. Their tools and techniques allow them to provide value in the form of space. At the same time, Architects think that what they do isn't architecture. Fornes however argues that this is "absolutely not true, because, compared with theoretical projects that never get built, we are actually engaged in place-making and the production of social space."

For Fornes, "working at the edge" also means knowing how to craft different narratives for different audiences. This requires the ability to change how projects are described in terms of their conceptual, technical and formal qualities for different audiences. For

example, Fornes notes that his pop-up project for Louis Vuitton was the first architectural structure ever fabricated completely in carbon fiber. This agenda was driven entirely by the design team in response to the logistical requirements of the project rather than by the client. However, in discussing the project they generally focus on its aesthetic qualities, downplaying the technical aspects of the project.

DIGITAL/ANALOG CRAFT and DESIGN PROCESS

In their design process, Marc and his staff primarily work in digital scripting design environments. Renderings, models, diagrams and CAD are critical to their process of responding for calls for submission and design competitions. Digital design techniques allow for the detection of clashes, structural and material optimization and integration with existing structures. As these problems are overcome, the team is able to take on larger and more ambitious projects, further advancing their design research. Rather than designing an object, Theverymany designs unified systems which fuse ornament, structure and aperture to express form, space and light.

They have mockups fabricated and assemble the components in their studio to test out connection strategies and assembly processes. They are heavily involved in the installation of their own work. They subcontract out aspects of the production such as machining and coating of parts. This requires the production of extensive documentation for the production and assembly of the work. Systems for nesting, tagging and tabbing thousands of individual components are critical. Designing the work parametrically and being involved in its installation allows the team to develop efficient design-to-fabrication workflows, but requires good communication and good relationships with subcontractors.

Fornes is intrigued by cutting edge developments in construction technology and the potentials that the future holds, but his practice is firmly rooted in what is buildable and achievable today. “I’m more intrigued with what is possible now with cutting edge technology we are developing.”

Marc notes that while he sees architects generally taking less and less responsibility for construction documentation, Theverymany is much more production-focused than typical architectural practices, extending beyond construction documentation and into shop drawings and machine files for fabrication. While reclaiming the territory of production was one of the promises of the early 2000’s digital revolution in architecture, Fornes argues that “the academy doesn’t talk enough about the liability and the stress that comes with that. It’s one thing to claim the territory, but it’s something else to be willing to do it.”

Fornes proposes that the digital revolution was actually two separate revolutions. The first involved digital fabrication tools and form finding software. The second, “less noisy” revolution involved the development of AutoCAD Lisp routines to automate tasks. Theverymany emerged out of these revolutions, combining the form-finding tools and the fabrication processes to begin to develop proofs of concept that these forms could be produced at an architectural scale through a unified system which supersedes the need for heavy structural members.

While there have been many design collectives who have tried to engage with the romantic idea that they can take on all aspects of design and fabrication, he has found

that it is better to engage with industry and rely on specialists who are better equipped and more skilled within their particular domains. Trying to do everything yourself, according to Fornes, limits the possibilities of design, and means you will be too busy carrying materials, fixing machines or programming robots. Also, by focusing too much on the technical aspects of fabrication, by getting lost in the process of making little triangles, designers can forget about the more ephemeral and intangible qualities of art and space, and what the true purpose of art, design and architecture really is.

DIGITAL COLLABORATION

Today, the team is led by Marc Fornes, and includes about 8 full-time collaborators. They work together in a small studio space in Brooklyn filled with mockups and prototypes. According to Fornes, the idea of the digital design and fabrication collaborative has been romanticized as a means of self-promotion, and in his experience, real collaboration has been more difficult. Each project requires collaboration with the fabrication team and the client in order to realize the budgetary, regulatory and logistical demands of the project. However, being responsible for every part of the design, planning and oversight of projects in house requires a great degree of attention to detail, and a high level of commitment. Fornes describes the design and detailing process as "very introverted," and "highly empirical". The team is engaged in an iterative problem-solving process in which solutions emerge from working within the project parameters and building off of the learning from previous projects. By controlling the variables and limiting their scope to a few principle lines of investigation, they have been able to innovate, inventing new techniques and systems to advance their specific agenda.

ENGAGEMENT

While Theverymany don't have an explicitly defined public engagement strategy, building and testing ideas in the real world provides a wealth of information which feeds back into the projects. Every aspect of a project can be thought of as a performance metric; even how it is shared on social media sites like Instagram. Fornes notes that posting a selfie in front of a project "means you're engaged with it, you felt the necessity of putting yourself in front of it ...By following those appropriation pictures, as we call them here, we do learn more."

4.5 CONCLUSION

This chapter has examined case studies of collaborative forms of practice who design and make ornament, objects and public sculpture, and who, to varying extents, engage with digital technologies. These case studies have helped to shed light on the challenges of developing a successful business model within the hybrid space between art and architecture in the public realm, and the opportunities that this form of practice offers.

This analysis shows that there is a broad spectrum of possible approaches to working in this field, ranging from traditional and site-specific to radical forms emerging from digital experimentation. Pattern and ornament play an important role in each of these practices. In the case of Leighton, Geist and Cha, pattern is expressed in the rhythm of repetitive forms with slight variations, and in the expression of the natural patterns of stone. Theverymany are the most fully engaged with computational design, and perhaps the least concerned with site and context, while Leighton, Geist and Cha's approach is more rooted in traditional sculpture, modeling and sketching in pursuit of revealing something essential about a site. Projectone admit that form continues to pose a

challenge, and choose instead to focus on surface and pattern. Both Projectone and Leighton, Geist and Cha are interested in interrogating materials and processes, while Theverymany prioritizes the idea of a "unified system" which addresses form, space and envelope. Leighton, Geist and Cha and Projectone are both very hands on, engaging with their projects both as designers and makers, while Theverymany acknowledges the economies of scale available through specialized industrial production processes, and accepts the responsibility of producing the necessary fabrication files.

In all three cases, the practitioners were quick to point out the need to balance creative exploration with the realities of maintaining a business, which sometimes put constraints on their creativity. In each case, every new project represents an opportunity to learn from the mistakes of previous ones, to try new techniques and to constantly improve in terms of efficiency, scale and impact.

These case studies show how pattern, form and material can be leveraged in a variety of different ways to engage user's perception through public works that push the boundaries of contemporary architectural ornament and public sculpture. They demonstrate how networks between the digital and physical worlds are blurring the boundaries between the roles of designers, makers and users of public space, and how designers and their works can function as interfaces or connection points between site, materials, technologies and the public.

As an observer of these different approaches to practice, I was struck by the high level of collaboration that takes place between team members, particularly between Adam and Kyle and Del and Patricia. Working side by side, day in and day out, collaborating with their hands and their minds has allowed them to form deep connections, to the point

where they regularly finish each other's sentences. More external forms of collaboration, with administrators, consultants and stakeholders seemed to be a challenge for everyone I interviewed. A common discussion point was the importance of communication. Each of the case studies described the process of adapting their narrative to suit a particular audience, whether it is the jury, the fabrication team or the general public.

In all of the case studies, a mixture of digital technologies and human intuition play into the creative process. It is interesting to speculate about how amplifying one or the other of these properties would affect the practice and the work. In the case of *Triassic Towers*, employing parametric modeling techniques could have helped to mitigate some of the cost and hassle of being required to re-engineer their work multiple times. Ultimately the larger issue with their project, and one which was out of their control, is the way it was received and the communication strategy chosen by city administration. As a result of the controversy around the project, members of city council have suggested that perhaps allowing the public to see and respond to digital renderings of artworks early in the selection process, or even selecting artworks via web poll could help address some of the concerns around the public art program.[144] While I am in favor of providing opportunities for increased engagement early in the design process, my concern is that this approach represents a superficial form of participation which will prioritize appealing imagery over meaningful and inclusive narratives.

For all three case studies, public engagement was not what drives their projects. There is minimal preliminary engagement with the public at the outset of projects - in most cases the designs were developed without input from the public. The focus is on making work

[144] (Gerson, 2017)

that is engaging to users, rather than producing work that emerges as a result of engagement exercises. In all cases, the works are proof of concept experiments which exist within the urban realm, providing further opportunities to learn about how users, designers and makers experience the built environment. The next chapter will outline a series of case studies developed by the author which investigate various methods for engaging user groups through ornament, pattern and digital design and fabrication technologies.

Chapter Five: **CASE STUDIES IN DIGITAL ORNAMENT**

5.1 Introduction

In this chapter I will describe a series of case studies illustrating my personal experience with computational design and fabrication of ornamental surfaces, assemblies and objects. One of the important motivations for pursuing this thesis was my on-going hands-on experimentation with ornament, sculpture, installations and objects in the public realm built using a combination of digital and analog craft processes. The design and production of the projects in these case studies occurred concurrently with the literature review and practitioner interviews, and have helped to guide the direction of my research and inform the development of my practice. These case studies will be briefly summarized, as their technical details have been described more thoroughly elsewhere.

5.2 Limenitis Wall

Figure 14. Limenitis Wall, County of Stratcona, 2017

Limenitis Wall (*L-Wall* for short) is a public artwork executed for the County of Strathcona in collaboration with Jason Johnson and the Laboratory for Integrative Design (LID) (Fig16.). The work was designed and fabricated over the summer and fall of 2016 and provided an opportunity to generate and test ideas and to experiment with hands-on production techniques in a design-build scenario.

Our approach to the project was to create a component-based assembly mounted on a structural frame fixed to an exterior wall. The design of the components and the way in which they were aggregated was refined through an iterative prototyping process in which they evolved to adapt to aesthetic and functional considerations. These include the fabrication and assembly process, cost, strength and durability of the parts and their finish. Initial rough prototypes were fabricated in paper and plastic and were scaled up to full scale studies in sheet metal. The components evolved in several iterative stages from

a single element held together with rivets to a composite of two interlocking pieces with tabs and slots located to hold a specified curvature (fig. 17). Aluminum was chosen as a light-weight, easily machined and durable material capable of producing curvature, reflections and accepting surface variation through various treatment methods.

At each stage in the process, the aesthetic and performative qualities of the individual parts, as well as the composition of the assembly were evaluated. These considerations are reflected in decisions such as the shape of edges, slots and tabs, types of fasteners and color of the anodized finish.

Figure 15. Limenitis Wall, prototype models and component fabrication

L-Wall was installed on a cold weekend in November of 2016 on the south-facing exterior of a newly built "Sports Pavilion" building acting as a field house for a football field and an activity hub for the local community.

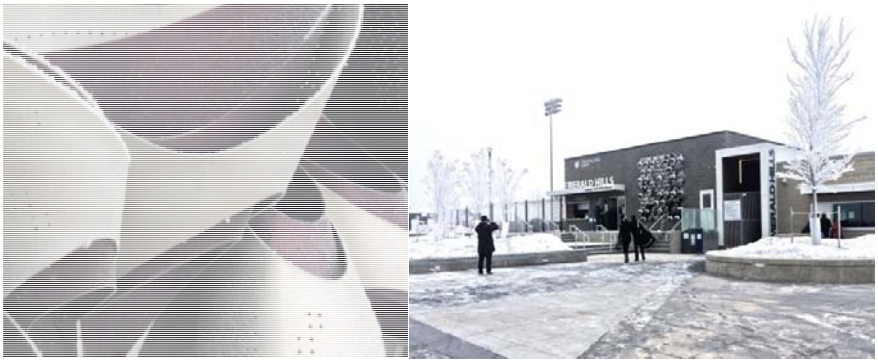

Figure 16. Limenitis Wall, detail view and overview

The official opening of the finished work early in January of 2017 provided an opportunity to gather initial feedback from community members experiencing the piece for the first time. Viewers we spoke with reported seeing a range of imagery, including armor, shields, footballs and insects, and a significant number reported that they imagined that the components resembled faces or masks. What this feedback suggested was that for a number of people, the work induces some level of pareidolia, allowing it to be read in a variety of different ways through the production of a range of potential associations.

Figure 17. Limenitis Wall, detail view

Gaining an awareness of pareidolia, realizing that it operates within a range of complexity and that it can be used to tune individual experiences of spaces, and recognizing its potential to engage users was an important outcome *L-Wall*. The project demonstrated that a wide range of user-generated, historical, or environmental information can be inscribed onto works, enriching the content and allowing for a variety of interpretations. It helped us understand how pattern and ornament can activate and provide a focal point, and how 'patterned complexity' can be a means of enriching public space. It also showed how integrating the optimization of material properties, such as adding perforations to assist in bending or expressing fasteners could also

convey ornamental qualities. Building off these lessons, subsequent projects continued to focus on developing methods for deploying image, pattern and ornamentation as a means of embedding information within forms and surfaces through digital fabrication processes.

L-wall also provided a valuable experience in producing a permanent built work which involved a number of stages:

- Developing a viable design proposal, producing explanatory images and a cohesive narrative and pitching it to a jury
- Working with consultants to understand the project requirements, including site and budgetary constraints,
- Prototyping the work and developing parametric models to test various iterations
- Producing working drawings
- Collaborating with contractors to interpret the design and overseeing their work
- Fabricating components and sub-assemblies
- Installing the project
- Producing a maintenance manual for the project
- Engaging with the public and gaining an understanding of how it was perceived and understood by different users.
- Interpreting and synthesizing the project as a design research exercise and presenting that research at an academic conference.

These lessons informed subsequent projects and laid the foundation for the development of the model of practice-based design research outlined in this chapter.

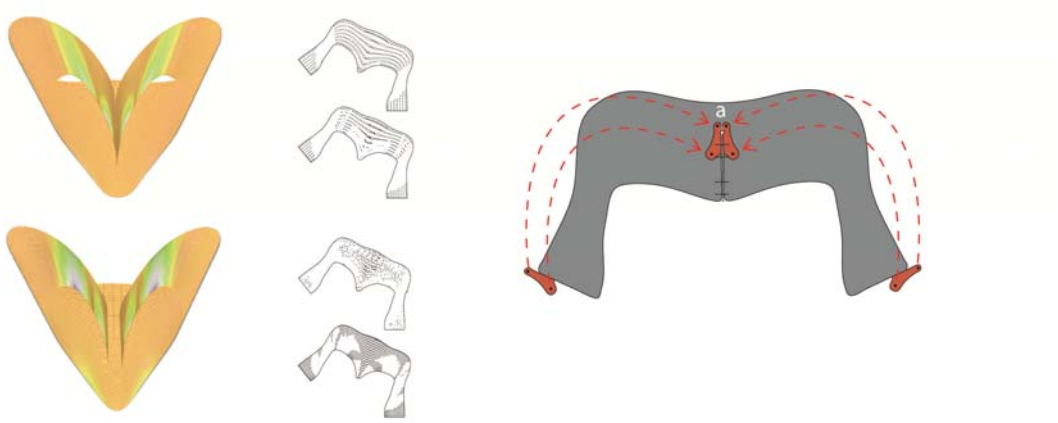

Figure 18. Limenitis Wall. perforation based on curvature analysis, L and component assembly sequence, R

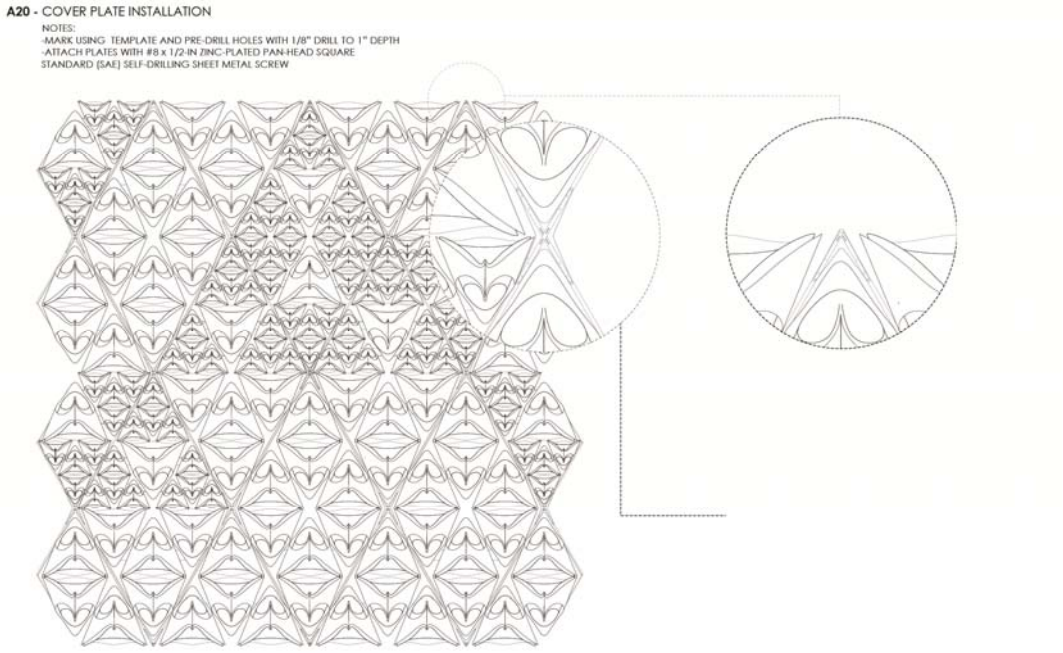

Figure 19. Limenitis Wall. Elevation and details showing the cover plate at support structure intersection points

5.3 Columnulous

Figure 20. "Columnulous,"Design Proposal, 2016

Columnulous (fig. 21) was a proposal for a series of column-like objects designed to form an entry threshold at the property line of a redeveloped historic school which has been converted into an "arts hub," including a theatre and studio spaces. The patterning and texture of the columns was designed to echo specific moments within the historic school façade. "Samples" are extracted from the original 1912 set of architectural drawings of the sandstone building's south façade, approximately corresponding to the location of each column. These samples are digitally projected onto the columns. The linework acts as a restraint as the column is digitally "inflated" (fig. 22). The inflated forms are then trimmed, creating a combination of soft surfaces and hard edges designed to be cast in concrete using CNC milled molds (fig. 23).

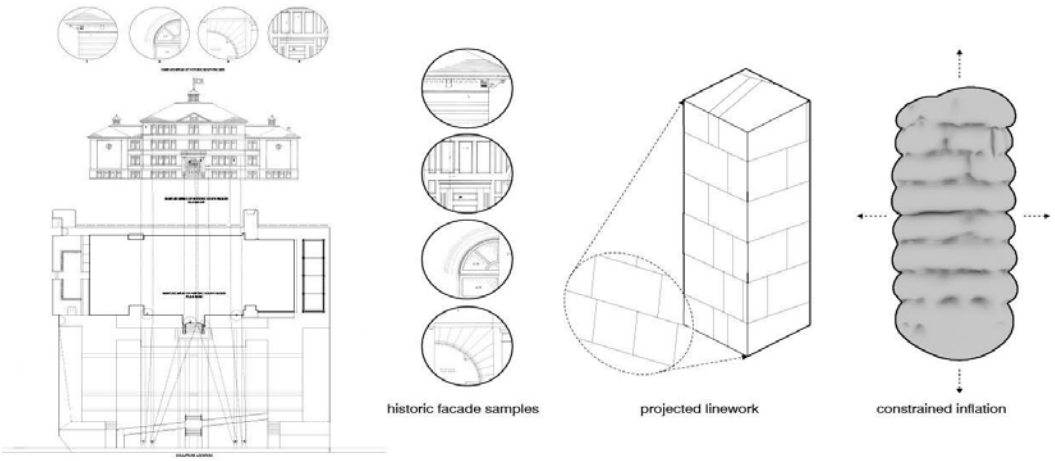

Figure 21. "Columnulous," Sampling, Projection and Inflation

The intent behind *Columnulous* is that viewers could potentially follow a similar procedure of projection and editing, translating their own subjectivity into the work. While the columns are visually connected through sightlines to the façade details that they sample, the objects can be read in a variety of ways. They operate both in series and as individual sculptural instances, and the surface patterns referencing particular moments in the building façade are obscured in a way that allows them to be read as simultaneously contextual and alien.

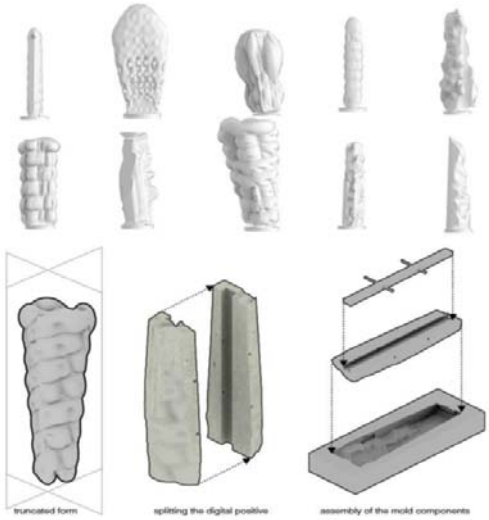

Figure 22. "Columnulous," Iterations and Fabrication

While *Columnulous* ultimately never made it past the design phase, it provided some useful lessons in approaching a public art project of this scale. These included:

- Considering the potential for existing materials, buildings and historical documentation to become useful resources in the production of a design proposal.
- Developing a contextual and site-specific response by drawing on historic documentation, and sampling and remixing that material through digital workflows
- Developing an approach which uses ornament and pattern as a means of translating generative source images and text into 3-dimensional form
- Using simulation and form-finding techniques to express ornamental qualities
- Thinking about ornamental strategies for producing volumetric rather than strictly surface-based effects

The intention for *Columnulous* was that it would provide an opportunity to use robotic hot wire cutting and milling for the production of the concrete molds. Thinking about the possibilities for incorporating robotic fabrication became a more significant consideration on subsequent projects.

5.4 Aarhus FOAMdome

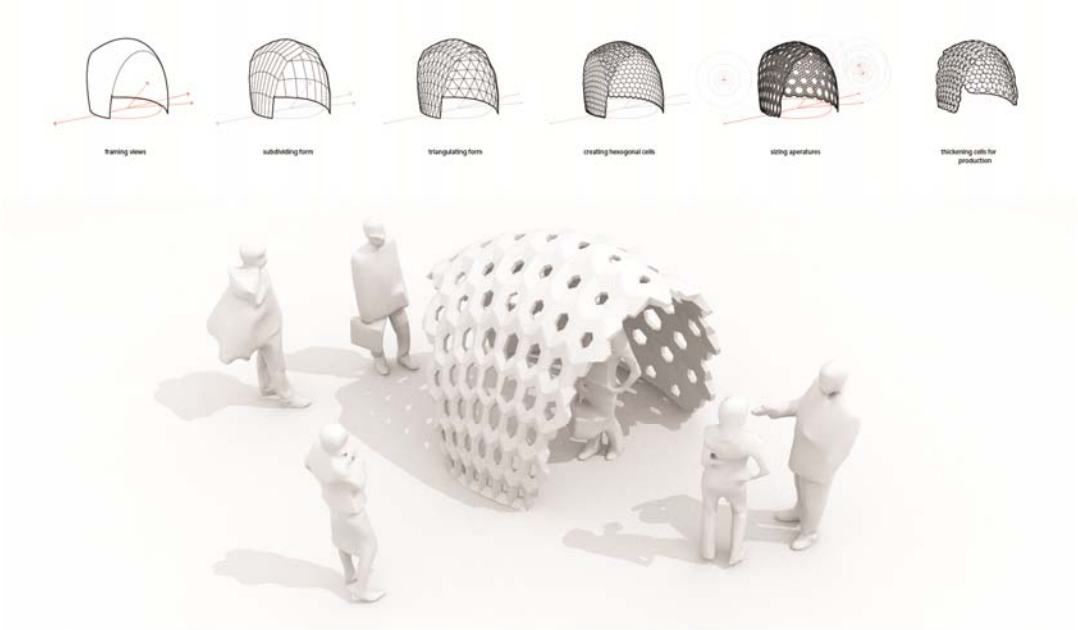

Figure 23. "Foamdome" design proposal

In the summer of 2016 I travelled to Denmark to participate in a robotic fabrication workshop in order to learn about using parametric modelling techniques in conjunction with robotic fabrication. During the course of the 10-day workshop, I worked in a team of 4 students to produce a small pavilion out of EPS foam using a robotic hot-wire cutting process. This project provided me with a first-hand introduction to the world of robotic fabrication in architecture.

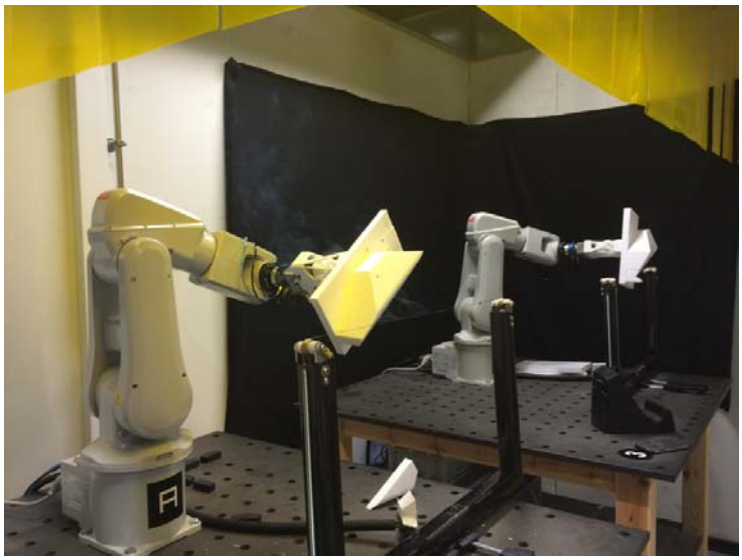

Figure 24. Robotic hot wire cutting of components

Our team developed a procedure for discretizing a vaulted structure produced using Kangaroo, a physics engine plugin for Rhino/Grasshopper into approximately 300 hexagonal components. The components were rationalized into a sequence of ruled surfaces. We performed simulations to model how the robots would pick up foam blanks using a gripper and proceed with a series of cuts using a fixed hot wire. Over the course of the last 2 days of the workshop, we output the digital components into RAPID code, the language used by ABB industrial robots, cut all the components and assembled them into chunks for transport. We then completed the final assembly of the structure at the

site of the exhibition. The components were held together using laser-cut plywood "staples," help to stabilize the piece until it was able to act under compression.

FOAMdome was a good introduction to robotic production, and taught a number of important lessons:

- How robotic movement, based on Inverse Kinematics, is different from Cartesian movement in the xyz plane used by typical CNC machines.
- The potential for a parametric script to be used to generate a sequential set of instructions for a machinic process
- The process of converting a digital model into robotic movement instructions, and the value of simulation in this process
- The importance of understanding concepts such as singularity, reach, work environment and joint collisions in planning robotic fabrication processes
- The potential for robotic fabrication as a mass-customization process

Figure 25. FOAMdome, completed installation

5.5 Solium Stock Wall

Figure 26. "Stock Wall" Solium Capital, 2017.

Stock Wall, (figure. 27) resulted from a response to a project brief from a local firm who was interested in collaborating with the LID to produce an artwork for the reception area of an office renovation they were designing. The brief called for an articulated surface with limited depth that could interact with the ambient lighting conditions of the room and communicate the unique identity of the client's brand, in this case a financial services tech firm. Taking into consideration the client's interest in technology and finance, the proposal combined data visualization and robotic fabrication to produce a sculptural, panelized wall system with a graphic element.

From the outset, we kept the design open-ended and allow for the use of a variety of source imagery and data. The intention was to develop a process which would defamiliarize an image in order to allow a range of potential interpretations. Initial investigations developed a set of techniques to generate patterns using simple materials and colours. A parametric model was used to iterate through concept designs which combined data visualization and image mapping techniques. These iterations were

shared with the client, allowing them to provide feedback and participate in the design process.

Our initial proposal was based on portraits of Queen Elizabeth from Canadian bank notes, and associated values to each pixel based on daily changes to the value of the stock market. The image was translated into a series of extrusions assigned a vector and length based on the daily change in value of the Dow Jones Industrial Average over the course of 50 years (fig. 10). The brightness values of the image were remapped to colours of the company's logo.

When we presented the proposal, the client liked the concept, but not the image. They commented that they were interested in something that spoke to the local landscape and identity. The script we had developed allowed us to quickly replace the initial proposal with a series of alternative images. We presented a series of possible choices, and the client chose one of the options. While the choice of the image was important, capturing and holding viewer's attention through the process of blurring the imagery and layering additional data onto the pixels was the most important aspect the work.

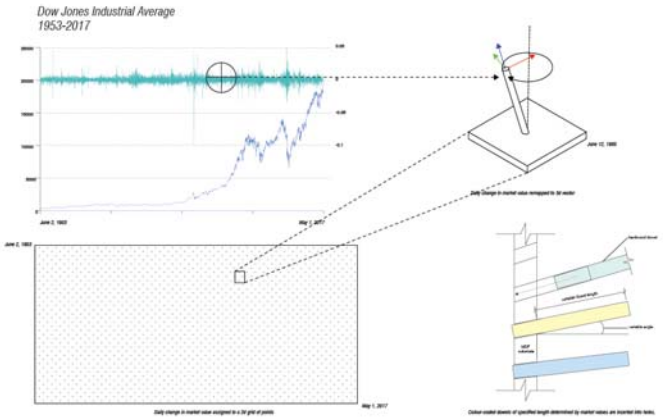

Figure 27. "Stock Wall" data mapping

Once the design was finalized, the parametric model was used to produce shop drawings and fabrication files. One of the advantages from the perspective of the client and the firm was that the project provided an opportunity to incorporate industrial robots into the digital fabrication workflow, which contributed to the narrative that the client wanted to build. The workflow was designed as follows:

- Vectors from the parametric model were translated into RAPID Code for an ABB industrial robot attached to a milling spindle to cut holes at the appropriate size and angle in the base panels.
- A second pass added colour coding to the perforation pattern, assisting in the placement of dowels of various lengths and colours in the finished panels.

Among the challenges involved in the project was the quick turnaround time (a little over 1 month including design and production) and the learning curve involved with getting the robotic fabrication process on-line. There were also some challenges involved with the on-site installation, including the strapping to support the panels being installed in the wrong location for the panel sizes, and the amount of congestion on the jobsite during the installation, but we were able to overcome these issues with the cooperation of the general contractor.

The process of designing, prototyping and building the project provided some valuable lessons in developing workflows for translating visual imagery and data into motion paths executed by industrial robots. These included the potential for inscribed traces of movement, such as a paint stroke, and layered compositing of information to add a more subjective reading of space and form. The project also demonstrated the importance of compelling video documentation as a means of describing projects involving robots.

5.6 *Apediment (*Millbourne-Woodvale Transit Station)

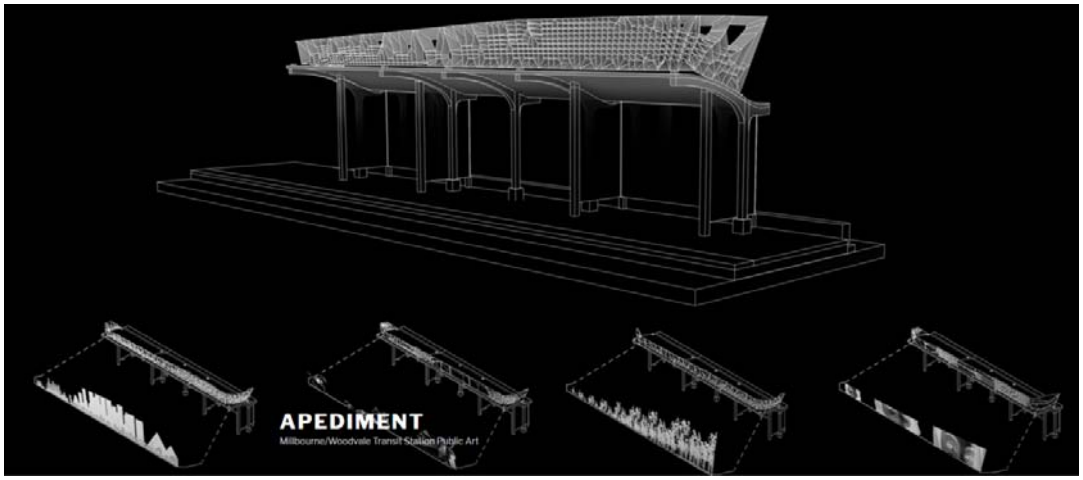

Figure 28. "Apediment," home page

The final project presented here is, at the time of writing, still in the design stage. It is a public artwork designed to sit on top of a transit station shelter. The project builds off of the idea of the pediment and its historical function as a communicative ornamental device. Using a variety of source material drawn from images, text, events or human/plant/animal figures *Apediment* translates images into an articulated assembly of cells constructed from pieces of folded and slotted sheet metal. These articulated structural folds will maintain its strength while allowing for change throughout the seasons as it reflects light, collects snow and frost and activates the spaces around it.

Apediment explores opportunities to use digital technologies not just for design and fabrication, but also as a way of allowing the public to become more involved in the creation of public works, and even to begin to become co-designers. The project employs user-generated content collected via a website as a means of engaging the public. The site for the Millbourne/Woodvale transit station public art project is intended

to allow members of the community to connect with and collaborate on the project. The site encourages everyone to participate in the design process by uploading images that speak to the unique character of the communities of Millbourne and Woodvale, in the City of Edmonton (figure. 29)

The site includes a blog which allows for progress updates and demonstrations of how user-generated content is informing the design and fabrication of the work. So far, the blog has included images of prototypes, models and renderings that have been completed (figre 30). There is also an opportunity for visitors to complete a survey which involves responding to cropped images of previous projects. The results of the survey will inform the engagement strategy for upcoming projects.

Figure 29. "Apediment," blog content showing component fabrication

Finally, the site provides a means for gathering user-generated content through a web interface via the submission of images to an online database. This allows the users to participate in the design process by providing imagery and data which can then be fed back into the generative patterns. The project investigates the use of digital technologies to generate broader engagement with works that exist in the public realm. By developing techniques to test user's responses, we hope to understand more precisely how works of

ornament and public art in the public realm can communicate and contribute to a sense of place and identity.

5.7 Conclusion

In reflecting on these projects, they have provided opportunities to explore a diverse range of processes and techniques. They are also a valuable source of qualitative data related to designing, making and experiencing ornament and pattern for the built environment. This data supports the notion that the physical act of making augments critical thinking around topics related to technology and society, the central argument put forward under the framework of Critical Making.[145]

These examples of projects designed for the public realm emerge from a model of practice-based design research. This method of working emphasizes experiential knowledge gained through practice. Press proposes that contemporary approaches to design research can be thought of as the co-creation of shared, open-source forms of knowledge.[146] In this model, co-creation involving designers, users and clients can take place both within and outside of institutions, and can involve collaborative and hybrid forms of practice, entrepreneurship and social activism. Rather than relying on the designer to provide a solution, this approach provides a framework within which users are empowered to become involved in creating unique design solutions for themselves.[147]

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[145] (Ratto, 2011)
[146] (Press, 2016, p. 22)
[147] (Press, 2016, p. 24)

All of the projects employ open-ended, parametric and associative techniques for designing in which the final outcome is not pre-determined. The designs are essentially reconfigurable systems. In various ways, these projects allow for the personalization and customization of spaces and objects through ornament and pattern. Working on these projects has provided insight into the challenges of pursuing alternative forms of design practice highlighted in the previous practitioner case study chapter, or as Marc Fornes describes it, "practicing on the edge". Digital craft, computational design and digital fabrication provide both opportunities and risks in terms of taking ownership over and responsibility for design and production.

Determining metrics with which to quantify the subjective aspects of these projects such as user engagement poses a challenge, but the benefits of new digital design and fabrication technologies for customization and variation are clear. There is no doubt that digital tools can be used to create compelling, intricate forms and patterns capable of engaging user's perception. The act of communicating meaning and connecting with users on an emotional level can benefit from leveraging designing and making as a means of forming connections and empowering users.

The next chapter will focus on digital processes for designing and fabricating mass-customized and personalized objects with ornamental characteristics. It will continue to explore ideas involving the democratization of design, co-creation and the merging of the roles of designer, maker and user.

Chapter Five: **OBJECT/ORNAMENT**

5.1 Introduction

Previous chapters have explored how people relate to ornament through embodied forms of cognition, based on the premise that we experience the built environment on multiple levels, through both haptic and optic forms of perception.[148] Architecture has always been concerned with relationship between the body and space. Emotion, empathy and projection are critical to our understanding of the objects and environments that surround us.[149] This chapter is focused on the relationship between digitally designed and fabricated objects and the body, and the personalization and mass-customization of ornament, using 3d printing, robotic fabrication and computer vision algorithms.

5.2 FDM Printing

3d printing has become a widely accessible technology, particularly in recent years with the advent of inexpensive desktop 3d printers and online platforms such as Shapeways. The widespread accessibility of 3d printing has been one of the major drivers of the democratization of design, manufacturing and innovation. The democratization of design refers to a process whereby creative individuals are empowered to participate in product development by being given access to software and equipment which was previously restricted to manufacturing corporations and professionals.[150]

Fused Deposition Modeling (FDM) involves a continuous feed of plastic filament which is extruded through a small diameter heated nozzle, where it is deposited layer by layer.

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[148] (Goldhagen, 2017, p. 46)
[149] (Payne, 2012, p. 64)
[150] (Forbes & Schaefer, 2017, p. 406)

The layer height and nozzle size are among the factors which shape the extruded material and determine the line width, adhesion between layers, strength and precision of the print. The most commonly used materials are ABS and PLA plastics. For the purpose of this case study, the primary material used is PLA.

In order to move and print, 3D printers use a set of instructions known as G-Code. A line of G-code is composed of a movement command, a feed rate instruction, a coordinate and an extrusion rate. There are also G-code commands for certain tasks specific to each printer. For example, there are commands to heat the print bed, or to turn on the cooling fan. Normally, a digital object is produced using modeling software such as Rhinoceros3d and then converted to a file format which can be "sliced," or contoured into layers by a 3rd party slicing software, which then converts the slices into G-Code instructions for the printer.

5.3 STAX: A CASE STUDY IN OPTIMIZING DESIGN FOR FDM PRINTING

Stax is a competition entry that allowed for experimentation with FDM rapid prototyping processes as an opportunity to test ideas around personalization and mass customization. The project involves a proposal for a 3d printed chair that leverages the power of computational design and large-format 3d printing, a technology which is increasingly becoming available as new large-format printers are developed and as extruders are being adapted for use with industrial robots.

Each chair consists of an interchangeable base and seat that stack and interlock. The components consist of a lattice made up of multiple layers of stacked cells. The density of the cells, the type and thickness of the line network and the colour of filament can all

be specified by the user, allowing for a high degree of variation and customization (Figure 31).

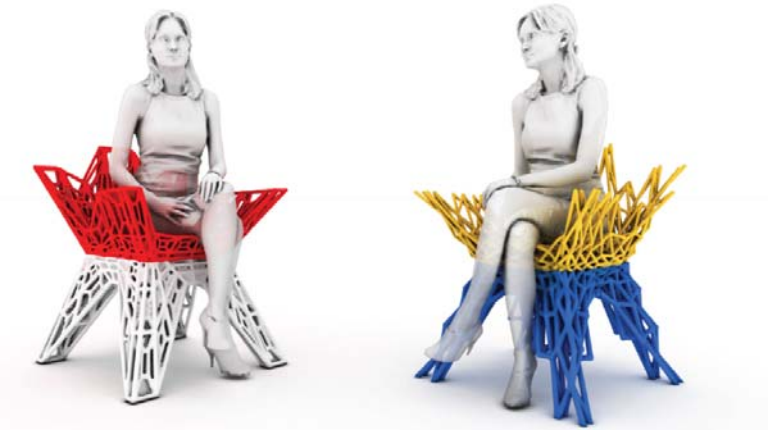

Figure 30. staX proposal rendering

Iconic furniture of the 20th century expressed a machine aesthetic made possible by modern materials and industrial production. 21st-century digital design and fabrication technologies like 3d printing allow for a new approach to detail and ornamentation capable of producing mass-customized forms with intricate structures and variable properties. Parametric lattice structures are ideally suited to FDM printing because angles, thickness and spans can be tuned to the printer specifications, such as the overhang angle and bridging distance, and to optimize the structural, functional and aesthetic characteristics.

Ergonomics

The dimensions and angles of the seat, back and arms of staX are based on standard proportions to accommodate different body types and postures. The open, gridded surface of the seat and back balances support, comfort and breathability. To extend the ergonomics of the design, the lower section of the chair could also be used as a coffee

table or ottoman. The customizable parametric design could also easily adapt to different chair heights such as bar stools or kids chairs.

Production

staX is designed to be printed in 2 parts which fit within the 1m bed size of the BigRep One printer. The span and angles of the network are tuned to the bridging distance and overhang angles of the printer, and with the base flipped upside down, both parts can be printed without support material, speeding up printing time and reducing cleanup. The top can be nested inside the base for shipping, reducing shipping costs and carbon footprint (figure 32).

Structure

staX employs computational design to balance aesthetics and structure. The thickness of the network of lines is a gradient with the thickest sectional dimension at the base where load forces are concentrated, and the thinnest near the top, expressing the structural properties of the lattice as an ornamental device.

Rapid prototyping processes such as 3d printing are allowing for a greater degree of personalization and mass customization in the production of consumer products. Design workflows which integrate mass customization and the variation of factors such as structure, aperture, coloration, and the optimization of fabrication parameters provide a new approach to ornamentation in which aesthetic qualities emerge as a result of material properties and fabrication techniques.

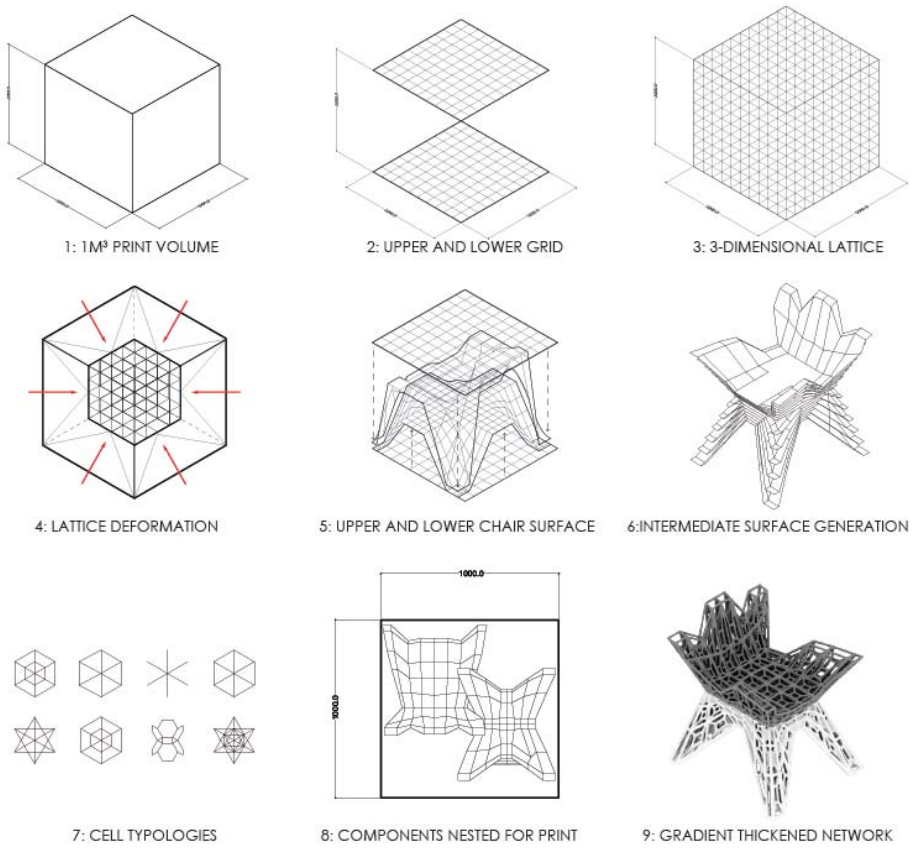

Figure 31: staX proposal, generative diagrams

5.4 Investigations in Custom Movement Paths

Custom Robotic Tool Paths

Leading up to the production of *Stock Wall*, and while I was working as a teaching assistant for *Introduction to Robotic Fabrication*, I developed a number of studies involving robotic drawing processes, designing a series of custom end-effectors to hold various pens, pencils and markers. This process relied on a combination of software including HAL and TACO, plugins for Rhino/Grasshopper, and Robotstudio, a software for creating robot control code for ABB industrial robots. With these tools, I produced several drawings to teach myself how to parametrically create and control toolpaths for

an industrial robot. Working on a flat surface provided a way of controlling some of the variables involved, but also required attention to factors such as the strength of the tool, the precision of the movement, and calibration between real and virtual environments. The first iterations of these drawings were abstracted forms of ornamentation created by either continuous curves or intermittent lines (figure 33). The next series involved two self-portraits created through the layering of different media and multiple passes (figure 34). Some of these toolpaths were eventually also converted into 3d light paintings using an LED mounted to the end effector, and captured using long-exposure photographic techniques (figure 35).

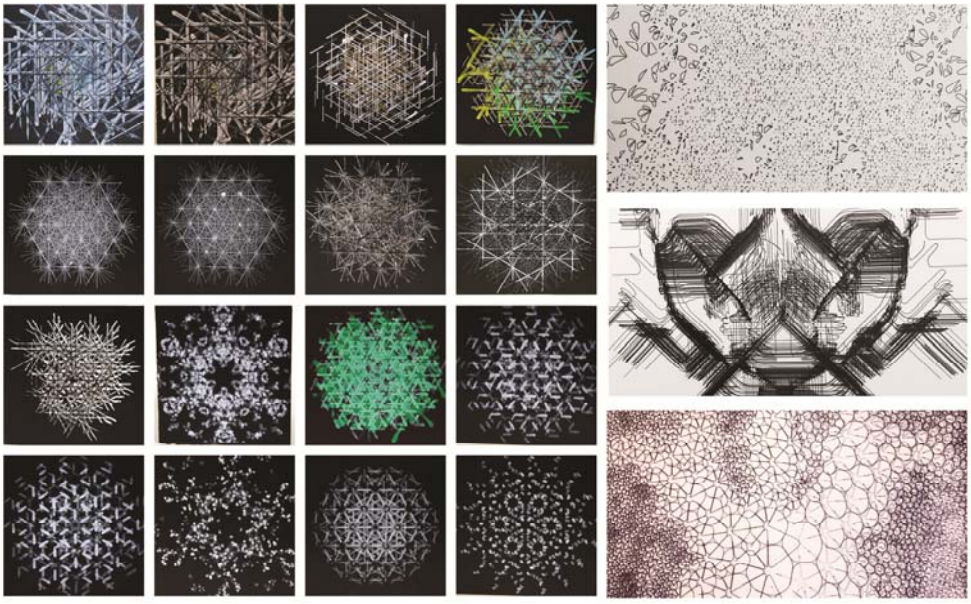

Figure 32. Ornament drawings produced through robotic toolpaths

Figure 33. Portraits produced through robotic toolpaths

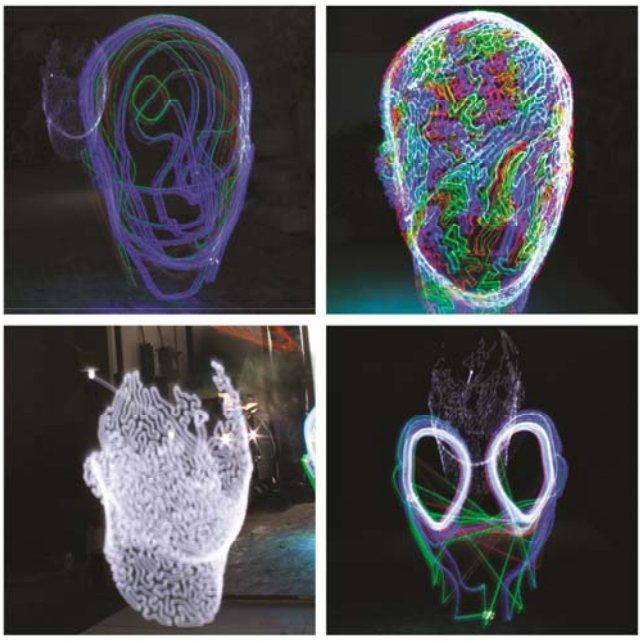

Figure 34 Light Paintings produced through robotic toolpaths

Custom G-Code

Using Silkworm, a plugin for Grasshopper3d, G-code commands can be generated within the Rhino/Grasshopper3d design environment. This provides opportunities for a non-standard form of printing, allowing for more control over extrusion and feed rates as well as movements. By controlling these parameters, it is possible to create customized patterns by intentionally instructing the machine to produce glitches and errors, such as thin strands or blobs or unsupported loops of extruded plastic. These glitch patterns can produce unique ornamental surface effects resembling textiles or fur.

A series of studies were executed using Silkworm and a Delta Wasp 2040 FDM printer. These tests began with 2-dimensional investigations into controlling travel speed and extrusion feeds using image values (figure 36).

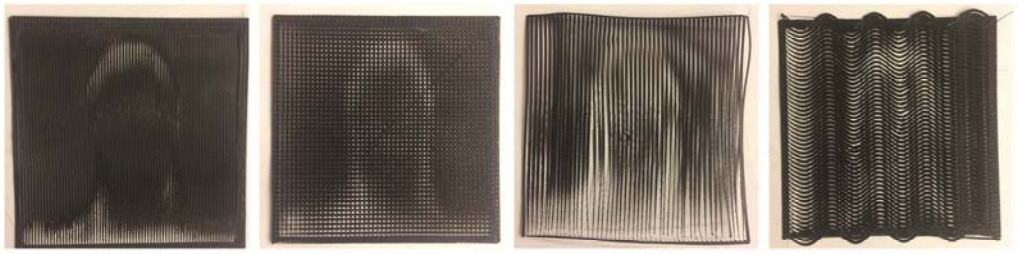

Figure 35. Using images to control 3d printer parameters

A second set of investigations involved creating ornaments printed directly onto card stock using custom toolpaths from user input data, in this case the first letter of a user's name (figure 37). Other tests focused on rapid prototyping of volumetric forms with varied surface textures produced through the intentional deployment of glitches and errors such as stringing, blobs and loops (figure 38). These were executed in both PLA and ceramic materials.

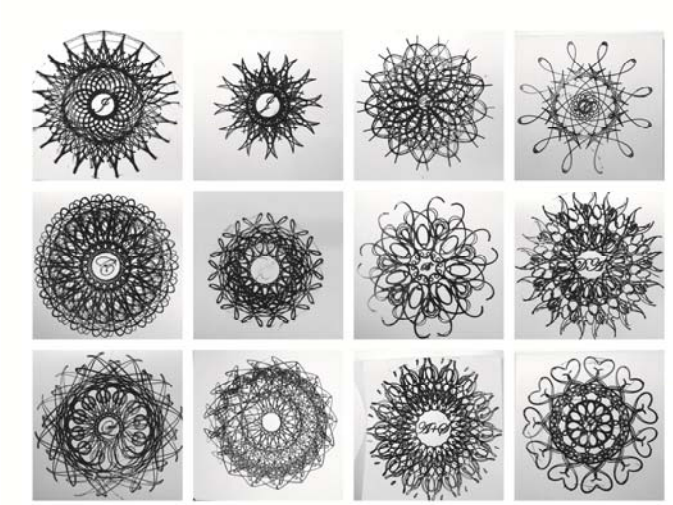

Figure 36. Ornamental drawings produced using 3d printer

Figure 37. Surface effects created through 3d-printed glitches

5.5 Investigations into using Computer Vision Algorithms to Embed Human Emotions In Rapid Prototyping Processes.

The final part of these studies, which is ongoing, brings together various aspects of these previous investigations. Drawing on a number of precedents that explore customization of G-code and facial emotion detection this project aims to directly engage users in the design process by translating their emotions into parametric data. This data can be used to control digital geometry, and to generate toolpaths for computer-controlled fabrication equipment.

As was discussed in chapter 2, designers have leveraged our tendency to perceive and recognize the human face within ornament throughout history. This case study references apotropaic objects, which traditionally functioned as magic charms capable of protecting against evil spirits. These objects are animated through their formal articulation and the presence of intricate, ambiguous elements which arrest perception and elicit an emotional response. In "A Sense of Order" Gombrich writes about the many cross-cultural examples which indicate a universal tendency to animate apotropaic vessels, masks and other objects with "elusive faces." [151]

The proposed workflow gathers user data in a variety of forms including facial emotional data, 3d Scans and survey responses. That data is translated into emotive objects produced through rapid prototyping processes. This workflow provides opportunities for creating a feedback loop in which facial recognition software can be used to measure emotional responses to the built work. The case study further speculates about the potential to test these ideas at various scales from object to urban ornament.

[151] Gombrich 259

This case study builds off of previous explorations and continues to examine ideas involving using digital tools to engage users, makers and designers in the production and perception of pattern and ornament. It goes a step further by seeking to embed user-generated content containing human emotional cues within ornament and pattern. The eventual goal is to be able to test whether it is possible for users to read these emotions in objects, surfaces or spaces.

The case study has 3 main components:

- An investigation into potential methods for gathering user generated content including through facial emotion recognition technologies and parametric modeling techniques for translating that content into useful data
- An exploration of how this parametric data can be translated into physical objects using rapid prototyping techniques
- An exploration of how those objects and the translated data that they contain are interpreted by users

Facial Emotion Recognition

Facial recognition software is an example of a common application of computer vision technology. It works by mapping landmarks on the human face. Facial recognition software is also used to track emotional responses in order to tune content towards individuals. Recognizing that we live in an era when our personal information including biometrics and facial expression data is tracked, it is possible to imagine how this data can be used to manipulate the organization and articulation of the spaces we inhabit, and the potential for ornament designed in response to user's moods and emotions. Using ratios of measurements of facial landmarks corresponding to specific emotions, it is possible to link these parameters with digital modeling techniques to create a responsive digital model. The work explores how emotion can be linked to formal qualities and how

that could be translated through specific 3d printing techniques in order to produce material and surface qualities.

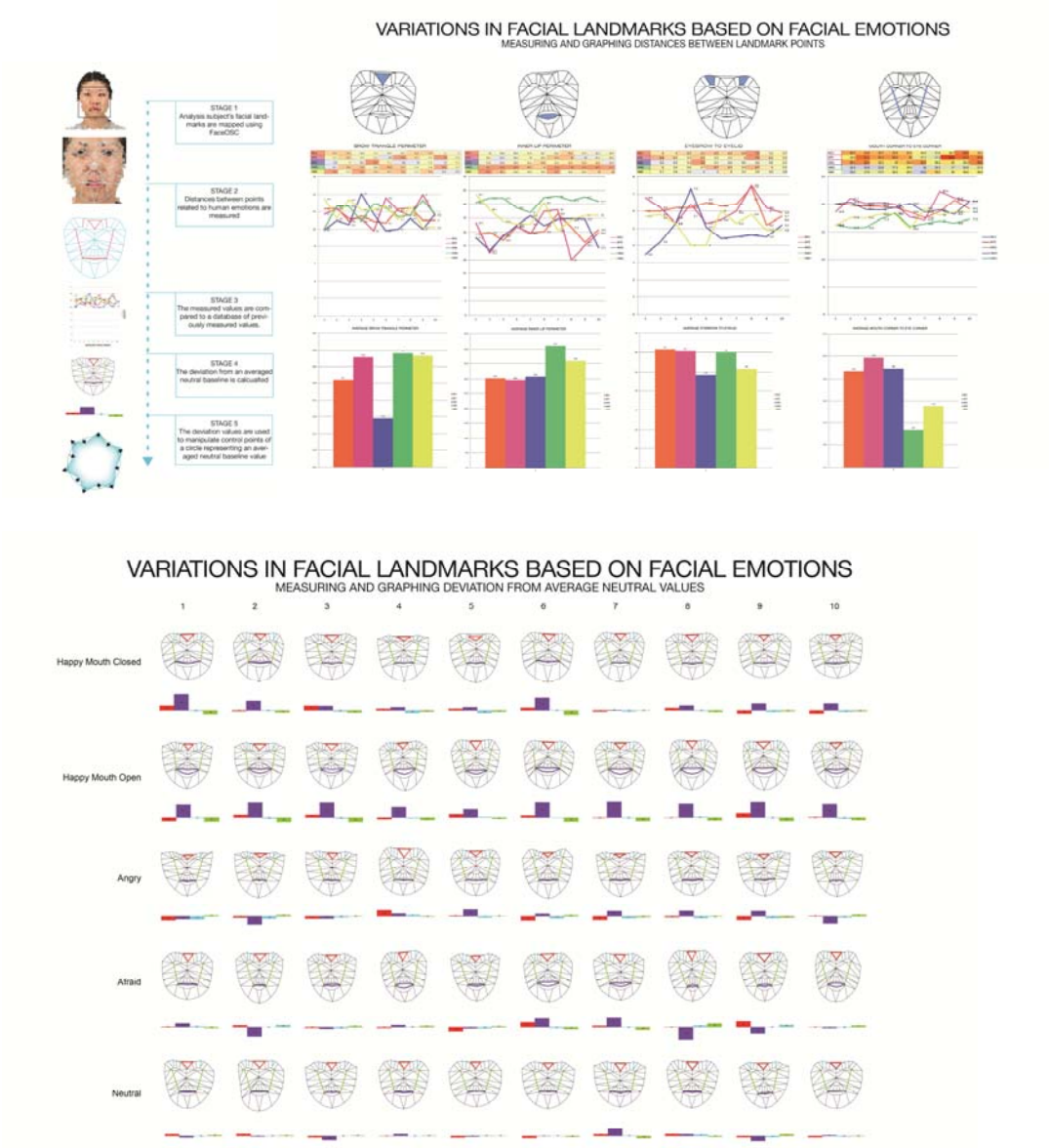

Figure 38 Converting emotional data to geometry

The process relies on a piece of facial tracking software called Face OSC.[152] The preliminary stages, outlined in figure 39 describe how data from facial landmarks is used to control digital geometry.

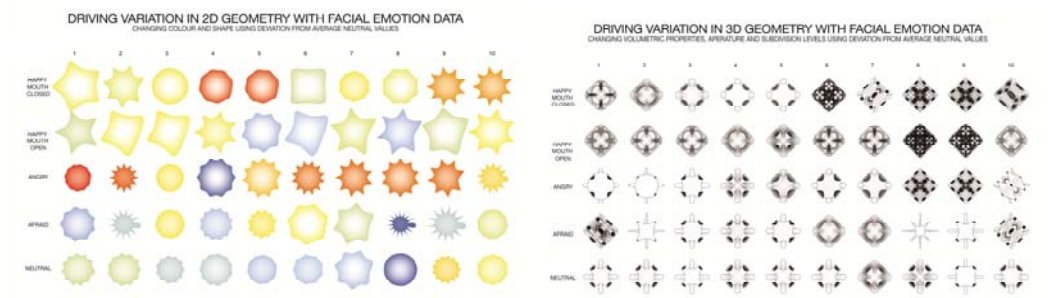

Figure 39 Output geometry

Further iterations of this case study examine the production of more complex geometries, including objects such as chairs and masks. These iterations are then translated into toolpaths for FDM printing. Understanding the parameters of the 3d printer allows it to be used as a design/making tool in a digital craft process. In the process of translation that occurs between the digital model and 3d printed physical objects, layers of information are materially encoded. 3d printing can thus be used as a means to provide the user with some agency in the production of the geometry. The way in which the translation process is curated by the designer allows the rapid prototyping process to overlay its own technique. In this case the traces of the motion of the machine become the marks of the maker.

This exploration has been developed iteratively through a number of experiments which build off each other, allowing for an understanding of the specific and unique opportunities and challenges involved with 3d printing, and how they can be leveraged

[152] (Xiyao, 2017) Face Osc is developed by Kyle Macdonald

as a means of engaging uses makers and designers in the production of personalized, affective ornamental objects.

5.6 Conclusion

These ongoing experiments demonstrate the potential for digital craft processes to contribute to the production of affective, mass-customized ornamentation by bringing users into the process of design and production. They also demonstrate the potential for ornament to provide a means for rapid, iterative experimentation and improvisation in digital and physical space across scales and media.

The studies and experiments presented in this chapter have allowed for an exploration of the convergence of the digital and material environments, the role of the designer as a machinic interface, and the potential of digital fabrication, prototyping and making as a means of forming connections. Developing responsive and interactive design workflows which incorporate the emotional responses of users into design and making may provide opportunities to facilitate engagement.

Lessons learned from the design and production of ornamental objects which engage users, makers and designers in the process of creating and manufacturing can be applied at a larger scale to objects and spaces in the urban realm. These lessons go beyond the specifics of design and fabrication techniques and include methods for involving end users as active participants. The methodologies for engaging users which have been developed in these experiments include the customization of products via user data, including facial emotions. Continuing research will involve scaling this methodology up to an approach for designing ornamentation for public space through the production of articulated surfaces, forms and patterns resulting from the aggregation of customized

components designed and fabricated using crowdsourced information. This approach can provide a means of engaging individuals and reflecting the diversity of communities by harnessing the potential for collective participation through 'mass collaboration'.[153] Further research will also continue to refine techniques for measuring user's emotional responses to design outcomes and feeding these responses back into subsequent iterations.

Our increasingly networked society in which individuals are simultaneously connected and isolated by the forces of urbanization and technology presents challenges and opportunities for design. Enabling co-creation provides a means of leveraging the opportunities in order to address the challenges. It re-frames the role of the designer as a facilitator for knowledge transfer who develops opportunities for users to creatively participate in shaping their own design outcomes.[154] The design, production and perception of ornament, with its long history and connection to human culture, provides a unique vantage point from which to approach these objectives.

[153] (Forbes & Schaefer, 2017, p. 406)
[154] (Press, 2016, p. 26)

Chapter Six: **DISCUSSION**

Summary

I began this research project with the intention to study how computational design and digital fabrication could facilitate integration and engagement. I thought that emerging production technologies and new ways of working could provide a greater level of interaction and participation between various user groups. I anticipated that gaining hands-on experience through designing and making would be an important means of testing these ideas.

To support my research, I conducted a literature review focused on architectural ornament. I wanted to understand its communicative function, and how machine production has changed our understanding of its role in the built environment.
I researched precedents and conducted interviews, and I developed a number of my own case study projects which looked at various ways that ornament can provide a range of potential readings and allow users to participate in design and making. What I've discovered in the course of this research is that new design and production technologies provide designers, makers and users with opportunities to participate in creating and engaging with the built environment, and that ornament can function as an interface for interaction. Computationally designed and digitally fabricated ornament can facilitate co-creation, allow for new narratives and interpretations, and can provide opportunities for an inclusive and democratic approach to design.

Early on in my research, due to unforeseen circumstances, the design-build project which was initially going to be the focus of my study fell through. Moving forward

required a significant “pivot.” I needed to quickly develop a new digital fabrication-based design-build project and find an alternative source of funding. With the support of my supervisor and the Laboratory for Integrative Design, I developed a template qualification document, submitted competition entries and responded to requests for proposals. After several unsuccessful submissions, two opportunities involving public art projects arose. First, I was hired as an artist mentee for a large-scale public art project in Calgary. Second, we submitted a successful proposal for a public art project in the County of Strathcona, *L-Wall.*

These two projects unfolded simultaneously, they both fit the criteria for the type of project I was interested in studying, and in many ways they were at opposite ends of the spectrum in terms of scale, content and approach. The Bowfort interchange project was developed by a team of artists with experience working at a massive scale. They produced their designs using hand-drawing and model making techniques and relied on subcontractors to execute the work. *L-wall* involved parametric models and CNC cut components which I designed, produced fabrication files for, assembled and installed with a small team of collaborators.

Along with these two projects came a number of other opportunities. A new robotic fabrication lab was opened in our faculty. I travelled to Denmark to participate in a robotic fabrication workshop and I received training on basic robot programming at the ABB Robotics facility in Brampton, Ontario. I worked as a teaching assistant for the first robotic fabrication course taught at the Faculty of Environmental Design. Our lab was approached by an architecture firm and commissioned to use robots to produce a feature wall installation. I continued to work with the LID to submit competition entries and

public art proposals, one of which, *Apediment* was selected for the new transit line in Edmonton. My design for a large-scale 3d printed chair, *staX* was a finalist in a design competition. I took a directed study course focused on writing styles for design and research, and I co-wrote and submitted a research paper describing the various projects up to this point. A version of this paper was accepted by the ACADIA conference, and I travelled to Boston to present it at MIT.

To support the entrepreneurial activities involved in pursuing these projects, I enrolled in courses through the Haskayne School of Business on Entrepreneurship and Innovation. I learned about preparing a business plan and developing a pitch. In an effort to contextualize what I was doing, I travelled to conduct interviews with practitioners who were operating in the same hybrid area of alternative practice in which I have found myself. I travelled to Muncie, Indianapolis, and Columbus Indiana and then to New York to conduct studio visits and interviews. I continued to oversee the design and development of *Apediment,* including the production of a prototype and the design of the web page. *Solium Stock Wall* was accepted as a featured project at the 2018 ACADIA conference, and I was able to travel to Mexico City to attend.

New Insights

This thesis has been quite a journey. Since setting out, I have participated in the design and construction of permanent public art projects, installations, furniture and finishes for commercial and residential projects. I have made countless models, prototypes and mockups. I have entered design competitions and presented proposals to juries. I have travelled internationally and throughout the North America to present papers, to attend conferences, to participate in training and workshops and conduct interviews.

Along the way I have picked up a few new skills. I became fairly proficient at putting in rivets and forming sheet metal using a WWII-era hand-cranked roller. Measuring and documenting rocks in a quarry on the side of a mountain taught me about what kinds of defects to avoid when selecting giant slabs of natural stone. I've learned the basics of programming industrial robots for non-standard fabrication processes and I've developed custom end of arm tooling for specific tasks. I've gained an understanding of how to customize G-code in order to manipulate 3d printed objects using computer vision tools. I've worked alongside and learned a great deal from numerous fabricators, tradespeople, artists, designers, entrepreneurs, and researchers. These experiences have demonstrated the value of collaboration and teamwork, and the potential for design and research to provide a world of opportunities for forming networks and accessing knowledge.

Shifting the focus of my thesis towards the topics of ornament and public art has allowed me to return to subjects which I have gravitated towards throughout my education and working career. Before entering university, I worked as a fabricator on several large scale public art projects. In my undergraduate degree I studied sculpture and the history of ornament and craft. After conducting an extensive literature review and engaging in hands-on investigations into contemporary approaches to the production of ornament, I continue to be captivated by the subject.

Approaching the topics of public art, ornament and craft as an architect with training in computational design and digital fabrication has led to a desire to rethink how we ask people to engage with the built environment. This arose out of a sense that there is a

breakdown in communication between “the public” and those who design and make objects and spaces in the public realm. It is clear that many people don’t feel a connection with public space, can’t see the value of design, and don’t think their opinions are being considered. Often, designers and artists feel at best a sense of apathy, and at worst a feeling of hostility towards their work from the public.

While we have new tools at our disposal, we continue to approach this problem in the same way. Public space and the elements that define it, including sculpture, ornament and objects represent a social good. They offer a means of highlighting specific narratives and local contexts and provide places where people can come together to participate in shaping their communities. I wanted to know if the recent re-emergence of ornamentation enabled by the convergence of the digital and material worlds which has disrupted so many aspects of design and production could help to address some of the issues involving engagement with the public realm.

In comparing the various case studies and precedents outlined in this work, which provide a few different possible approaches, I can draw the following conclusions:

Digital design and fabrication technologies have entered all aspects of design and production of the built environment. This trend will only continue. There is too much inherent complexity in projects that exist in the public realm for an individual to manage, so we should accept that we need to develop new ways of working which involve collaboration between various user groups, across disciplines and practices and between humans and machines. This understanding should be balanced with awareness that technology should augment rather than displace human subjectivity and intuition in

design. We need to build in opportunities for intuition to play a role in the creative process.

Addressing the complexity of the urban environment is a valid approach to engaging its various user groups. Digital technologies can facilitate a greater level of public engagement by providing a means of dealing with complexity.

The translation from the digital to the physical realm comes with liabilities and challenges as well as opportunities for creativity. Developing a greater awareness and understanding of digital craft can allow users to exert a greater level of authorship over the design and production of ornament, objects and environments, regardless of their level of experience or proficiency with digital technologies.

The blurring of boundaries between digital, material and human domains within the built environment presents opportunities for creativity and connection. We are living in an exciting moment in history in which we are learning a great deal about how we perceive and process our environments. With the rise of AI and robotic fabrication, the ability of design and production to address complex and multi-faceted challenges is increasing exponentially. All of these factors are converging in a way that allows for the integration of the functional, aesthetic and psychological aspects of design. Rapid urbanization, which is one of the great challenges of our time and which is critical to managing population growth, requires that we consider the subjective experience of the urban realm and learn what goes in to making engaging and cognitively stimulating public spaces. Failing to consider these factors will result in the continued wasteful production of alienating environments, with severe consequences for individuals, cities and society as a whole.

Robots, AI, and a greater understanding of human consciousness are revolutionizing our conception of the world. We are in the midst of the fourth industrial revolution, which is merging digital, physical and biological systems and leading to massive economic and social disruption. What is not likely to change is that as humans we still need a sense of connection, community and meaning. A central question facing us is: what will the future of work look like? Many jobs are already disappearing as a result of automation. New approaches to digital craft, design and production may provide to an opportunity to "reskill" some people whose jobs will be displaced. While not everyone can learn to code, perhaps an integrated and collaborative approach which combines digital design and fabrication technologies with analog design-build activities could provide some opportunities for meaningful employment. As designers, our proficiency and knowledge in the realm of digital craft and social place-making give us the tools to empower users to leverage CAD/CAM, rapid prototyping and distributed manufacturing to improve their communities. While it may be wishful thinking to imagine that this new industrial revolution will allow for a re-emergence of the utopian ideals of the Arts and Crafts movement set out by Morris, we should harness these technologies to reduce some of the potential social disruption by providing opportunities for meaningful, pleasurable and skillful work.

Finding alternative ways to encourage the public to be more involved in the design and production of their environments is a challenging goal worth pursuing. Attention is a valuable commodity, and there is fierce competition from all directions. When designers are seeking public input for a work, there is only a small percentage of the population who are willing to attend meetings, visit websites, fill out surveys or listen to talks.

When a public work becomes a controversial news story, suddenly everyone cares. Having looked at a number of approaches to engagement I have observed that communicating a coherent and compelling narrative is an important part of any design project. The narrative can be tailored to specific audiences, but no matter who is listening, they need a reason to buy in. A good strategy is to allow works to emerge from and to reveal something specific about their context. In this way, projects can frame content without judgment or commentary, allowing users to form their own opinions. This is not unique to a digital approach to ornament and public art, but because of the ability to access and synthesize vast amounts of data, digital tools and workflows can augment and enrich this process.

What is unique about contemporary approaches to ornamentation and public art which rely on digital design and fabrication is that they act as a connection point between the physical and the digital worlds. Their physical manifestation represents one of many potential versions. Additional layers of information are inscribed by the interaction between production processes and physical material. The built versions of these projects provide an interface which we can not only see and touch, but through which we can access additional layers of digital content. These physical objects have a second life in the digital world, where they can go on evolving and adapting, and where they can reach beyond the specific location and audience they were designed for.

Lessons Learned + Value to Others

The case studies I have presented demonstrate a number of techniques for connecting users and contexts through built work. They show how ornament and pattern can be tuned to attract user's attention, encourage the production of associative imagery, elicit

emotional responses and encourage engagement with the built environment. Further development of techniques for gathering data on subjective responses represents an opportunity for ongoing investigation. What is clear is that a holistic design approach which integrates aesthetics, performance optimization and user engagement has significant value.

There are some potential dangers in leveraging tools such as pareidolia and patterned complexity. At the extreme end, some people can potentially be triggered by certain patterns and optical effects and can experience unwanted associations. Others can experience discomfort when confronted by things they don't immediately recognize or understand, and prefer order and simplicity. Where we fall within this spectrum can change from moment to moment depending on our thoughts and emotions. In spite of these precautions, the benefits of designing engaging and stimulating public environments remain clear. Contemporary integrative ornamentation fulfills a valuable function. It can provide a means of making sense of the vast quantities of ambiguous sensory data that we take in on a regular basis as we navigate our urban environments. It can provide a respite from sensory overload by helping to make the chaotic complexity of the city more coherent. It can catch our eye and make us pause, return to the present moment and to a sense that we have a body which is interacting with the space around us, whether we are always aware of it or not.

Digital craft and ornament allow for productive forms of experimentation across scales, processes and media. Lessons learned from experiments and improvisation within the studio using, for example small-scale 3d printing can be carried through into large-scale public art projects. The efforts made to connect with users and stakeholders in these

large scale projects can inform design approaches which allow for the personalization and customization of small-scale objects.

The common thread between the case studies presented here, and their greatest contribution is in how they demonstrate the potential for the creation of networks and connections between designers, makers and users. As non-experts gain greater access to design tools, equipment and resources formerly reserved for experts, and as more practitioners move into alternative forms of practice which blur the boundaries between entrepreneurship, research and design, new forms and opportunities for engagement are emerging.

Machines are extending our capabilities and becoming sentient collaborators in production, with significant implications for design. The convergence of digital and physical realms and the collaboration between human and machine is allowing the rich texture and variety of contemporary society to express itself in the built environment. If our identities have become a hybrid of digital and embodied experience, our cities and their ornamentation should reflect this new reality. We can only speculate about what new narratives and forms of expression will emerge from these interfaces.

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