CRAFTSMANSHIP'S VALUE:

EXPLORING THE SHIFTING ROLE OF THE MAKER IN CONTEMPORARY SLIP-CAST FABRICATION

by
Candace Haddy

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

As technologies become increasingly integrated into production, the maker's relationship with material is transferred from direct physical engagement to roles as programmer and operator, leading to a risk in loss of craftsmanship.[1] While technological advancement has increased the efficiency and possibilities of architectural production by reducing time, labour, and cost, it has also altered the relationship between designers, makers, and materials.[2] This raises questions about how values of craftsmanship, such as reflective judgement learned through making and a responsibility toward the user and society, can persist within contemporary fabrication.

This thesis investigates the role and value of craftsmanship in contemporary production processes by speaking with craftsmen through field research and working with slip cast ceramics, a pottery-forming process using absorbent molds with liquid clay (slip),[3] to design and produce a screen system. Field research examines slip casting across different scales and methods of production through visits to Bryan Hopkins - an expert in small-scale slip casting, Ludowici Roof Tiles - a large-scale production facility for ceramic architectural components, Joshua Stein at Radical Craft - an experimental ceramicist who pushes the capabilities of fabrication methods, and a variety of toilet manufacturing facilities - high-quality mass production facilities of slip casted ceramic toilets. Each case study adapts the traditional slip casting process toward innovation or efficiency, revealing different values and motivations behind the maker's choice of technique. These findings inform research through fabrication in which the identified methods and design goals are tested through the fabrication of a slip-cast screen system, providing a means for further analysis of craftsmanship and its role in contemporary craft.

The cases studies and fabrication research are focused on the shift in knowledge, tools, and material connection from handcraft to contemporary machine fabrication, which can be further understood through architect and researcher Dr. Christoph Schindler's framework of fabrication technology and evolution of techniques. Schindler describes fabrication processes as a continuous development with three waves of processing technology - hand tool, machine-tool, and information-tool technology, relating to evolving industrial developments and technological introductions.[4] While this evolution can optimize production and expand its possibilities, the research examines the tensions and consequences that arise when knowledge shifts away from the craftsperson, particularly the potential loss of craftsmanship.[5] As material and process knowledge enables informed design decisions, transferring this knowledge from the human to machines and digital information can distance the designer from the material and, consequently, from their responsibility toward the environments they create.[6]

This physical design analysis establishes the role and value of craftsmanship within contemporary production while informing a slip-cast fabrication methodology that incorporates these values. The research is evaluated through the conclusions drawn from comparing the values embedded within different approaches to production across varying scales and design intentions.

1 "2007_Schindler_Information-Tool-Technology," n.d., 17.

2 Jonathan Crary, 24/7: Late Capitalism and the Ends of Sleep (Verso, 2013); Suzanne Staubach, Clay: The History and Evolution of Humankind's Relationship with Earth's Most Primal Element, 1. ed (Berkley Books, 2005), 44; Richard Sennett, The Craftsman (Yale University Press, 2008), 9.

3 "Slip Casting," accessed March 14, 2025, https://digitalfire.com/glossary/slip+casting.

4 "2007_Schindler_Information-Tool-Technology."

5 "2007_Schindler_Information-Tool-Technology," 13.

6 Sennett, The Craftsman; "2007_Schindler_Information-Tool-Technology."

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TABLE OF CONTENTS

Author's Declaration ii
Abstract iii
Acknowledgements v
List of Figures viii

01 INTRODUCTION 1

1.1 CRAFTSMANSHIP WITHIN FABRICATION 2
1.2 CONTEMPORARY PRACTICE 8
1.3 OBJECTIVES 12
1.4 STRUCTURE 13

02 CONTEXT 15

2.1 THE JOURNEY 18
2.2 MATERIAL AND METHODOLOGY 26

03 CONTEMPORARY PRACTICE 31

3.1 INNOVATIONS WITH CERAMIC OBJECT MANUFACTURING 32
3.2 CASE STUDIES 37
3.3 COMPARATIVE ANALYSIS 82

04 METHODOLOGY 87

4.1 CASE STUDIES INFORMING DESIGN GOALS 88
4.2 DESIGN TESTS 92
4.3 DESIGN METHOD 100

05 RESULTS 109

5.1 DESIGN TESTS 110

06 DISCUSSION 153

6.1 OUTCOME OF DESIGN TESTS 154
6.2 FUTURE DIRECTIONS 156
6.3 INTERPRETATION OF RESULTS 158

Bibliography 164
Appendices 169

A. Interview Questions 170
B. Additional Field Research 172
C. Additional Fabrication Design Development 184

LIST OF FIGURES

01 INTRODUCTION

Fig. 1.1 *Diagram stating three parameters in production*. Diagram redrawn by author. Original source: Schindler, 2007, Schindler_Information-Tool-Technology, 1.

Fig. 1.2 *Diagram showing three kinds of knowledge interacting in waves of development,* Diagram by Christoph Schindler, 2007, Schindler_Information-Tool-Technology, 1.

Fig. 1.3 *Adaption of Christofph Schindlers diagram describing accumulation of knowledge and methods,* Diagram by author, Original source: 2007, Schindler_Information-Tool-Technology, 1.

Fig. 1.4 *Timeline of material processing and use of tools with associated operations,* Diagram by author.

Fig. 1.5 *diagram of slip casting method,* Illustration by author.

Fig. 1.6 *Photo of Boston Valley Terracotta using a 3D laser scanner,* Image by Boston Valley Terracotta, n.d, https://bostonvalley.com/about/.

Fig. 1.7 *Photo of Ludowici using a pressure tester,* Image by author.

Fig. 1.8 *Photo of Joshua Stein's work, Tectonic Horizons, that used a CNC router,* Photo by Joshua Stein, https://radical-craft.com/Tectonic-Horizons.

Fig. 1.9 *Photo of 6-axis robotic arm used by UPenn for 'These Things Swirl project',* Photo by UPenn, https://ras.design.upenn.edu/project/these-things-swirl-0.

Fig. 1.10 *Photo of UofT's robotic arm,* Photo by UofT, 2024, https://www.daniels.utoronto.ca/news/fri-sep-22-2023-all-day/daniels-faculty-cohost-interdisciplinary-robarch-2024-conference.

Fig. 1.11 *Photo of Studio RAP's robotic arms,* Photo by Studio RAP, https://studiorap.nl/Ceramic-House.

02 CONTEXT

Fig. 2.1 *Diagram of Ceramic FDM workflow,* Illustration by author.

Fig. 2.2 *Image of Ceramic FDM prints,* Image by author.

Fig. 2.3 *Photo of train kiln at Steven Corner's studio,* Image by author.

Fig. 2.4 *Collage of foil saggar firing workshop by Gene Timpany ,* Collage by author.

Fig. 2.5 *Photo of all initial method tests,* Image by author.

Fig. 2.6 *Photo of press mold test,* Image by author.

Fig. 2.7 *Photo of slip cast test,* Image by author.

Fig. 2.8 *Photo of extrusion die test,* Image by author.

Fig. 2.9 *Photo of 3D clay printing test,* Image by author.

Fig. 2.10 *Photo of slip casting process,* Image by author, edited using AI tools.

Fig. 2.11 *Diagram of material properties,* Illustration by author.

Fig. 2.12 *Collage of Louis Sullivan's Guaranty Building,* Collage by Boston Valley Terracotta.

03 CONTEMPORARY PRACTICE

Fig. 3.1 *Photo of ACAW presentation facade system by* Superkül demonstrating the use of the 3-axis wirecutter, Images by Superkül, edited by author, https://www.youtube.com/watch?v=TkqR5_e04c0&t=945s.

Fig. 3.2 *Collage of Studio RAP ceramic facade modules for Ceramic House Project,* Collage by Studio RAP, https://studiorap.nl/Ceramic-House.

Fig. 3.3 *Collage of Smodules created for 'these things swirl' project,* Collage by UPenn, https://ras.design.upenn.edu/.

Fig. 3.4 *Photo of Bryan Hopkins stamping texture for plaster mold,* Image by author.

Fig. 3.5 *Collage of Bryans cups,* Collage by author.

Fig. 3.6 *Diagram of Bryan Hopkin's process of production,* Diagram by author.

Fig. 3.7 *Photo of textures translated into clay in the library of textures,* Image by author.

Fig. 3.8 *Photo of porcelain slab wrapped around smooth vessel with texture facing outwards,* Image by author.

Fig. 3.9 *Photo of a piece of flashing rolled around the outside of the vessel, leaving a minimum of 1" gap,* Image by author.

Fig. 3.10 *Photo of plaster mold being sliced using a miter box jig and a saw blade so that the pieces have perfectly vertical cuts,* Image by author.

Fig. 3.11 *Photo of a circle assembled using pieces from various plaster molds that contain different patterns,* Image by author.

Fig. 3.12 *Photo of library of plaster molds of different sizes and textures,* Image by author.

Fig. 3.13 *Photo of Bryan Hopkins carving the lip of the cup,* Image by author.

Fig. 3.14 *Photo of mold releasing from slip-casted object,* Image by author.

Fig. 3.15 *Photo of translucency achieved through creating a thin vessel,* Image by author.

Fig. 3.16 *Photo of Bryans studio,* Image by author.

Fig. 3.17 *Photo of Ludowici factory worker,* Image by author.

Fig. 3.18 *Photo of clay extraction site,* Image by author.

Fig. 3.19 *Photo of quarry location,* Image by author.

Fig. 3.20 *Photo of two different stages of clay from the crusher,* Image by author.

Fig. 3.21 *Photo of belt system running through crusher operation,* Image by author.

Fig. 3.22 *Photo of crane system for slip casting room,* Image by author.

Fig. 3.23 *Photo of multi-part plaster mold,* Image by author.

Fig. 3.24 *Collage of glaze samples and buckets,* Collage by author.

Fig. 3.25 *Photo of carts stacked in preparation for firing,* Image by author.

Fig. 3.26 *Photo of Gate of Harmonious Interest before renovation,* Image by Krista Lougton, https://www.instagram.com/p/DWPhrphEkzm/?hl=en&img_index=1

Fig. 3.27 *Photo of Gate of Harmonious Interest after renovation,* Image by Krista Lougton, https://www.instagram.com/p/DWPhrphEkzm/?hl=en&img_index=1

Fig. 3.28 *Photo of sculpted form from image reference for Bishops Palace Project,* Image by author.

Fig. 3.29 *Photo of 3D plastic printed form to scale for Bishops Palace Project,* Image by author.

Fig. 3.30 *Photo of post-processing details scored into tiles by hand,* Image by author.

Fig. 3.31 *Photo of raw material being carried to factory site,* Images by author.

Fig. 3.32 *Photo of Joshua Stein's Upscaling Project,* Image by Joshua Stein, https://radical-craft.com/Upscaling.

Fig. 3.33 *Photo of CNC router for Stein's projects,* Image by Joshua Stein, https://radical-craft.com/Upscaling.

Fig. 3.34 *Photo of plaster mold divided into slices for Upscaling project,* Image by Joshua Stein, , https://radical-craft.com/Upscaling.

Fig. 3.35 *Diagram of five centimeter-high slices due to machine limitatations for Upscaling project,* Illustration by Joshua Stein, , https://radical-craft.com/Upscaling.

Fig. 3.36 *Photo of completed modules for Upscaling project,* Image by Joshua Stein, , https://radical-craft.com/Upscaling.

Fig. 3.37 *Photo of CNC router cutting plaster for 'Tectonic Horizons' project,* Image by Joshua Stein, https://radical-craft.com/Tectonic-Horizons.

Fig. 3.38 *Diagram of CNC router toolpath for 'Tectonic Horizons" project,* Illustration by Joshua Stein, https://radical-craft.com/Tectonic-Horizons.

Fig. 3.39 *Photo of completed module for 'Tectonic Horizons" project,* Image by Joshua Stein, https://radical-craft.com/Tectonic-Horizons.

Fig. 3.40 *Photo of pattern achieved through technology and machine (CNC),* Image by Joshua Stein, https://radical-craft.com/Tectonic-Horizons.

Fig. 3.41 *Photo of completed toilets in JOMOO storage,* Image by JOMOO, AI-enhanced for image quality, https://www.youtube.com/watch?v=pMBx9W1DRyA.

Fig. 3.42 *Photo of resin molds,* Image by Betta Sanitaryware, https://www.youtube.com/watch?v=QJcuR54YQAU.

Fig. 3.43 *Photo of pneumatic lifters,* Image by Betta Sanitaryware, https://www.youtube.com/watch?v=QJcuR54YQAU.

Fig. 3.44 *Photo of glaze robot,* Image by Betta Sanitaryware, https://www.youtube.com/watch?v=QJcuR54YQAU.

Fig. 3.45 *Photo of kiln cart,* Image by Betta Sanitaryware, https://www.youtube.com/watch?v=QJcuR54YQAU.

Fig. 3.46 *Photo of toilet stock prepared for shipping,* Image by Fohome, https://fohomeceramics.com/our-design-capabilities-for-toilet-basin/

Fig. 3.47 *Photo of final quality check,* Image by Estrella Chang, https://www.jabrasanitary.com/how-toilets-are-made.

04 METHODOLOGY

Fig. 4.1 *Table of design goals,* Illustration by author.

Fig. 4.2 *Diagram of design structure,* Diagram by author.

Fig. 4.3 *Diagram of artifact tests,* Diagram by author.

Fig. 4.4 *Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages,* Diagram by author.

Fig. 4.5 *Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages,* Diagram by author.

Fig. 4.6 *Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages,* Diagram by author.

Fig. 4.7 *Diagram of slip casting workflow,* Diagram by author.

Fig. 4.8 *Photo of pre-mixed slip sourced from S&S,* Image by author.

Fig. 4.9 *Photo of USG No. 1. Pottery Plaster,* Image by author.

Fig. 4.10 *Photo of workshop,* Image by author.

Fig. 4.11 *Photo of workshop plaster bench and tools for plaster mold creation,* Image by author.

Fig. 4.12 *Photo of Clay Lab,* Image by author.

Fig. 4.13 *Photo of clay lab workstation tools for slip casting,* Image by author.

Fig. 4.14 *Photo of bambu lab P1s 3D plastic printer,* Image by Ulyana Bunina.

Fig. 4.15 *Photo of AXYZ CNC router,* Image by author.

Fig. 4.16 *Photo of Euclids CF-255 front-loading electric ceramic kiln,* Image by author.

05 RESULTS

Fig. 5.1 *Photo of final form for Design Test 1,* Image by author.

Fig. 5.2 *Diagram of design development,* Illustration by author.

Fig. 5.3 *Diagram of plaster mixing directions,* Illustration by author.

Fig. 5.4 *Photo of gathered textures printed in clay,* Image by author.

Fig. 5.5 *Photo of plasticine taking texture of fired clay,* Image by author.

Fig. 5.6 *Photo of formwork prepared for plaster mold creation,* Image by author.

Fig. 5.7 *Photo of measurements for cutting plaster,* Image by author.

Fig. 5.8 *Photo of plaster blocks being cut,* Image by author.

Fig. 5.9 *Photo of plaster coddle boards prepared for slip,* Image by author.

Fig. 5.10 *Photo of slip after mold was drained,* Image by author.

Fig. 5.11 *Photo of slip casted piece after removal from mold,* Image by author.

Fig. 5.12 *Photo of slip casted piece assembled with base,* Image by author.

Fig. 5.13 *Collage of texture and depth achieved in final forms,* Image by author.

Fig. 5.14 *Photo of final screen,* Image by author.

Fig. 5.15 *Photo of Design Test 2,* Image by author.

Fig. 5.16 *Diagram of design development,* Illustration by author.

Fig. 5.17 *Collage of 3D plastic printed design,* Collage by author.

Fig. 5.18 *Photo of 3D plastic printed object,* Image by author.

Fig. 5.19 *Photo of plaster mold created from 3D printed object,* Image by author.

Fig. 5.20 *Photo of plaster mold section creation,* Image by author.

Fig. 5.21 *Photo of plaster mold assembly,* Image by author.

Fig. 5.22 *Photo of plaster mold assembled to pour slip,* Image by author.

Fig. 5.23 *Photo of slip-casted object during un-molding,* Image by author.

Fig. 5.24 *Photo of post-processing for attachment,* Image by author.

Fig. 5.25 *Photo of kiln fired module,* Image by author.

Fig. 5.26 *Photo of modular system - front side,* Image by author.

Fig. 5.27 *Photo of modular system - back side,* Image by author.

Fig. 5.28 *Photo of modules for screen,* Image by author.

Fig. 5.29 *Photo of modular system unassembled,* Image by author.

Fig. 5.30 *Photo of modular system assembled for Design Test 3,* Image by author.

Fig. 5.31 *Photo of modular system assembled,* Image by author.

Fig. 5.32 *Diagram of design development,* Illustration by author.

Fig. 5.33 *Photo of plaster block pre-roughed and prepared for CNC router, using 3.5lbs water and 5.14 lbs plaster,* Image by author.*Photo of initial cuts to test dryness on plaster blocks,* Image by author.

Fig. 5.34

Photo of plaster block pre-roughed and prepared for CNC router, using 1.7lbs water and 2.43 lbs plaster,

Fig. 5.35 Image by author.

Fig. 5.36 *Photo of dryness cut test after 72 hours of drying. Result is too wet with liquid forming as cuts occured,* Image by author.

Fig. 5.37 *Photo of dryness cut test after 166 hours of drying. Result is top layer too dry and bottom layers are too wet,* Image by author.

Fig. 5.38 *Diagram of RhinoCAM simulation of plaster block cuts for type 1,* Illustration by author.

image of plaster mold cut for type 1, Image by author, edited using AI tools.

Fig. 5.39

Diagram of RhinoCAM simulation of plaster block cuts for type 2, Illustration by author.

Fig. 5.40 *Photo of plaster block being cut on CNC showing type 1 transform into type 2,* Image by author.

Fig. 5.41 *Diagram of RhinoCAM simulation of plaster block cuts for type 3,* Illustration by author.

Fig. 5.42 *Photo of plaster block showing type 3,* Image by author.

Fig. 5.43 *Photos of type 2 plaster block on left and type 3 on right after opening mold,* Image by author.

Fig. 5.44 *Photo of plaster blocks type 1,* Image by author.

Fig. 5.45 *Photo of plaster blocks assembled,* Image by author.

Fig. 5.46 *Photo of plaster blocks with slip before being drained,* Image by author.

Fig. 5.47 *Photo of slip casted object being removed from plaster mold,* Image by author.

Fig. 5.48 *Photo of modules in kiln to be fired,* Image by author.

Fig. 5.49 *Photo of module being assembled on steel rod,* Image by author

Fig. 5.50 *Collage of modular system,* Collage by author.

Fig. 5.51 *Photo of form achieved and toolpath variation,* Image by author.

Fig. 5.52 *Diagram of maximum cutting depth due to tool length,* Illustration by author.

Fig. 5.53 *Diagram of radius in plaster due to tool leaving mold,* Illustration by author.

Fig. 5.54 *Photo of modular system assembled,* Image by author.

01 | INTRODUCTION

1.1 CRAFTSMANSHIP WITHIN FABRICATION

Technological advancement has shaped contemporary architectural production, making it more economically efficient and innovative through digital and automated fabrication methods.[1] While these advancements expand design possibilities and reduce the time, labour, and cost required for production, they also alter the relationship between designers, makers, and materials.[2] As fabrication increasingly transitions to machine-controlled and digitally mediated processes, knowledge of materials and processes develops less through direct human engagement with materials and increasingly through digital information and automated systems, shifting where knowledge resides. Ceramics fabrication began with analogue processes, which created a direct connection between the maker's hand and the designer's intent.[3] Over time, the implementation and manipulation of ceramics in architecture have advanced alongside industrial developments, while clay has remained a fundamental building material.[4] Craft holds value not only because people appreciate the tangible product, process, and effort that goes into its creation, but also because there is an ethical integrity associated with craftsmanship.[5] With the digital shift in method, there is a growing risk that the reflective judgement learned through making will be diminished.[6] Therefore, if we do not find ways to understand and preserve the characteristics of craftsmanship within contemporary practice, the craftsman's responsibility towards society and the quality of the environments we inhabit may ultimately be diminished.[7]

The cultural historian Richard Sennett argues that craftsmanship is not defined by hand production alone, but by the desire to do work well through sustained practice, informed judgement, and an ongoing dialogue between thinking and making.[8] Similarly, Juhani Pallasmaa, a Finnish architect and former professor, contends that craftsmanship embodies a way of engaging with materials that fosters care, responsibility, and human connection—qualities increasingly threatened by technologically driven production.[9] Together, these perspectives suggest that the value of craftsmanship lies not in preserving traditional methods for their own sake, but in maintaining the mindset and knowledge they cultivate. Contemporary technologies, including digital fabrication, automation, and robotics, offer unprecedented opportunities for innovation; however, when these processes replace rather than extend human agency, the designer risks abstracting themselves from the methods of design by limiting their ability to practice care, demonstrate responsibility, foster connections to materials, and improve production knowledge and cultures.

This research argues that technological advancement does not necessitate the loss of craftsmanship. Instead, craftsmanship can, and should, remain integral to contemporary fabrication by informing how new technologies are applied. Through the study of ceramic production, this research investigates why the values of craftsmanship, including material knowledge, reflective making, ethical responsibility, and opportunities for design innovation, should be retained and embedded within contemporary fabrication processes.

1 Jonathan Crary, 24/7: Late Capitalism and the Ends of Sleep (Verso, 2013).

2 Crary, 24/7 : Late Capitalism and the Ends of Sleep .

3 Suzanne Staubach, Clay: The History and Evolution of Humankind's Relationship with Earth's Most Primal Element, 1. ed (Berkley Books, 2005), 44.

4 Staubach, Clay: The History and Evolution of Humankind's Relationship with Earth's Most Primal Element, 139.

5 Crary, 24/7 : Late Capitalism and the Ends of Sleep .

6 Richard Sennett, The Craftsman (Yale University Press, 2008); "2007_Schindler_Information-Tool-Technology," n.d.

7 Sennett, The Craftsman, 13.

8 Sennett, The Craftsman, 9.

9 Juhani Pallasmaa, The Thinking Hand: Existential and Embodied Wisdom in Architecture, AD Primers (Wiley, 2009), 52.

Changing production methods have affected how craft and craftsmanship, and their place within contemporary fabrication, are defined. Sennett defines craft as a trained skill, stating that the person who performs a duty again and again acquires the technical skill of a craftsman through practice and experience.[10] Every craftsman conducts a dialogue between practicing and thinking; their dialogue evolves into sustained habits, and these habits establish a craft which may be seen as a rhythm between problem solving and problem finding.[11]

Pallasmaa builds on Sennett's writing and establishes the importance of craft and its relationship to our modern technological world, stating:

> The tradition of craftsmanship is clearly gaining increasing value and appreciation in today's reality of the technological world, mechanical production, and the regrettable loss of touch of the human hand in our mechanically mass-produced products and environments. In traditional cultures, the entire life world is the product of human hands, and the daily sphere of work and life means an endless passing of the hand skills and their products on to others; a traditional world is a continuous meeting of hands of successive generations.[12]

Pallasmaa highlights the decline of care in traditional craft practices following the introduction of mechanical tools and technologies into production systems. As these practices become increasingly rare, society places greater value on the care and human involvement associated with "handcrafted" objects.

The meaning of craftsmanship in traditional practices must be reconsidered with the loss of direct human-to-material contact in contemporary craft methodologies. Sennett argues that craftsmanship is a mindset expressed in how someone performs a craft and the desire to do a job well, rather than being inherently tied to traditional methods.[13] Based on Sennett's statement, skilled professionals in their specific practice would be considered craftspeople, as the term refers to knowledge developed through practice.

This does not contradict Pallasmaa's argument that modern production has diminished human touch; rather, it demonstrates that the absence of visible handwork does not necessarily imply a loss of craftsmanship. Craftsmanship may still exist through knowledge, judgement, and care, even when machines or contemporary technologies are involved. As technologies become increasingly integrated into production, they transform the maker's relationship with material from direct physical engagement to roles as machine programmer and operator.[14] Technologically mediated production methods further abstract the connection between human and material. [15] This raises questions about how the characteristics and value of craftsmanship may change within contemporary fabrication as the physical connection between the craftsperson and material diminishes, weakening the direct material engagement through which knowledge, judgement, and care have traditionally developed.

10 Sennett, The Craftsman, 177.

11 Sennett, The Craftsman, 9.

12 Pallasmaa, *The Thinking Hand*, 51.

13 Sennett, The Craftsman, 9.

14 "2007_Schindler_Information-Tool-Technology," 17.

15 Sennett, The Craftsman, 9.

INFORMATION-TOOL-TECHNOLOGY

Fabrication methods inevitably influence architectural outcomes, so it is imperative to discuss the relationship between production processes and design. Architect and researcher Christoph Schindler identifies three fundamental parameters within every production process: energy, material, and information.[16] These three parameters establish a framework for understanding fabrication as the relationship between the energy that drives production, the material that forms the product, and the design information that directs how the material is manipulated through energy.* This framework clarifies how the relationship between the maker, material, and tools shapes the translation of a design from idea to physical form.

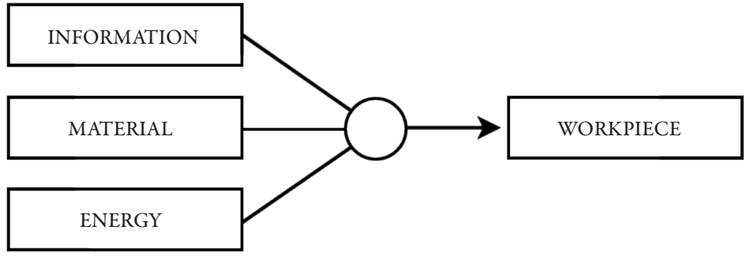


Fig. 1.1 *Diagram stating three parameters in production,* Diagram redrawn by author.

Schindler's framework of material systems builds upon broader system theories, which historically described natural and constructed systems through relationships between material elements and energy.[17] Early system theories from Ancient Greece and Chinese Daoism described nature and the universe in terms of material elements and energy.[18] Later, Ludwig von Bertalanffy, a founder of general systems theory, introduced information as a third fundamental system parameter.[19] Schindler applies this foundational understanding to fabrication processes, demonstrating how the evolution of production methods can be understood through changes in the relationship between material, energy, and information. Schindler's material systems framework offers a way to examine the entire system through which clay becomes a finished architectural object, rather than treating clay as simply a material to be shaped.[20]

While the production material may remain constant throughout the evolution of fabrication methods, Schindler argues that production itself transforms when the distribution of energy and information shifts from direct human processing toward machine-driven and digitally controlled operations. He states that "man is not replaced, but revalued, as his function shifts from processor to process designer."[21] Schindler reinforces Pallasmaa's conclusions that the relationship between the "processor" and "process" is transforming as fabrication methods evolve through technological development and digitized fabrication methods. This transition redistributes where knowledge resides within the production process and alters the relationship between the designer, material, and act of making.

16 "2007_Schindler_Information-Tool-Technology," 1.

* This thesis uses "energy" to describe the broader act of material manipulation. The terms "production", "fabrication", and "manufacturing" are used to describe this process, with each term referring to different scales of operation. Additionally, "information" will be referred to as "knowledge" to relate to Sennett's and Pallasmaa's terms.

17 "Systems Theory," The Decision Lab, 2026, https://thedecisionlab.com/reference-guide/psychology/systems-theory.

18 Anna Afonasina, trans, Empedocles' fragment B 17. Ancient Philosophy and the Classical Tradition 13, no. 1 (2019):194–212.

19 Ludwig von Bertalanffy, General System Theory. Rev. ed, 10. print (Braziller, 1988).

20 "2007_Schindler_Information-Tool-Technology," 4.

21 "2007_Schindler_Information-Tool-Technology," 17.

SCHINDLER'S TERMS

Schindler describes the changing relationship between operator, tools, and materials by highlighting three distinct waves of production technologies.[22] Each wave has a different relationship between operator, tool, and materials. These three waves of processing technology are hand-tool, machine-tool, and information-tool.

Hand-tool technology:
Manual processing of material, similar to the term "handcraft." The act of processing by a human hand-tool operator. Knowledge exists in the craftsperson.

Machine-tool technology:
Machine processing of material to substitute physical human operations. A human machine-tool operator processes the information. Knowledge exists partially in the machine and partially in the craftsperson.

Information-tool technology:
The technological concept of automation, which uses machines to replace both physical and intellectual processing of information and material. Schindler better explains this process as, "the function to transform material and information flow with help of energy flow in a way that impresses information to the material."[23] Knowledge exists as digital information, separate from the craftsperson, and the machine reads the digital information in the form of software.

22 "2007_Schindler_Information-Tool-Technology," 1.

23 "2007_Schindler_Information-Tool-Technology," 4.

RELATIONSHIP

This thesis explores the relationship between the methods of production, observing the impact of the evolving production process, and challenging the tension of material, product, and process knowledge in contemporary practice.

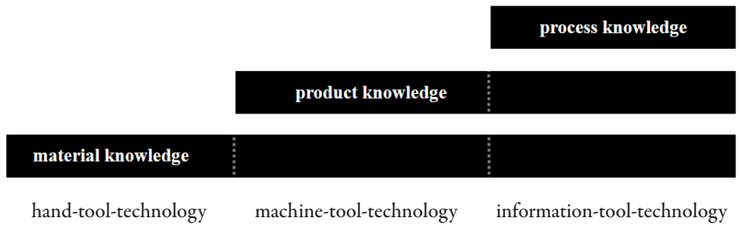


Fig. 1.2. *Diagram showing three kinds of knowledge interacting in waves of development,* Diagram by Christoph Schindler.

This study argues that fabrication evolution is not a linear progression that replaces human physical and intellectual operations, but an accumulation of knowledge in which new technologies build on previous methods of making, keeping craftsmanship relevant to current modes of fabrication. This research investigates how craftsmanship continues to provide value within contemporary fabrication processes by examining the persistence of material knowledge, reflective judgement, and ethical responsibility. It is informed by Schindler's three waves of processing technology, using the accumulated history of knowledge and methods to examine how they inform contemporary craftsmanship.

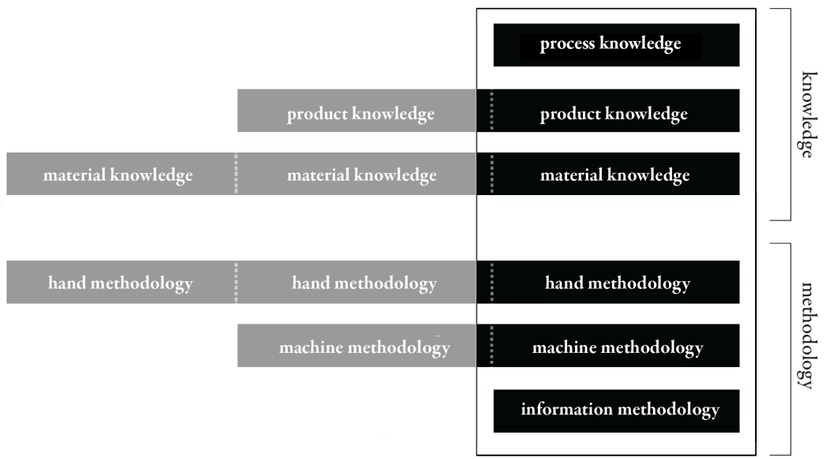


Fig. 1.3

Adaptation of Christoph Schindler's diagram describing accumulation of knowledge and methods, Diagram by author.

Schindler's three waves describe the changing relationship between the operator, tool, and material as part of a continuous historical development of fabrication methods. This progression aligns with broader industrial developments.[24] The first industrial revolution of the 18th century, which introduced mechanization, and the second industrial revolution of the late 19th and early 20th centuries, which introduced mass production and assembly-line manufacturing, allowed for a shift in tools. The third industrial revolution of the late 20th century shifted both physical operations and the location of knowledge with the introduction of computerization and automated production systems. Each industrial development transforms the human role in fabrication not through complete replacement, but through a redistribution of labour, knowledge, and decision-making.

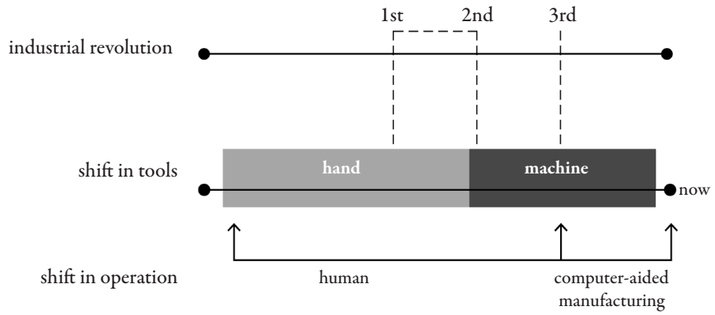


Fig. 1.4

Timeline of material processing and use of tools with associated operations, Diagram by author.

Schindler's framework emerged in the early 2000s during the transition into digital fabrication with the fourth industrial revolution. The fourth industrial revolution, commonly referred to as Industry 4.0, was first introduced as a term by the German government as part of a strategy to describe the integration of digital technologies such as automation, data exchange, and artificial intelligence into manufacturing.[25] Unlike previous fabrication developments that primarily transformed physical labour, Industry 4.0 has influenced the role of thought and judgement, enabling machines to process data, recognize patterns, and perform increasingly autonomous decision-making within production processes. In this latest development, human involvement in both the physical and informational aspects of production is reduced.

As contemporary fabrication processes become more automated and information-driven, it is essential to define craftsmanship and understand its value. Drawing from Pallasmaa and Sennett's understandings of craftsmanship, material, reflective judgement, and ethical responsibility are values which need to remain fundamental to production processes, continuing to inform fabrication despite changing methods and the evolving role of humans within technological systems.[26] Contemporary fabrication is challenged with adapting methods to balance technological innovation with the values associated with craftsmanship.[27]

24 Robert C. Allen, The Industrial Revolution: A Very Short Introduction, (Oxford University Press, 2017), 2–14, https:// doi.orgactrade

25 Omoseni Oyindamola Adepoju et al., Risk Management Framework for Fourth Industrial Revolution Technologies, First edition (CRC Press, 2025), https://doi.org

26 Pallasmaa, The Thinking Hand; Sennett, The Craftsman.

27 "2007_Schindler_ Information-Tool-Technology," 19.

1.2 CONTEMPORARY PRACTICE

MATERIAL AND METHOD

The thesis discourse is situated in the broader context of craftmanship in contemporary fabrication, but the research employs the practice of ceramic slip casting as a lens of investigation. Slip casting is a process of forming ceramics by pouring slip into plaster molds which absorb water from the slurry to build a layer of clay against the mold. Once the desired wall thickness is achieved, the excess slip is drained, and the clay is allowed to stiffen before being released from the mold.[28] To evaluate craftsmanship within contemporary ceramic fabrication and examine the relationship between maker, material, and tools, slip and slip casting are held constant throughout the investigation to minimize material and process variables. Slip is a liquid clay material used in the process of slip casting, consisting of a mixture of clay, water, and sometimes additives such as deflocculant agents that allow for easy flow of the clay.[29] *

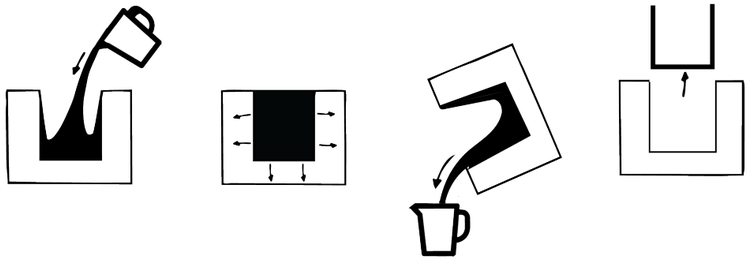


Fig. 1.5.
diagram of slip casting method,
Illustration by author.

TOOLS

In the case of architectural ceramic manufacturing, clay and its production processes remain constant while the tools—hand tools, machines, or technologies—involved in its fabrication reflect different technological developments.

In this research, "machine" refers to the physical equipment used to manipulate or process material, while "technology" refers primarily to digital tools and systems that support or control fabrication. This distinction reflects the hybrid nature of contemporary fabrication, in which traditional material-based processes are increasingly combined with technologies developed across different industrial eras. Contemporary fabrication may integrate traditional craft practices with CNC machining, 3D printing, automated machinery, and robotics, allowing different methods to be combined according to their respective capabilities. Rather than replacing traditional processes entirely, these technologies can modify or extend existing methods, creating opportunities to reconsider how knowledge, labour, and control are distributed between the maker, material, and machine.

Therefore, drawing on Schindler's three parameters of production: material, energy, and information,[30] this investigation focuses on how knowledge is distributed and located within the production process.

28 "Slip Casting," accessed June 11, 2025, https://digitalfire.com/glossary/slip+casting.

29 "Slip-Casting," Open Learning, 1, accessed July 14, 2025, https://www.open.edu/openlearn/science-maths-technology/engineering-technology/manupedia/slip-casting.

30 "2007_Schindler_Information-Tool-Technology."

* The casting slip is a suspension of fine particles (<5 µm) in a liquid medium (water). A pH of 10 is controlled for good dispersion of the ceramic particles and to achieve a low viscosity of the slip.

APPLICATION OF TOOLS

As technological advances become increasingly integrated into contemporary practice, examining current fabrication tools provides a basis for investigating how they are used, and what they contribute to the practices that employ them.

Boston Valley Terracotta in Buffalo, NY, and Ludowici Roof Tile Factory in New Lexington, Ohio are two ceramic production practices that adapt to industrialization and digitization through the introduction of new technologies within their large manufacturing facilities. Originally ceramic cladding or roof tile manufacturers, both facilities expanded their methods of production and range of products over time. While rooted in traditional craft, they both adopt machines and technologies such as 3D plastic printers, 3-axis wire-cutters, CNC water jet cutters, extrusion dies, and hydraulic presses for design opportunity and efficiency. Boston Valley Terracotta also introduces the Architectural Ceramic Assemblies Workshop (ACAW) to focus on the research and development of novel architectural ceramic product design methods.





left to right;

Fig. 1.6

Photo of Boston Valley Terracotta using a 3D laser scanner,
Image by Boston Valley Terracotta.

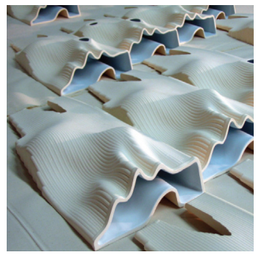
Fig. 1.7

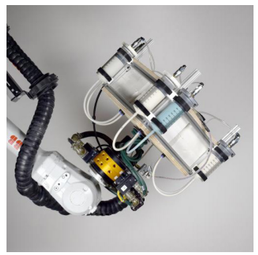
Photo of Ludowici using a pressure tester,
Image by author.

Within slip cast ceramics methods, mass-production toilet manufacturing facilities introduce technology from the most recent industrial era. JOMOO, a large-scale sanitaryware manufacturer in China, adopts artificial intelligence in the management and operations of their "5G cloud manufacturing centre" factory. [31] This technology is introduced to replace customer-to-manufacturer contact for efficiency and to avoid human error.

31 JOMOO Kitchen & Bath, How Are Toilets Made?, 2021, 09:25, https://www.youtube.com/watch?v=pMBx9W1DRyA.

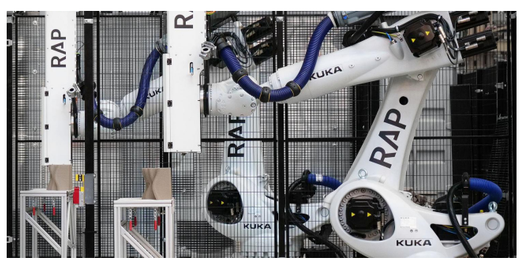
Academic institutions also experiment with advanced digital technologies as a form of testing material and tool limits. Joshua Stein, a professor of architecture at Woodbury University in California, explores material agency through digitization.[32] His work includes the use of a CNC router on a plaster mold for slip casting ceramics. Students at the University of Pennsylvania also work with slip using a robotically controlled process of slip casting to achieve efficiency in material use.[33] Maria Yablonina, an architect, researcher, artist, and professor at the University of Toronto, also experiments with robotic ceramic production methods.[34] Her research develops custom robotic systems in which the machine, material, and design parameters are interdependent, allowing the fabrication process to adapt to a design's specific requirements. This approach demonstrates how contemporary fabrication can shift the machine's role from a predetermined production tool to an actor within the design process.







Fabrication research extends beyond academic institutions. Studio RAP, a Rotterdam-based design-build studio specializing in architectural ceramics, demonstrates how technology can be integrated into the production of architectural components.[35] They use 3D ceramic liquid deposition modelling that reads a software-produced design to create entire modular façade assemblies. Their use of new technology underpins their entire practice.



These contemporary approaches to clay processing demonstrate two distinct objectives for integrating technology into fabrication: expanding design possibilities through technological innovation, and improving production efficiency by reducing time, labour, and material consumption. Each objective and strategy of integrating technologies represents different priorities, and this thesis will assess how the divergent priorities influence the role of craftsmanship in contemporary fabrication.

32 "RadicalCraft," https://radical-craft.com/About.

33 "Robotic Approaches to Dynamic Slip Casting | MSD-RAS," https://ras.design.upenn.edu.

34 "Maria Yablonina | Daniels," https://www.daniels.utoronto.ca/people/core-faculty/maria-yablonina.

left to right;

Fig. 1.8
Photo of Joshua Stein's work, Tectonic Horizons, that used a CNC router,
Photo by Joshua Stein.
Fig. 1.9
Photo of 6-axis robotic arm used by UPenn for 'These Things Swirl project',
Photo by UPenn.
Fig. 1.10
Photo of UofT's robotic arm,
Photo by UofT.

Fig. 1.11

Photo of Studio RAP's robotic arms,
Photo by Studio RAP.

35 Studio RAP, accessed July 15, 2025, https://studiorap.nl/Contact.

EVOLUTION OF METHOD

Having established why fabrication methods evolve, this section considers the influence of these methodological shifts and the introduction of new tools and technologies on the role of craftsmanship within production. A significant shift is the introduction of technology that threatens human involvement as the intellectual operator but benefits profit and mass production. These tools within the scope of this study include CNC routers and ceramic 3D printers. As processing knowledge shifts from the human to autonomous systems, the craftsperson becomes increasingly distanced from the material, design, and fabrication process, potentially weakening their connection to the consequences and broader impact of their work. Whether craftsmanship can retain its value amid technological shifts depends not on the tools themselves, but on how they are integrated into the fabrication process.

Sennett investigates this loss of craftsmanship as fabrication methods evolve from traditional practices to contemporary processes by observing the hand's connection to material. Traditional approaches to ceramic manipulation require an unavoidable level of care, skills gained through practice, and knowledge of material and process gained through direct manipulation. This not only produces works that demonstrate the care and time that go into creation, but as art and cultural theorist Jonathan Crary argues, the act of caring in making gives craft an ethical integrity.[36] The value of craftsmanship lies not only in the creation of a product, but more importantly in the development of the craftsperson through the act of making.

Christopher Bardt, a professor of architecture and author of 'Material and Mind', speaks about his pioneering theory of material engagement (MET), stating that to recapture meaning and the "what" of design in a modern world, while overcoming the unidirectionality of digital tools, requires a structure that recognizes and builds upon the roles of resistance and reasoning within the design process.[37] Material has historically provided this attention to process, explaining its separation from digital tools. We cannot deny that the world develops with new inventions and methods of working with traditional materials, so this work looks to embrace these changes by recognizing the logic behind the development.

Methods of fabrication adapt over time and will continue with the introduction of new tools, but the relevance of the conclusions drawn from this thesis is constant throughout societal and methodological shifts.

36 Crary, 24/7 : Late Caitalism and the Ends of Sleep .

37 Christopher Bardt, "Recapturing Meaning: Toward a New Material-Based Design Theory for Architecture," *Frontiers of Architectural Research* 11, no. 4 (2022): 609–17, https://doi.org/10.1016/j.foar.2022.03.005.

1.3 OBJECTIVES

The following objectives establish the framework for the research and design investigation. They establish criteria to evaluate the meaning of craftsmanship and its value within contemporary fabrication, examining how its value can be maintained as fabrication methods evolve. Together, these objectives connect the theoretical research, case studies, and design tests that structure the thesis.

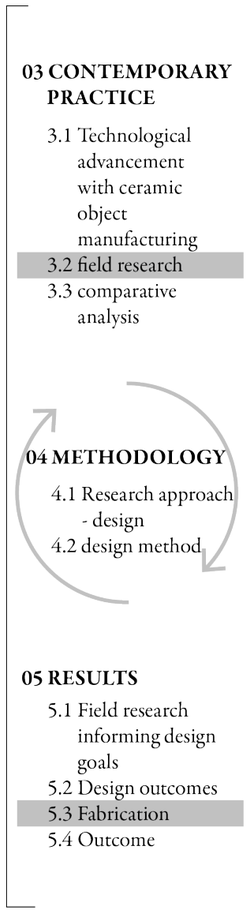
1) **Understanding the role of craftsmanship in contemporary fabrication.**
   - Examining the relationship between the maker, material, tools, and knowledge within traditional and contemporary production.
   - Investigating how human knowledge, judgement, and material engagement can remain essential when machines and digital technologies mediate the fabrication process.
   - Critically evaluating assumptions that increasing automation results in greater efficiency by comparing the outcomes, processes, and labour involved in traditional and technologically assisted fabrication.

2) **Investigating the value of craftsmen in contemporary fabrication.**
   - Identifying the values associated with craftsmanship, including material knowledge, embodied skill, judgement, care, and responsibility.
   - Examining how these values are maintained, transformed, or diminished as production methods evolve.

1.4 STRUCTURE

Architectural value is shaped not only by the final design, but also by how it is produced. A narrative of value can be uncovered by studying the thought process, material selection, tools used, and every decision that go into the production process.[38]

38 Bardt, "Recapturing Meaning."



'02 Context' explains the material selection of clay and slip casting, the ceramic method selected for investigation.

'03 Contemporary Practice' maintains the material scope and studies current practices that explore the possibilities of ceramics using new methods incorporating digital technologies. The investigation compares information across various production scales, with different motivations for production and design, and different tools used to realize these designs. Information is gathered from North American sources involved in ceramics and architecture, so the scope of material sourcing and technique is relevant to the location of this design research.

The chapter introduction (3.1) provides a broad overview of technological advances in ceramic object manufacturing, as seen in three selected practices. The follow-up section (3.2) narrows the contemporary practice research to practices that automate slip casting, providing a more in-depth analysis with information gathered directly from interviews.

'04 Methodology' transitions between the case studies and design fabrication. To address the objectives of this thesis and understand the role and value of craftsmanship in contemporary fabrication, this research engages directly with craftsmen actively involved in these practices. This is complemented by direct engagement with the material through the development and fabrication of a design.
This order allows the case studies to inform the design by identifying the values of craftsmanship worth retaining in contemporary practice. Comparing production processes, material choices, and underlying values in each practice establishes a set of 'design goals' that guide each design while maintaining craftsmanship involving decision-making, material knowledge, and developed skill.

In '05 Results', having established that each design will meet the design goals, this research conducts a series of design tests using methods ranging from traditional to contemporary practices to examine the impact of digital technologies on craftsmanship, culminating in a screen system for architectural engagement. These tests compare analogue processes, where knowledge is held by the maker, with digital processes, where knowledge is embedded within the machine.

'06 Discussion' reflects on the research objectives by evaluating the role and value of craftsmanship within contemporary fabrication based on the findings from the case studies, design test outcomes, and anticipated developments in contemporary fabrication.

02 | CONTEXT

CRAFTSMANSHIP

Craftsmanship is a way of thinking through manipulation of materials. Juhani Pallasmaa emphasizes this point by describing the dialogue between the hand and body as a window into the mind through material engagement.[1] His understanding does not exclude the use of tools or machines; rather, tools can extend the maker's physical and cognitive abilities, allowing the product to be an expression of the maker. Conversely, the craftsman needs to internalize the nature of the material they are working with, coming from experience and touch, "eventually turning themselves into their own product"[2] – a tool capable of responding to material. However, as knowledge shifts from direct material engagement toward technological systems, craftsmanship risks being diminished when the craftsperson is no longer actively involved in developing and applying that knowledge.

Traditionally, craftsmanship was integral to the fabrication of ceramic objects, as makers selected materials, developed an understanding of their properties, and refined techniques through manipulation by hand to transform ideas into physical forms. With limited technological alternatives, direct engagement between the hand and material was fundamental to the fabrication process. As a result, craftsmanship did not need to be consciously preserved; it was inherently embedded within how ceramic objects were made. The introduction of new technologies has since created greater separation between the maker and material, raising questions about how these forms of knowledge and engagement can be maintained within contemporary fabrication.

The involvement of the human hand, or mere human presence itself, can enhance the value of material things because human effort signals intentionality and authenticity.[3] When a handmade product is purchased, the buyer pays for the labour, time, and love that went into its creation, which contributes to the value of the final object. American social psychologist Justin Cruger and his research collaborators Wirtz, van Boven, and Altermatt describe this phenomenon as the Effort Heuristic Theory.[4] Effort Heuristic Theory is a concept based on a series of social studies explaining that people consciously or subconsciously judge the value of something based on the perceived effort put into it. The studies showed that more value was placed on works that showed signs of hand fabrication that took more effort to create. Even though technology and machines have in most cases taken the need for human manipulation out of many crafts, traditionally made versions of the same products are perceived to hold more value.

The amalgamation of these ideas establishes craftsmanship not only as the use of the hand, but as a way of engaging with material to pursue quality.[5] This expanded the understanding of how craftsmanship can be expressed across ceramic production, leading to an exploration of different stages of the process, including clay manipulation, glazing, and firing.

1 Juhani Pallasmaa, The Thinking Hand: Existential and Embodied Wisdom in Architecture, AD Primers (Wiley, 2009), 52.

2 Pallasmaa, The Thinking Hand, 53.

3 Adam Waytz, The Power of Human (W. W. Norton & Company, Incorporated, 2019), 31."source"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}

4 "The Appeal of Handmade in an Era of Automation," Kellogg Insight, July 31, 2019, https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}

5 Richard Sennett, The Craftsman (Yale University Press, 2008), 9.

2.1 THE JOURNEY

STAGE OF PROCESSING – Authors Perspective

This thesis uses ceramics as the material lens for investigation, but the specific method of clay manipulation emerged through a combination of this research journey and the broader experiences that have shaped the development of this work. This section is written from the author's perspective, as the development of this thesis was shaped by a personal research journey.

I had always been drawn to ceramics as a meditative craft, captivated by the strong connection of the hand and clay. High school art class was my introduction to ceramics, creating functional dinnerware from pinch pots and a selection of hand tools such as ribs, wire, and wooden sculpting tools. As I worked, I would think about how much my family would love these pieces and the impact they would make as part of our kitchen sets. I loved being able to show people my work and see them interact with the final piece, watching the connection people have with products that began as clay and hands coming together to make an idea tangible. The time spent shaping clay was accompanied by ambient music playing lightly in the background, with random thoughts flowing through my mind. I would think about all the things I should be doing, with no way of quickly completing side tasks since my hands were covered with remnants of the piece I was currently crafting. It was a practice of focus and an escape from responsibility. This led me to study architecture, where I could create spaces for people to interact with on a larger scale while maintaining the principle that initially drew me to ceramics: creating experiences through the shaping of materials.

During my architectural education, I continued working with hand-crafted ceramics as a way of relieving stress and occupying my mind and hands with things. I took a class on using the pottery wheel, intrigued by the refined forms of bowls and cups that could be created on the wheel. I was drawn to exploring machines in ceramic production, but questioned whether I would find the process as rewarding as working with only hand tools, since using a pottery wheel felt like some control was lost to the machine. I discovered that it takes a lot of practice to master the ceramic wheel, and you must learn how to work with the wheel, learning the feeling, movements, and correct pressures to use.

Wheel-thrown ceramics are created through a traditional process in which the machine assists the hand. Building on this exploration of machine use in ceramic production, I turned to Fused Deposition Modelling (FDM) ceramic printing—a contemporary process that uses digital technology to automate the formation of clay layer by layer. Unlike the pottery wheel, the human assists the machine in place of the machine assisting the human. In the first year of my master's program, I took a ceramic morphologies course with instructors James Clarke-Hicks and Isabel Ochoa at the University of Waterloo that taught me how to independently work through the FDM ceramic printing process. From preparing the clay consistency to creating clay wedges to feed the printer, the hand is always involved in the FDM ceramics process. Beyond the preparation process, the design is digitally created and predetermined by the designer using Rhinoceros 3D and Grasshopper, establishing the parameters that are translated through G-code to the machine for design production.

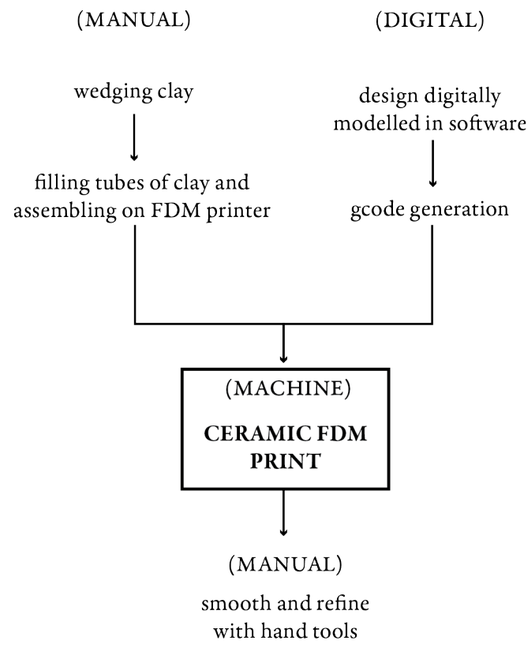


Fig. 2.1

Diagram of Ceramic FDM workflow, Illustration by author.



Fig. 2.2

Image of Ceramic FDM prints, Image by author.

There are many ways clay can be manipulated through the interaction of hand, machine, and material under the umbrella of digital ceramic fabrication. Rather than trying to discover these practices on my own, I chose to learn from local artisans whose experience could deepen my understanding of the hand-machine-material methods in their respective practices.

The making of a ceramic object extends beyond the manipulation of clay itself. For example, the firing process introduces another stage of clay transformation, where heat, atmosphere, and firing technique have significant influence over the final appearance and character of the work. Other techniques, such as glazing can also affect the final product of ceramics production. To explore the broader scope of ceramics fabrication beyond clay manipulation, I visited local practitioners whose expertise represented different stages and approaches to ceramic production.

First, to study the role of firing, I visited Steven Corner, who has been a full-time potter since 1998, wood-firing his work in a train kiln in Southern Ontario.[6] He demonstrated how craftsmanship works with unpredictability rather than eliminating it. Although the firing outcome cannot be fully predetermined once items are placed into the kiln, his knowledge as a craftsman allowed him to influence the process, resulting in functional ware whose distinctive firing patterns and colouration revealed the interaction between the potter, the clay, and the firing environment.

6 Stephen Corner | Steve the Potter, n.d., accessed June 11, 2025, http://stephencorner.com/.



Fig. 2.3

Photo of train kiln at Steven Corner's studio,
Image by author.

My visit to Corner's studio led me to take part in a foil saggar firing workshop led by Gene Timpany at the Donn Zver School of Pottery in Troy, Ontario.[7] Saggar firing is an ancient technique that has been altered in contemporary practice by the firing techniques and equipment available. In this case, the technique uses tinfoil as a "saggar" and fires in a gas kiln. Historically, saggars were protective vessels made from clay and used inside open-fire or pit fires to shield the pottery from direct flame, ash, and debris during the firing process, and allowed for more control over the firing conditions.[8] The process remains similar and is still referred to as saggar firing, but its purpose has shifted from protecting the ceramic during firing to intentionally creating unique and controllable surface effects on the final piece. The foil created a reduction environment by limiting oxygen, allowing chemical reactions between the clay's iron content and added materials that alter the final surface. In the workshop, we worked with combustible materials, soluble salts, sawdust, leaves, horsehair, sugar, Epsom salts, ferric chloride, copper carbonate, copper scrubs, and stainless-steel wire.

Then, I took a glaze chemistry class to learn different techniques and processes, building further upon my research into finishes and surface effects. In this course, I experimented with different chemical combinations to observe their effects on ceramic post-firing colour. The glazes applied by brush produced a predictable appearance once fired (whether by gas, electric or wood kiln) because the colour chemistry remains consistent due to the chemical composition of the glazes themselves. While learning about firing and glazing methods, I came to understand that my interest lied in the manipulation of clay to create ceramic objects rather than their final appearance, design, or surface treatment. Therefore, I focused my research on the method of fabrication and the relationship between the hand and the formal outcome of the ceramic object.

7 Donn Zver Pottery, "Donn Zver School of Pottery," Donn Zver Pottery, accessed July 8, 2026, https://donnzver.com/pages/donn-zver-school-of-pottery.

8 "The Art and Alchemy of Saggar Fired Pottery: Exploring Ferric Chloride," accessed June 11, 2025, https://alliancechemical.com/blogs/articles/the-art-and-alchemy-of-saggar-fired-pottery-exploring-ferric-chloride-s-transformative-role-in-modern-ceramics.

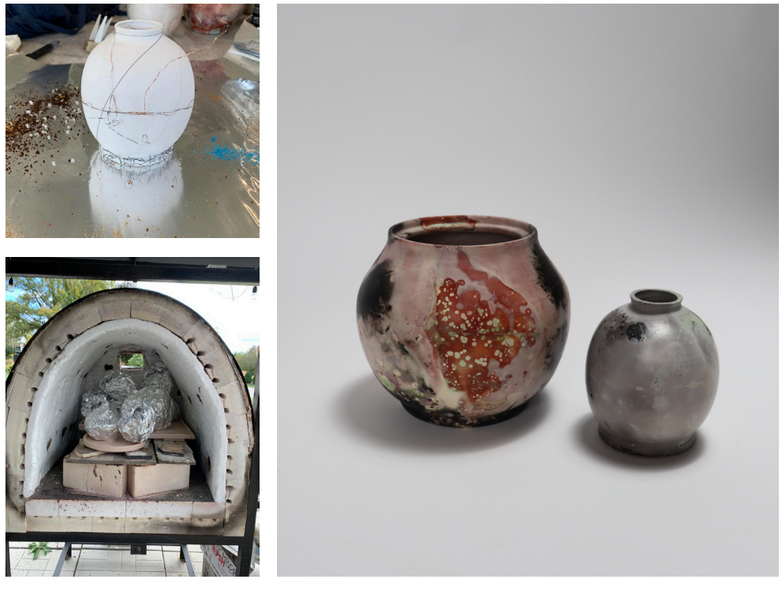


Fig. 2.4

Collage of foil saggar firing workshop by Gene Timpany ,
Collage by author.



METHOD OF CLAY MANIPULATION

The various clay manipulation methods rooted in traditional ceramic practice include hand forming, such as coil and pinch forming, slab building, wheel throwing, press molding, extrusion, and slip casting. Of these methods, coil forming, press molding, extrusion, and slip casting remain relevant to contemporary ceramic production because they have been adapted through new technologies and machinery, allowing traditional processes to be applied to larger-scale manufacturing. FDM ceramic printing, for example, can be understood as a technologically assisted evolution of coil forming, using digital technology and machinery to automate the deposition of clay.



left side, top to bottom

Fig. 2.6

Photo of press mold test,
Image by author.

Fig. 2.7

Photo of slip cast test,
Image by author.

right side, top to bottom

Fig. 2.8

Photo of extrusion die test,
Image by author.

Fig. 2.9

Photo of 3D clay printing test,
Image by author.

Fig. 2.5

Photo of all initial method tests, Image by author.



Fig. 2.10

Photo of slip casting process, Image by author, edited using AI tools.

Slip casting is used as the medium for this investigation because it occupies a position between traditional craftsmanship and industrial production. Although traditional slip casting did not rely on machines, its final forms often contained little visible evidence of the hand. Reusable molds allow the process to produce consistent forms repeatedly and at a larger scale, making slip casting relevant to both craft-based practice and industrial manufacturing, as demonstrated by its use in architectural ceramics and sanitaryware. The ability to repeatedly achieve this precision demonstrates a different expression of craftsmanship—one based not on visible traces of making, but on the knowledge, judgement, and skill required to control the clay and process of manipulation. Although slip casting can be mechanized, it retains aspects of ceramic craft as it relies on an understanding of the clay body during the preparation of the clay, the design and fabrication of molds, and the knowledge required to control casting, drying, and firing. This tension between human knowledge and the appearance of perfection provides an important foundation for examining how craftsmanship can persist within technologically assisted fabrication.

Slip casting also offers specific fabrication capabilities that will be investigated through this research. It can efficiently produce enclosed, hollow forms with consistent wall thickness, it can reduce material weight, and it can reproduce continuous patterns or complex details across multiple faces. Unlike methods that require multiple pieces to be assembled, slip casting can produce these characteristics within a single continuous form while maintaining smooth surfaces, precision, and repeatability.

FDM ceramic printing provides a useful contrast to slip casting. Because the ceramic object design is embedded directly within the fabrication process, each clay print can be generated from a digitally modelled form, allowing iterative or entirely new designs to be produced without changing the fabrication setup. Slip casting, by contrast, relies on a physical mold and is therefore optimized for repeatedly reproducing a predetermined form. While FDM offers greater flexibility for design variation, slip casting presents an opportunity to investigate innovation within the fabrication process itself.

Machine and digital technologies have not been as widely integrated into slip casting, in part due to its reliance on mold-based production. However, emerging innovations, such as the use of robotic systems to automate slip casting processes, demonstrate the potential for greater technological integration. Despite these developments, there are few established processes to integrate technology into slip casting. Therefore, there is an opportunity to explore how contemporary technologies can be introduced into slip casting processes and how this integration may redefine the relationship between craftsmanship, material knowledge, and machine production.

2.2 MATERIAL AND METHOD

CLAY

Clay is a natural soil material composed of fine mineral particles, and is an abundant, accessible, and local material.[9] Early in the search for shelter, humans discovered they could use clay to form protective enclosures against the elements. Sun-dried mud was the first recognized use of clay in architecture and appears in structures globally.[10] Clay offers many environmental advantages for architecture including, but not limited to, a lower carbon footprint due to the ability to source the clay locally, durability, low maintenance, and the ability to regulate temperatures with a high thermal mass.[11]

By utilizing clay as the sole material in all fabrication studies, this limits the variability between different fabrication processes, providing more clarity for investigating fabrication methods across traditional craftsmanship and contemporary digital production. Due to clay's complex properties such as moisture content, drying, shrinkage, and firing reactions, developing ceramic forms requires an understanding of the clay material and its behaviour throughout the fabrication process.

Clay demonstrates how material properties influence the transition between digital and physical forms. While digital fabrication lets a design be precisely defined in software, clay's physical characteristics can alter the final outcome, creating differences between the intended digital form and the produced object. Joshua Stein's research is founded on the observation that "digital fabrication is usually executed with homogeneous materials, so the outcome is expected."[12] The friction between digital and physical form is central to this investigation, demonstrating that effective fabrication relies on an integrated understanding of process and material, and the ability to engage critically with both.

9 Unearthed: The Timeless Tale of Clay in Architecture - Telling Rainscreens, August 8, 2023, https://tellingrainscreens.co.uk/unearthed-the-timeless-tale-of-clay-in-architecture/.

10 Suzanne Staubach, Clay: The History and Evolution of Humankind's Relationship with Earth's Most Primal Element, 1. ed (Berkley Books, 2005), 119.

11 Armelle Tardiveau, Toni Cumella i Vendrell, and Asociación Española de Fabricantes de Azulejos y Pavimentos Cerámicos, eds., Moulding, Assembling, Designing: Ceramics in Architecture (Barcelona: Actar, 2006), 126.

12 Joshua Stein, "Interview Joshua Stein," interview by Candace Haddy, July 25, 2025, Microsoft Teams, transcript available upon request."

The following are clay properties referred to throughout this thesis that affect fabrication and material performance.

Sustainable	Natural, abundant resource.
Durability	Once fired, clay becomes capable of resisting physical wear and weathering.
Versatility	Can be modified in composition, firing treatment, and forming method.
Translucency (porcelain)	Clay body influencing the ability of light to pass partially through the ceramic form.
Plasticity	The ability to retain its shape and resist cracking. Stability in maintaining its shape with varying dimensions of the form.
Formability	Ability to be formed within the method of manipulation (e.g., castability, workability, etc.)
Moisture Content	Water-to-clay ratio.
Drying Response	Clay behaviour as it loses its moisture content.
Shrinkage	Reduction in the dimensions and volume of a clay body that occurs during drying and firing as water is removed.

Fig. 2.11

Diagram of material properties, Illustration by author.

SLIP CASTING

Within clay as the broader material category for investigation, slip casting is selected as both the material process and method of fabrication. The clay body used for the slip casting investigations is Pottery Supply House's Cone 6 910 porcelain casting slip. It is selected for its pure-white fired appearance and pre-mixed formulation, which ensures material consistency and a uniform finish throughout fabrication. Working with a single slip body establishes a controlled variable throughout the research, focusing the investigation on the relationship between clay properties, fabrication methods, and design outcomes.

The method of slip casting is believed to have originated in prehistoric Peru, where Indigenous peoples used the technique to produce the hollow shells of panpipes, as evidenced by archaeological specimens.[13] The process later developed in Europe during the mid-eighteenth century, with English potter Daniel Corbridge recorded as having learned to cast ceramic forms in Plaster of Paris molds in France in 1745.

In England, the development of slip casting coincided with an expanding market for ceramic tableware, driven in part by the growing population of tea drinkers. The technique enabled the consistent reproduction of detailed ceramic forms. Slip casting remains a widely used ceramic process for producing hollow, detailed forms, ranging from porcelain figurines and tableware to large-scale architectural products and sanitaryware such as toilets and sinks.[14]

An example of slip cast ceramics being applied at an architectural scale is Louis Sullivan's Guaranty Building. Often regarded as a "father of modernism," Sullivan was one of America's most influential architects of the nineteenth and twentieth centuries.[15] Completed in 1896 in Buffalo, New York, the Guaranty Building demonstrates the potential of ceramic production to translate the precision and repeatability of slip casting into an architectural façade at an early stage of industrial production. Its façade is composed of repetitive terracotta tiles produced as individual components, with repeated forms across the majority of the flat façade transitioning at the cornice into a more intricate composition of fan-like leaves and vines. The building shows how ceramic components are produced consistently while retaining intricate, craft-based ornament, positioning architectural ceramics between industrial repetition and individual craftsmanship.

13 Andrew Martin and Andrew Martin, The Essential Guide to Mold Making & Slip Casting, 1st ed, A Lark Ceramics Book (Lark Books, 2006).

14 "Upscaling - RadicalCraft," accessed July 9, 2026, https://radical-craft.com/filter/Casting/Upscaling.

15 Media Boston Valley, "Boston Valley's Work On Louis Sullivan Restoration Projects," Boston Valley Terra Cotta, July 15, 2020, https://bostonvalley.com/louis-sullivan-projects/.

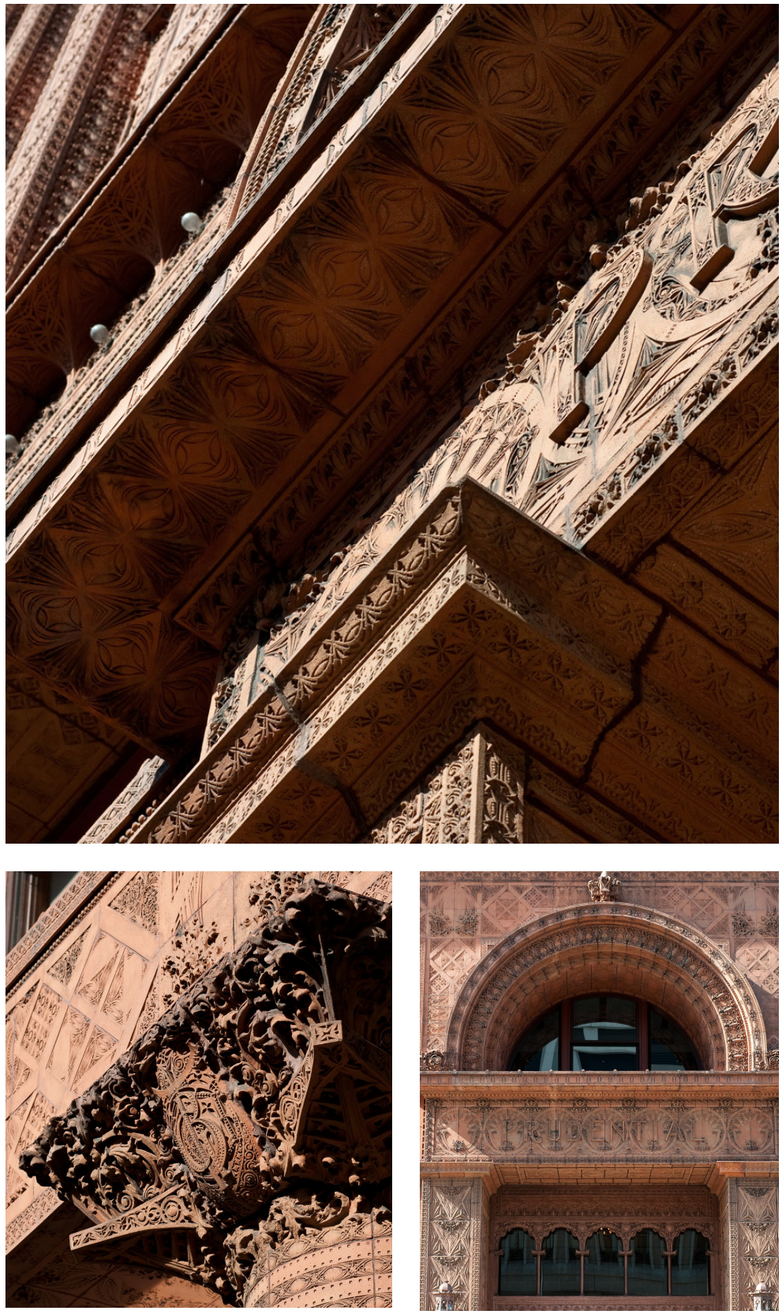


Fig. 2.12

Collage of Louis Sullivan's Guaranty Building, Collage by Boston Valley Terracotta.

03 | CONTEMPORARY PRACTICE

3.1 INNOVATIONS WITH CERAMIC OBJECT MANUFACTURING

Technological advancement is largely a result of the need for greater efficiency. Efficiency within the context of fabrication is defined in the Oxford Dictionary as "the ability to produce maximum good quality outputs of a desired result with the minimum time, cost, materials/resources, or effort (energy/labour)."[1] Within each stage of the production process, efficiency is assessed by asking if the current process is the fastest, easiest, least costly way to achieve a desired result. If robotics or machines can speed up certain parts of a process, resulting in a lower price due to less labour time, a shift occurs.

Some ceramicists choose to use this machinery and digital technology to achieve details, operations, and designs that are otherwise unachievable. Boston Valley Terracotta, Studio RAP, and the University of Pennsylvania Stuart Weitzman School of Design's Master of Science in Design: Robotics and Autonomous Systems (MSD-RAS), are selected because they explore the material possibilities of ceramics through new technologies. They demonstrate how contemporary tool and clay processing can expand what can be achieved through fabrication methods. Boston Valley Terracotta represents the integration of technology within an established industrial production, Studio RAP demonstrates how digital fabrication can expand architectural design possibilities, and the University of Pennsylvania demonstrates experimental research into robotic ceramic fabrication. Together, they explore the shift in ceramic production from direct hand manipulation to programming technological systems, providing a basis for examining how technology can influence material knowledge, craftsmanship, and production methods.

1 Jonathan Law, "Efficiency," in A Dictionary of Business and Management (Oxford University Press, 2009), https://www.oxfordreference.com

BOSTON VALLEY TERRACOTTA

Boston Valley Terracotta is a terracotta manufacturing facility in Buffalo, NY established in 1981,[2] that creates ceramic façade components with the goal of combining advanced technology with traditional craftsmanship. Shortly after its establishment, Boston Valley Terracotta undertook the restoration of the Guaranty Building, drawing on its specialized expertise in slip casting to reproduce the building's historic terracotta tiles. The project demonstrates how contemporary slip casting methods are used to replicate existing forms, enabling historical architectural ceramics to be reproduced while preserving their original design and character.

Boston Valley Terracotta presents a yearly workshop called the Architectural Ceramic Assemblies Workshop (ACAW), offering architecture firms the opportunity to engage with innovative ceramic techniques addressing sustainable design, water filtration, and passive design. The workshop's main goal is to reframe terracotta as a material relevant to contemporary architecture.[3] Participants engage with new technologies such as 3D clay printers, waterjet CNCs, and CNC routers to evaluate and test the potential of the tools at their disposal. Boston Valley Terracotta focuses on exploring the material possibilities of ceramics within contemporary practice, using new technologies to reveal and expand what can be achieved with clay. Because their use of technological tools is experimental, human knowledge remains essential to adapting the process and achieving new outcomes.

2 "About Boston Valley | Global Leader in Architectural Terra Cotta," Boston Valley Terra Cotta, n.d., accessed July 16, 2025, https://bostonvalley.com/about/.

3 Laura Garófalo and Omar Khan, eds., Architectural Ceramic Assemblies Workshop: Bioclimatic Ceramic Assemblies III, Architectural Ceramic Assemblies Workshop (Boston Valley, Terra Cotta, 2019), 40.

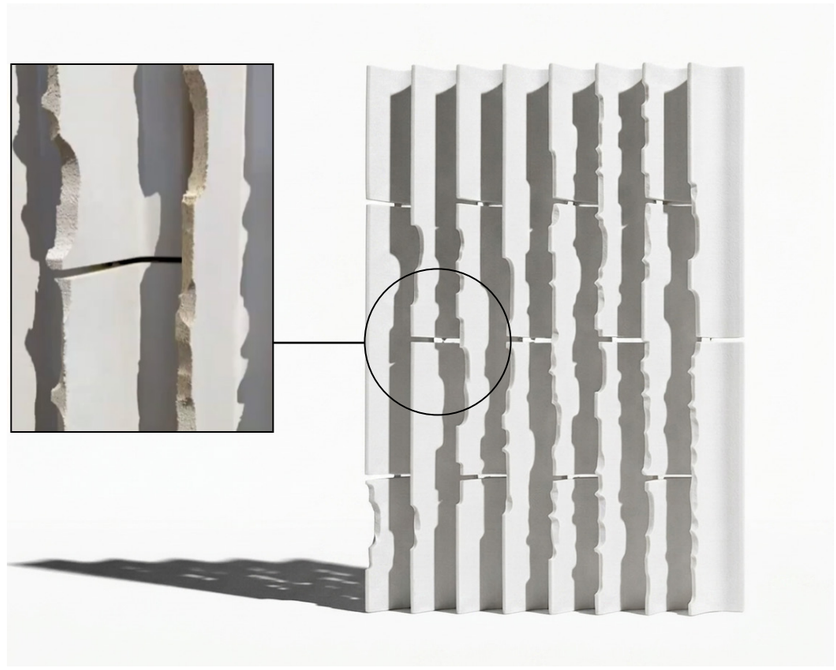


Fig. 3.1

Photo of ACAW presentation facade system by Superkül demonstrating the use of the 3-axis wirecutter, Images by Superkül, edited by author

STUDIO RAP

This contrasts with Studio RAP's approach, where the exploration of technology itself is central, with clay serving as the material through which its capabilities are investigated. A large amount of Studio RAP's work consists of digitally fabricated ceramic façades that demonstrate how computational design and robotic fabrication can expand the formal possibilities of architectural ceramics, while shifting the maker's role from direct manipulation of clay toward designing and controlling the digital and robotic fabrication process.[4]

Their designs are realized through clay fused deposition modelling (FDM/3D printed ceramics), so the entire design can be modelled digitally at 1:1 scale and then translated directly into G-code for the FDM ceramic printer. Digital design enables precision in connection points and dimensions, fine pattern details, and mass customization. Their modules are primarily used for façade cladding, where FDM ceramic printing offers the advantage of producing hollow components that reduce weight while maintaining the desired form. Studio RAP's method provides a lens for examining whether craftsmanship is lost or relocated when ceramic production shifts from direct hand manipulation to digital tools. However, designers retain control over customized outcomes through close collaboration with clients, using their knowledge and judgement to guide design decisions and the control of technological systems.

4 "Ceramic House - Studio RAP," accessed July 15, 2025, https://studiorap.nl/Ceramic-House.



Fig. 3.2

Collage of Studio RAP ceramic facade modules for Ceramic House Project,
Collage by Studio RAP.

UNIVERSITY OF PENNSYLVANIA

This exploration extends into academic research at the University of Pennsylvania, where the Stuart Weitzman School of Design's Master of Science in Design: Robotics and Autonomous Systems (MSD-RAS) program investigates novel approaches to architectural design and manufacturing through digital and robotic technologies. The program has a range of robotics, material systems, and design-computation software at their disposal for experimentation. This includes an Architectural Robotics Initiative Robotics Lab facility housing several high-performance 3D printers, a large cubical kiln, and several Asea Brown Boveri and Universal Robots, with a range of production activities possible such as robotic milling, additive manufacturing, sheet-metal bending, and robot hot-wire cutting.

MSD-RAS finds importance in adopting new technologies in the building industry as it undergoes transformation through the adoption of robotic technologies that reduce the time, cost and complexity of delivering buildings, with additional humanitarian and socio-economic benefits.[5] The students explore this opportunity in a slip casting project called 'These Things Swirl' whose research goal is to discover methods of creating mass-manufactured slip casted ceramic forms with controlled colour and pattern, using a 6-axis motion robot. Students create a digitally coded movement pattern and refine the proper consistency and amount of slip to insert into the plaster mold to reduce clay waste. The student team uses this technology to allow for variation, addressing the lack of visual variation faced by conventional slip casted components. They then use a custom robot pick-and-place routine and custom-developed generative design with a material physics simulation method to assemble the components and select orientation and placement in the post-processing stage.

This project demonstrates a dual focus on material efficiency and technological possibility: technology is used to reduce clay waste and optimize the slip casting process, while clay serves as a material through which new robotic fabrication methods can be explored. Their exploration is primarily experimental, focusing on controlling the production process and clay rather than prioritizing a predetermined outcome. To investigate material, process, and processor relationships beyond the technological systems used themselves, this research turns to the people working within ceramic production to understand how knowledge, judgement, and care are developed and applied through practice.

5 "Robotics and Autonomous Systems [MSD-RAS] | Weitzman," accessed July 16, 2025, https://www.design.upenn.edu/robotics-and-autonomous-systems-msd-ras.



Fig. 3.3

Collage of Smodules created for 'these things swirl' project,
Collage by UPenn.

CONCLUSIONS

Ceramic screen manufacturers' standard products are predominantly created using extrusion or pressed tile techniques for their ability to efficiently produce components at scale.[6] The introduction of machines and digital technologies creates new design opportunities, precision, uniformity, and versatility, while potentially reducing clay waste and production costs at larger scales.

Boston Valley Terracotta, Studio RAP, the University of Pennsylvania, and other contemporary ceramic practitioners show how digital technologies and machine tools are reshaping ceramic production. Their work uses digital processes to achieve forms and fabrication outcomes such as precision and mass-customization that would be difficult or impossible to produce through traditional methods alone.[7] While these technologies reduce direct hand manipulation, they do not eliminate the need for control, judgement, and care within the fabrication process. Instead, they shift where these qualities are expressed, raising questions about how craftsmanship is reshaped when the maker's role moves from directly manipulating the material to designing, programming, and controlling technological systems.

Although technological advancement is widely explored within ceramic production, fewer examples examine the automation of slip casting specifically. To understand the importance of craftsmanship in these contemporary practices, this research also engages with experts innovating within traditional slip casting methods through observation and conversation. These examples acknowledge ongoing developments in the field, while providing context for technological approaches, such as robotic automation, that extend beyond the tools and processes available within this investigation.

6 admin, "From Extruded to Pressed: The Evolution of Ceramic Tiles You Should Know," Kimgres, September 24, 2025, https://kimgres.com/from-extruded-to-pressed-the-evolution-of-ceramic-tiles-you-should-know/.

7 "2007_Schindler_Information-Tool-Technology," n.d., 12.

3.2 CASE STUDIES

LIMITATIONS

The case studies focus on North American companies to ensure that the clay sources, available tools, and product demands reflect the local context of the investigation in Cambridge, Ontario, making the identified methods applicable to the region. This constrains the distance of the four facilities selected for in-person interviews. Bryan Hopkins is located in Buffalo, New York, and Ludowici Roof Tiles is located in New Lexington, Ohio, so these two facilities could be toured in person as they are within a five-hour drive of the research location. Joshua Stein is located in California, so a remote interview is performed. The largest limitation is with the toilet manufacturing facilities located in the United States, as they are unable to give tours; therefore, all research for these factories is from online resources.

SELECTION

The selected case studies are experts in specific areas of automating the process of slip casting. Bryan Hopkins pushes the properties of slip material such as thinness, purity in colour, scale, unique design, slip recipe, and firing temperature/time for environmental sensitivity. He experiments by hand on a small-scale, whereas Ludowici roof tiles work in larger architectural scales in large quantities. They automate the process with machinery and new technology such as automated extrusion and hydraulic pressing, yet their slip casting process remains comparatively reliant on manual labour and operator knowledge. Joshua Stein works as an experimental ceramicist with new technology for slip casting production, and he questions the position of technology and machinery within ceramics. His discoveries have not yet been introduced into large-scale production. A variety of toilet manufacturing facilities that work with slip casting for mass production are also studied. The findings of these case studies are then translated into the development of a ceramic screen system, providing a framework for further investigation into the values and processes identified through the research. The following case studies guide the application of the identified methods, material capabilities, and technological processes to the design.

CASE STUDY 1; BRYAN HOPKINS
On-site Interview January 31st 2025.

Bryan Hopkins is an independent ceramic artist who has worked exclusively with porcelain for the past 25 years. He relies exclusively on hand fabrication, as this approach aligns with his commitment to and passion for the craft, making digital fabrication outside his practice. Hopkins experiments with the advantages of slip casted ceramics, testing minimum wall thickness, purity in colour given material properties, maximum scale, firing temperature and time required, and method of production. These experiments result in a collection of commercially available cups and bowls that combine functional and decorative qualities while reflecting his distinctive style of work. Although Hopkins sells his work, he claims income is not the primary driver of his practice; his financial freedom lets him prioritize experimentation, research, and personal satisfaction.

Hopkins developed a variation of traditional slip casting that maintains hand manipulation while intentionally introducing variation into the production process. Rather than using the keys in the plaster mold, a method that ensures each mold section aligns in the same position each time it's assembled, he removes them to allow the sections to shift between casts, producing a unique form with each cup.

When asked about his contribution to research, Hopkins replies, "I do all these tests without knowing where it's going. But my life goal is to add something to the whole continuum of ceramic research and at this point I've done it, and I'm happy. But what's next? I'm only 57, so there's got to be more."[8]

8 Hopkins, "Interview Bryan Hopkins," interview by Candace Haddy, 8."

Fig. 3.4

Photo of Bryan Hopkins stamping texture for plaster mold,
Image by author.

MATERIALS

Hopkins' recent work has been with porcelain. Due to the pure white and translucent results Hopkins strives to achieve, he mixes his own slip, which he calls 'Hopkins Low Fire Porcelain'. He fires to vitrification in a single fire at cone 05 in oxidation and obtains a non-porous, white, translucent object at lower temperatures, cutting the energy he uses in half.[9] This recipe was developed after 125 versions, ultimately obtaining the cleanest clay possible.[10]

For this slip recipe, he requires a clay from New Zealand because of the white-primary clay deposits found there. The kaolinite of this clay is a halloysite kaolin, therefore, its chemical composition is structured with tiny hollow tubes called nanotubes rather than flat plates. This allows this clay composition to transmit light better and be more translucent than others. A deflocculant allows the clay to pour and dry without cracking.

Hopkins' work is reliant on making his own slip to achieve the appearance he desires. It is a fully material-reliant process of production, using chemistry to control the outcome. Facilities have been known to stop mining components required in slip due to low demand and changes in the economy; therefore, the sources of his clay materials have been known to change location based on availability. Hopkins' material-reliant process highlights the importance of understanding the properties and limitations of clay and working with its inherent qualities to achieve a desired outcome, rather than forcing the material to perform beyond its capabilities.

9 "Walking the Talk: Sustainability in Ceramic," Default, accessed April 15, 2026, https://ceramicartsnetwork.org/ceramics-monthly/ceramics-monthly-article/walking-the-talk--sustainability-in-ceramic.

10 "How Low Can You Go?," Ceramics Monthly 62, no. 6 (2014): 58–61.





Fig. 3.5
Collage of Bryans cups,
Collage by author.

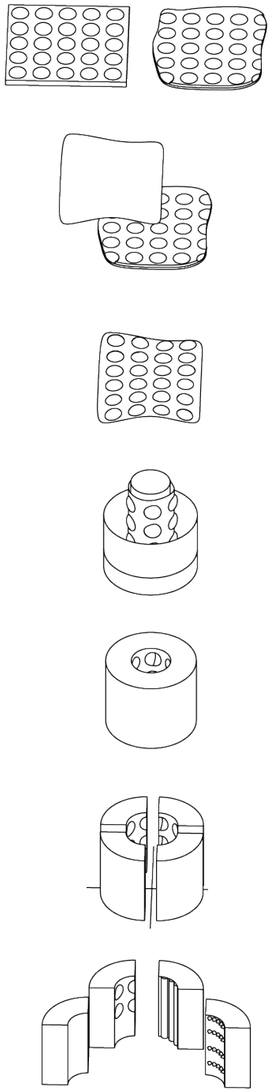


Fig. 3.6 *Diagram of Bryan Hopkin's process of production,* Diagram by author.

Image on right:

Fig. 3.7 *Photo of textures translated into clay in the library of textures,* Image by author.

PRODUCTION

The first stage of production is the negative clay mold created from textures in Hopkins' surroundings that carry meaning, personal memories, or significance. His textures include bike tires showcasing his interest in biking, tree bark, wood collected from 19th-century barns, or building blocks from his son's toys. Hopkins creates a library of plaster textures from porcelain slabs, allowing him to preserve and reuse textures throughout his production process. He selects from this library to introduce different patterns and combinations into each vessel. The texture is transferred to plaster by pouring plaster into a ring of formwork around the textured surface, which is removed once the plaster has set.





Fig. 3.8

Photo of porcelain slab wrapped around smooth vessel with texture facing outwards, Image by author.



Fig. 3.9

Photo of a piece of flashing rolled around the outside of the vessel, leaving a minimum of 1" gap, Image by author.

The tube of plaster that remains after it is completely set can be sliced in quarters. The method of slicing the plaster casts removes the ability to have keys that hold the plaster mold pieces together. Keys act as locks that eliminate any shifting and hold the plaster pieces in the exact same position every time. Hopkins intentionally removes this traditional step in the method of slip casting to obtain the advantage of shifting the plaster pieces to different positions and piecing together any plaster patterns. The removal of keys also makes each piece he creates unique as the probability of assembling the pieces the exact same each time is very unlikely. Hopkins does not use the mold simply as a means of reproducing a predetermined form; he alters the fabrication method to introduce human judgement and variation into each outcome.

To begin creating a vessel, he combines an array of various patterned plaster pieces to create a circle for the slip to be poured in. When pouring the slip, he adjusts casting time to experiment with thinner walls, demonstrating how his material knowledge and ongoing process experimentation directly influence the final form.



Fig. 3.10

Photo of plaster mold being sliced using a miter box jig and a saw blade so that the pieces have perfectly vertical cuts,
Image by author.



Fig. 3.*11*

Photo of a circle assembled using pieces from various plaster molds that contain different patterns,
Image by author.



Fig. 3.12

Photo of library of plaster molds of different sizes and textures,
Image by author.

When the ceramic piece is in leather-hard state, it is removed from the mold. Although his hands complete all necessary steps, they directly contact the clay only when he refines the lip with a trimming knife to the desired height. This step further enhances each piece's individuality, although his casting process already introduces variation between forms.

The limited direct contact between Hopkins' hands and the clay demonstrates that visible handwork is not necessarily required for human judgement to influence the final object. Instead, his craftsmanship is embedded in the decisions that govern the process.



Fig. 3.14

Photo of mold releasing from slip-casted object,
Image by author.

Fig. 3.13

Photo of Bryan Hopkins carving the lip of the cup,
Image by author.

PERSONAL ARTISANS' VALUES

Hopkins takes great pride in making work that is uniquely his.[11] His work is influenced by Japanese-style ceramics, particularly their use of colour and form, which he adapts into his own distinct style.

The value of the hand remains important as Hopkins develops his own style. Although his work relies entirely on hand fabrication, he argues that handwork alone does not inherently produce "humanness". He illustrates this through his friend Molly's experience in Malaysia, where her designs for mass production were rejected as 'too perfect'. Recognizing that processes such as slip casting are intended to produce identical forms, Hopkins instead aims to "add the human back into the mold" through subtle interventions, such as carving cup lips, hand-painting glaze, or removing mold keys to create variation. As he explains, customers increasingly value "the sense of humanity in a piece," seeking individuality and imperfection rather than the uniformity of mass production.[12]

This led Hopkins to establish a set of 'rules' that he maintains in his work. He uses the following as a starting structure but breaks them to experiment and discover something new. A 'rule' in ceramic fabrication is the minimum fired wall thickness, which is not defined explicitly and is instead avoided as a precaution - a convention Hopkins challenges by questioning what constitutes a wall that is 'too thin.' Hopkins pushes the clay to its limits, exploiting the thinness and natural properties of porcelain to achieve translucency throughout his work. The translucency achieved through porcelain is unachievable through any other material within clay fabrication. "Porcelain is a very rich material, perceived as worth a lot more than other types of clays, so I use it in juxtaposition with working-class textures - drawn from working-class environments, such as weathered materials and industrial or utilitarian surfaces - to provide a stark contrast to the traditional views of porcelain."[13] This material alone tells a story, so Hopkins continues it through his own working-class background, making the clay's identity his own.

11 Hopkins, "Interview Bryan Hopkins," interview by Candace Haddy, 2.

12 Joshua Stein, "Interview Joshua Stein," interview by Candace Haddy, July 25, 2025, 2, Microsoft Teams, transcript available upon request.

13 Hopkins, "Interview Bryan Hopkins," interview by Candace Haddy, 2.



Fig. 3.15
Photo of translucency achieved through creating a thin vessel,
Image by author.

Fig. 3.16

Photo of Bryans studio,
Image by author.

CASE STUDY 2; LUDOWICI

On-site Interview April 11th 2025.

Ludowici Roof Tiles is a historic clay roof tile institution based in New Lexington, Ohio, that has been in operation since 1905.[14] The Ludowici family began making roof tiles in Rome, Italy 400 years ago, so for centuries the production process was entirely hand-fabricated. The facility in Ohio began when the Celadon Company purchased the Imperial Clay Company and acquired the factory and quarry where they harvest clay. Since opening, they have expanded in factory scale and products, creating a larger operation. They now produce roof tiles, roof accessories, ceramic flooring, and exterior wall cladding systems. All of their products are made by Rapid Automatic Machine (RAM) pressing or die extrusion, with the exception of roof accessories that use slip casting for custom orders.[15] Ludowici has evolved into using a hybrid approach of old factory tools with new technology, which allows them to create products for large-scale architectural projects.[16]

Although Ludowici has modernized their production process by using machines and technology for extrusion and hydraulically pressed tiles, their slip casting facility remains very traditional in process.

14 "About Ludowici | Terracotta Tile | Ludowici Roof Tile," accessed April 22, 2026, https://ludowici.com/ludowici-difference/about/.

15 Carla Hunigan, "Ludowici Roof Tiles," interview by Candace Haddy, April 11, 2025, Tour, transcript available upon request.

16 "About Ludowici | Terracotta Tile | Ludowici Roof Tile."

Fig. 3.17

Photo of Ludowici factory worker,
Image by author.

MATERIALS

Ludowici sources and processes the clay for every type of tile on site in New Lexington, Ohio. The Ludowici factory used to use an on-site clay mine, with a belt system that deposited the clay directly into the factory until the 1950s, when there was no longer enough clay and minerals on site. Now they harvest their clay from a mine twelve miles up the road and use dump trucks to dump the clay at the very top of the hill on site. From the mine, the two raw materials sourced are shale and fire clay. Shale is a sedimentary rock, and fireclay is a sedimentary mudstone.[17] The raw clay is processed through a series of conveyors, crushers, grinders, and screening machines that progressively break down and refine the material into a consistent, workable clay body for production. *

Maintaining locally sourced clay is an important part of Ludowici's identity, allowing the factory to remain connected to its surroundings and giving clients a connection to the material and place from which their products originate. The change in their extraction site also reflects their broader approach to production: rather than adopting new clay or processes for the sake of innovation, they adapt their existing methods only when necessary. This is largely due to their commitment to traditional practices, which allows them to meet client expectations while maintaining a direct connection with the material throughout the production process.

17 "Shale Mineral," accessed April 25, 2026, https://digitalfire.com/mineral/shale.

*Refer to appendix for a detailed description of material processing



Fig. 3.18

Photo of clay extraction site,
Image by author.



Fig. 3.19

Photo of quarry location,
Image by author.



Fig. 3.20

Photo of two different stages of clay from the crusher,
Image by author.



Fig. 3.21

Photo of belt system running through crusher operation,
Image by author.

PRODUCTION

The slip casting facility at Ludowici was established in 2023, making it a relatively recent addition to their production capabilities. The investment in the slip casting facility is introduced to efficiently meet project requirements for lightweight, hollow forms with intricate details that could not otherwise be achieved. To accept a slip casting project, clients must commit to extended timelines and substantial budgets to accommodate the resources, skilled labour, testing, and production required. They accept these demands because slip casting may provide the only viable means of achieving the desired design.

Originally, slip was poured using a forklift positioned above a makeshift kiddie-table setup, with a hole in the centre allowing the draining slip to collect in a bucket below. Now they have a much larger production facility and more demand, so they use a crane to lift buckets of slip and larger tables pushed together so slip can drain between them. This enabled them to increase their efficiency in production by working with multiple slip casts at a time. An elevated plaster mold, fabricated using the same process as the molds used for their presses but modified with an opening at the top for slip to be poured into, was assembled on the table. A crane alleviates the limitations of human lifting force, or the height and weight limits of the forklift.

Technology is then introduced into their production process to meet client demands efficiently. They began slip casting intricate shapes by outsourcing 3D plastic printers so they could cast the positive form in plaster. This cost was $4000 per print, so unsustainable for long-term projects. They decided to purchase a scanner and 3D plastic printer to make in-house prints. This was a wise decision because they can now do any number of test prints or reprints if errors occur. The SolidWorks models are printed on the 3D plastic printers and can take up to a week, but the printer runs 24/7, increasing efficiency without additional human labour.

Although production occurs at a larger scale, large and intricate forms must still be divided into smaller sections for casting, firing, and transportation. This is largely due to facility constraints, including the size limitations of the 3D plastic printer and kiln, as well as the physical labour required to handle larger components.



Fig. 3.22

Photo of crane system for slip casting room,
Image by author.



Fig. 3.23

Photo of multi-part plaster mold,
Image by author.

GLAZE

After the pieces dry completely, glazing is used to achieve different material finishes on the surface of the slip casted materials. At Ludowici, glazing is a fully automated process, using a glaze sprayer. The robot copies the movements of a human operator to spray the pieces consistently. Despite the use of robotics in this process, Ludowici elects to maintain a human-component to the fabrication process by using a person to flip the pieces over when required. The spraying process could be automated, but it is not worth the investment for them as a person would still be required to flip pieces.

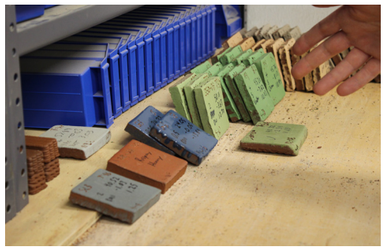




Fig. 3.24

Collage of glaze samples and buckets,
Collage by author.

FIRING

After the clay dries completely and glaze is added, the carts on the tracks get moved to the kiln room. The carts are placed in a queue where a worker called a skidder places each piece from the wooden cart on a metal skidder to be transferred to the kiln cart. Every cart's configuration is slightly different based on the glaze profile and colours, so Ludowici has elected to have a person coordinate stacking on the kiln racks.

Ludowici has the only water-sealed tunnel kiln in the country. The water-sealed tunnel kiln allows the operator to have much more control over the glaze colours than a sand-based kiln. The kilns are natural gas kilns for consistency and supply, so airflow affects how the pieces appear based on stacking within the kiln.

After firing, the pieces undergo quality control, where workers test quality by tapping pieces together and assessing the sounds produced. A dull sound indicates a defective piece, which is removed from production and recycled.



Fig. 3.25

Photo of carts stacked in preparation for firing,
Image by author.

SLIP CASTING PROJECTS

In the early 1940s, Ludowici only created roof tiles. However, with the intensity of World War 2, most of the men at the factory were sent to war, limiting manpower. As a result of the absent workforce, New Lexington and the surrounding counties employed women to keep the factory running until the war was over. The women began slip casting cookie jars and salt and pepper shakers, as roof tiles were not as popular during the war and were more labour-intensive. After the war, Ludowici rehired the men and discontinued slip casting as it did not generate as much profit as roof tiles.

Fifty years later, Ludowici accepted the first slip casting project: the restoration of the Gate of Harmonious Interest in Victoria, BC. This project is an entire recreation of a three-part finial on top of the gate, after years of deterioration caused safety hazards with degrading roof tiles. The City of Victoria was not concerned about the cost or timeline, as there is only one way to create these pieces and only one factory capable of doing this renovation: Ludowici.



Fig. 3.26
Photo of Gate of Harmonious Interest before renovation, Image by Krista Lougton.



Fig. 3.27
Photo of Gate of Harmonious Interest after renovation, Image by Krista Lougton.

Another project that emerged from similar method-specific requirements is Ludowici's current roof restoration project, Bishop's Palace in Galveston, Texas. They are tasked with recreating a hippocampus ornament that no longer exists, using only its known length of eleven feet as a dimensional reference. To achieve this custom product, they use a hybrid process in which a model is hand-sculpted and then scanned, allowing the design to be digitally scaled and reproduced using a 3D plastic printer.

Ludowici's introduction of slip casting is driven by the requirements of the design and the conditions of production rather than by the method itself. Slip casting was reintroduced when it provided the most effective means of achieving forms that could not be efficiently produced through Ludowici's previously established methods. From its initial introduction, the technology has been integrated with contemporary production methods to achieve design goals, demonstrating the value of hybridizing hand processes with machines and digital technologies.



Fig. 3.28
Photo of sculpted form from image reference for Bishops Palace Project, Image by author.



Fig. 3.29
Photo of 3D plastic printed form to scale for Bishops Palace Project, Image by author.

VALUES OF BUSINESS

Many of Ludowici's production decisions are driven by financial considerations, including profitability and production efficiency. They benefit from producing the same products and working with the same clay for over 135 years. Since their roof tiles can last over seventy-five years, repeat customers are uncommon, making the visibility and longevity of completed projects essential to attracting new business. Although they are a financially driven company, their approach suggests they value well-crafted, durable pieces over maximizing profit.

Ludowici's relationship with clients also serves as a teaching component of their operation, allowing factory tours to make visible the time, skill, and energy invested in the work. By sharing the many stages, people, and trials involved in production, they encourage clients to value the craftsmanship and labour beyond the finished product. This slower production process has remained relatively consistent since the company's inception, despite contemporary technologies increasing expectations for speed and efficiency. Rather than viewing this as a limitation, Ludowici's established process provides consistency and predictability for clients while emphasizing the value of time and labour in the production of each piece.

They also prefer to perform all operations in-house where possible. If a tool is used extensively and purchasing it for in-house use yields greater long-term profit, they will do so. Similar to the purchase of new tools, any investment for staff, tools, innovative technology, new production methods, or training will be done if the long-term profit within the company is greater than the investment. They are not rigid in their methods or processes and remain open to adopting new technologies when they offer meaningful benefits.

Fig. 3.30

Photo of post-processing details scored into tiles by hand,
Image by author.



PERSONAL ARTISANS' VALUES

Although working at the factory is a union job, each of the 225 people that work for Ludowici are carefully selected and have either entered with a passion for ceramic work or developed a connection with their work over time. Because they are unionized, there is little turnover, and employees learn each stage of the process and become skilled craftsmen. Everyone begins at the final stage in the kiln room and works their way up from there. The B jobs are most of the positions on the lineups – setting up presses, trimming, scoring, or loading machinery. The A and A+ positions are the skilled craftsmen who have been on the team the longest and have developed the skills to slip cast, create plaster molds, make wood mock-ups, stitch ceramic pieces together, or hand sculpt. Ludowici relies on specialized knowledge and collaboration across divisions, recognizing that no individual can possess all the expertise required.

As people remain at the company for longer, they grow connected to their work. Ludowici encourages this connection by placing TV's throughout the factory showing projects they've finished so people at the very beginning of the projects can see what evolves from their work and know they had a small part in this huge operation. It's hard work, but meaningful, as it will go on a building for a lifetime somewhere for all to see.

The irregularities in finish and the uniqueness of each piece come from people on the line touching the products as they move them around the line and trimming/scoring the pieces with hand tools. A hybrid method allows fabrication techniques to compensate for one another's limitations, combining machinery for consistency with skilled labour for decision-making and customization. Integrating hand and digital processes can also achieve otherwise unattainable forms. Their adoption of machines and technology supports rather than replaces the hand, driven primarily by efficiency rather than innovation. They use machines for consistency, stability, and a solid foundation, then consult with the client and customize the pieces accordingly. The people in the factory are valued not just as machine operators, but as craftsmen.

Although Ludowici is a company that produces a large quantity of products, they do not refer to themselves as mass-production because of the people involved, opportunity for customization, and handwork foundation of their production process. Ludowici's slip casting facility remains experimental, requiring continued learning and refinement as workers develop expertise throughout each stage of production. Dan Harris concluded his thoughts on the artisan values within Ludowici with a quote that perfectly summarizes their sentiments towards the people they work with "if people think we're Amazon, we're not."[18]

18 Hunigan, interview by Candace Haddy, "Ludowici Roof Tiles.

Fig. 3.31

Photo of raw material being carried to factory site,
Images by author.

CASE STUDY 3: JOSHUA STEIN

Remote Interview July 25th 2025.

Joshua Stein is a Los Angeles-based architect and Professor at Woodbury University. He founded Radical Craft, a research and design studio that advances historical design and addresses contemporary challenges through traditional techniques and new technologies for material manipulation.[19]

His investigation matters to architecture because it shows how digital technologies can expand the capabilities of traditional ceramic processes, enabling greater customization and formal complexity while retaining the material knowledge embedded in slip casting. In an interview with Stein, he mentioned that this interest stems from his curiosity about the role of materials within designs, with his digital background and education, directly stating, “I set myself the challenge of figuring out how to take all these digital skills I had and try to figure out how the material world could have some agency and pushback against the digital ease.”[20]

19 “About - RadicalCraft,” accessed April 8, 2026, https://radical-craft.com/About

20 Joshua Stein, “Interview Joshua Stein,” interview by Candace Haddy, July 25, 2025, Microsoft Teams, transcript available upon request.

Fig. 3.32

Photo of Joshua Stein’s Upscaling Project,
Image by Joshua Stein.

MATERIALS

Stein works with clay as a material and slip casting as the process of manipulation. He chooses clay because he wants to challenge the ease or lack of friction in moving between virtual space and physical space. He states, "If you were to think about digital fabrication, the materials that you would use for that are the dumbest materials, the most homogeneous materials. The idea that whatever you have on your screen, you push print and you get the same thing does not excite me."[21] Clay changes form, reacts to external factors such as temperature and pressure, so it matches the criteria of a material that creates friction between virtual and physical space. When you're thinking about clay in the conversation of architecture, you need control of its irregularities, and the small dimensions become crucial.

21 Stein, "Interview Joshua Stein," interview by Candace Haddy, 2."

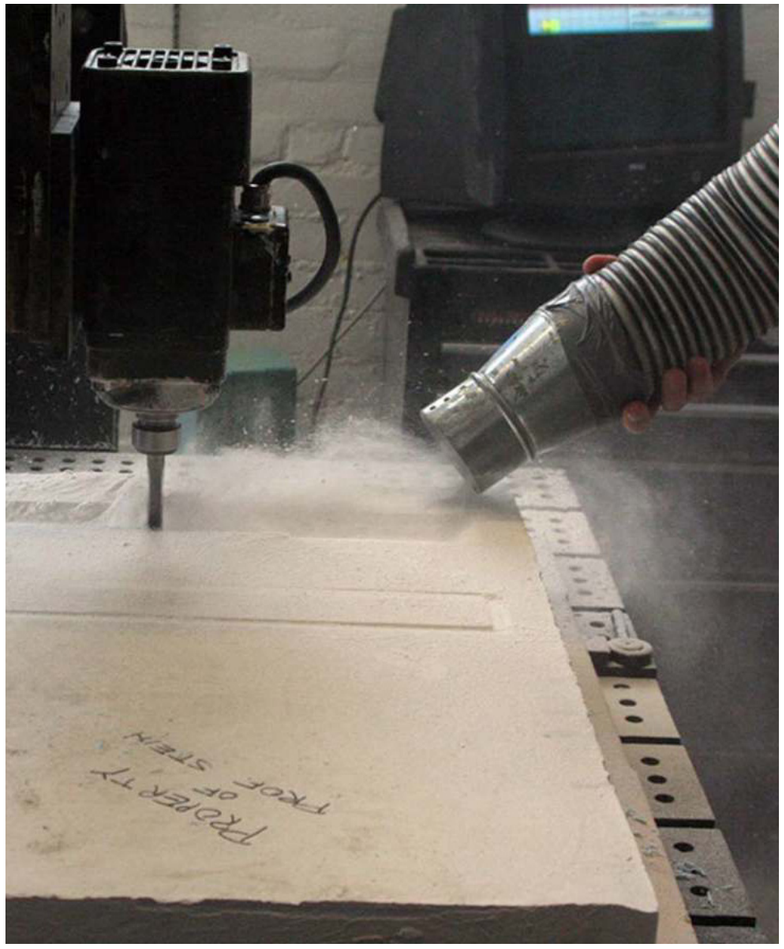


Fig. 3.33

Photo of CNC router for Stein's projects,
Image by Joshua Stein.

UPSCALING

Stein's project 'Upscaling' introduces technology as a processing logic in his work. Stein layers information with material, process, assembly, and performance logics, with each recast creating complex stratas of information materially embodied in the object. His use of clay remains consistent, but his process involves hand, machine, and digital operations all within the same object.

To scale up the object from product scale to architectural scale, limitations from material processing and technology influenced the molds to take the form of a set of slices. The small three-axis mill limits the work to a five-centimetre Z-axis clearance, so Stein divides the plaster into five-centimetre-high sections for milling.[22] This limitation becomes a design opportunity, as it makes it possible to reshuffle the slices to create new objects. Stein views these slices as a form-generating machine, reinventing the word machine to mean a pre-set process that assists the repetition of creating precise components. The 'machine' used (the slices) leaves traces in the form that tell the story of its fabrication process, much like how a CNC router would.

Although changing the scale is a project goal, the material naturally changes the scale from the positive model because the clay body shrinks upon drying and firing as it loses water. With the goal of reproduction and scale change, the exact object cannot be recreated because of clays properties, leaving some design agency to the material's influence.

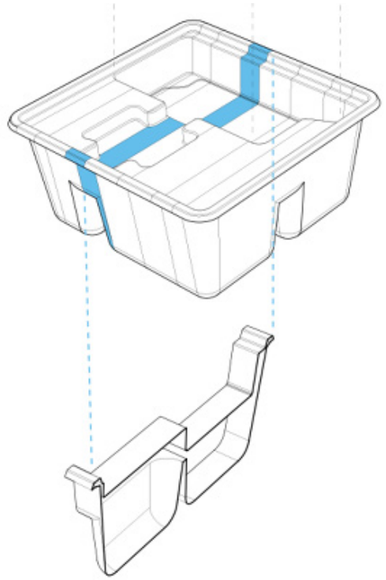
While initially aiming for exact reproduction, Stein lets the clay, technology, and processes shape his experiments, ultimately leading Stein to adapt the form and generate new variations, demonstrating how fabrication itself can become a source of design development.

22 Stein, "Interview Joshua Stein," interview by Candace Haddy, 7."



Fig. 3.34

Photo of plaster mold divided into slices for Upscaling project, Image by Joshua Stein.





left to right

Fig. 3.35

Diagram of five centimeter-high slices due to machine limitatations for Upscaling project, Illustration by Joshua Stein.

Fig. 3.36

Photo of completed modules for Upscaling project, Image by Joshua Stein.

TECTONIC HORIZONS

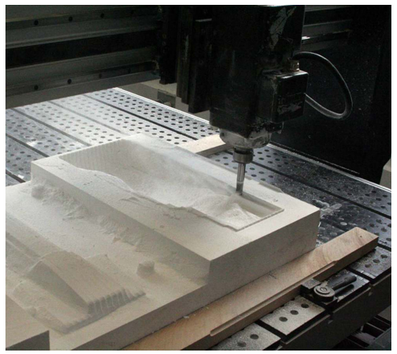
Stein's investigations into object scales continues with Tectonic Horizons, discovering the potential for larger-scale objects, achieved through modularity.[23] Once again, he uses a hybrid method of production with technology leading the machine operations for mold creation, and acting as a foundation to his hand post-processing operations that allow for differentiation in the pieces.

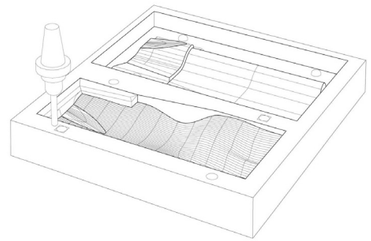
To create differentiation, Stein uses hand operations with a sculpting hand tool to cut larger holes and emphasize this inevitable outcome from the manufacturing process, resembling Boolean operations in Rhino.[24] That circles back to Stein's original goal of moving back and forth between digital and material techniques, physically and in the language of logic.

Stein's use of technology establishes the structure and scale of the work, while hand post-processing introduces variation and responds to the material outcome. Rather than positioning hand and machine fabrication as opposing methods, Stein's work suggests that their interaction can create opportunities within contemporary production.

23 "Tectonic Horizons - RadicalCraft," accessed November 13, 2024, https://radical-craft.com/Tectonic-Horizons.

24 Stein, "Interview Joshua Stein," interview by Candace Haddy, 5.





left to right

Fig. 3.37

Photo of CNC router cutting plaster for 'Tectonic Horizons' project, Image by Joshua Stein.

Fig. 3.38

Diagram of CNC router toolpath for 'Tectonic Horizons" project, Illustration by Joshua Stein.

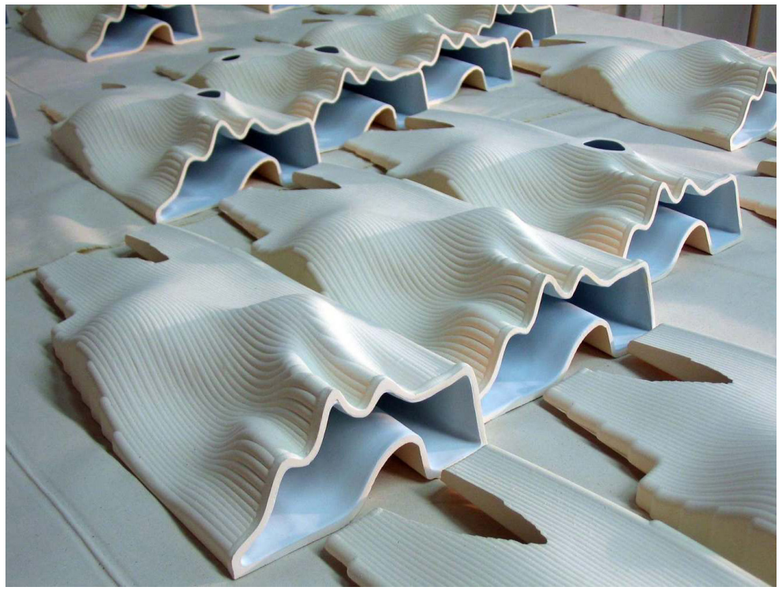


Fig. 3.39

Photo of completed module for 'Tectonic Horizons" project, Image by Joshua Stein.

PERSONAL ARTISANS' VALUES

"Of course I consider myself a craftsperson. For me it's an honour to use that word,"[25] Stein states in an interview. He explains that he views this term as an expert in a field where you can begin experimenting with a product from a foundation of knowing it so well. He takes this title with great responsibility, and in his work, he respects the practice of slip casting by incorporating traditional processes and materials into his experiments. "The machine is me, I've worked on every single module. Even if it's just trimming the edges, that's my time and sweat. My hands touched every piece I've made."[26] To hold this value as a craftsperson, Stein sees physically touching the pieces and working with his hands as a part of respecting the practice of working with clay.

Pushing tradition begins with asking questions in each part of the process, such as what it means when you pour the slip in, or questioning if there is room for variation in this process. If Stein has rules or guidelines in his work, he strives to break them to fail productively and create something new.

Stein always uses technology and machine operations as a starting point, while subsequent hand interventions and material responses intentionally transform the digitally generated form, making the final object distinct from its digital model. To be productive in research and discover something new, he avoids the widely adopted practice of pushing new technology to see its potential and instead experiments with hybridizing historical methods. He wants a method of production that machines and technology alone cannot achieve.

25 Stein, "Interview Joshua Stein," interview by Candace Haddy, 21."

26 Stein, "Interview Joshua Stein," interview by Candace Haddy, 10."

Fig. 3.40

Photo of pattern achieved through technology and machine (CNC), Image by Joshua Stein.

CASE STUDY 4; THE TOILET
No Interview - Information from public sources.

The process of production for toilets is the largest-scale slip casting produced worldwide using mass production processes. Their factories are mostly automated to reduce production time and increase capacity. For this thesis, these precedents provide insight into how slip casting can be scaled and optimized for efficient large-scale production.

Through the research process, access to toilet manufacturing facilities in North America is found to be limited, with facilities generally not open to public access, so research is gathered from public resources. The factories that have sufficient information available for public viewing are Kohler, an operation with over 50 manufacturing facilities, Betta Sanitaryware in South Africa, and JOMOO located in China.

A toilet must remain hollow through its bowl and internal piping, leaving only a thin shell while meeting requirements for smoothness, lightweight construction, durability, and watertightness. Slip casting is uniquely suited to producing this complex form while satisfying these constraints, which is why it remains the primary method of production despite its demanding process. Over time, factories have refined and automated the process to reduce production time and increase output.

Fig. 3.41

Photo of completed toilets in JOMOO storage,
Image by JOMOO, AI-enhanced for image quality.



PRODUCTION

This section provides a general overview of the production process based on information gathered from Kohler, Betta Sanitaryware, and JOMOO, as modern toilet manufacturers all operate using similar processes.

As digital and automated technologies develop, ceramic toilet manufacturing shifts from traditional plaster molds toward high-pressure injection molding with synthetic resin molds,[27] enabling greater consistency in size and wall thickness. The molds are created predominantly using a 3-axis CNC router to cut the digitally modelled form.[28] The separate pieces of the resin mold fit together and are held in place by hydraulic pressure, creating an airtight joint. The pressure from the slip injected into the molds forces water into the porous resin molds, acting similarly to the plaster casting by creating a layer of clay remaining on the lining of the mold. The molds therefore have a much longer lifespan and there is not a need for drying the plaster mold between casting. Pneumatic lifters lift and transport the toilets from one line to the next as they are in a very fragile state and very heavy due to the scale and water content. The mold is then automatically washed with high-pressure water directly after use.

After drying, the toilets are sanded and smoothed by a worker with a sanding pad to remove any rough edges before being sprayed with glaze. A rotating robotic arm then sprays the bowl, learning the human sprayer's movements and consistently repeating the same pattern. The toilets are tested by a human for flushing capability and sufficient suction to catch any error from the automated manufacturing process. These tests do not always produce the same outcome, so humans have remained in this role as they can make decisions based on the unexpected results of the tests.

27 Clayton Garrels et al., Toilet Made of Vitreous China and a Polymeric Outer Structure, 2022.

28 "The Art of Craft | See How Our Products Are Made | KOHLER," https://www.kohler.ca/how-its-made.

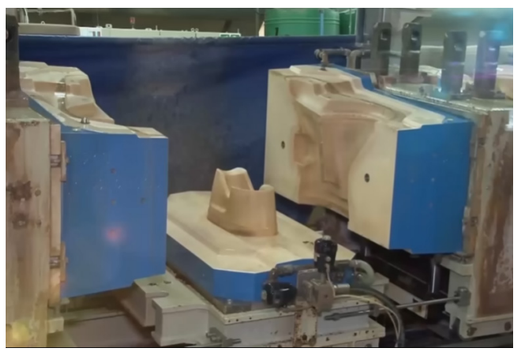


Fig. 3.42
Photo of resin molds, Image by Betta Sanitaryware.



Fig. 3.43
Photo of pneumatic lifters, Image by Betta Sanitaryware.

To complete this production process, JOMOO has adopted a digitally run manufacturing operation called the '5G cloud manufacturing center'.[29] From the initial customer order to packaging and shipping, all is handled electronically. A barcode is generated for each order and follows the toilet through the production process so production timing can be organized. The program also controls safety, quality control, smart cloud warehouse storage, and energy management. This benefits the company through efficiency and cost, making the initial investment in new operational technology worthwhile in the long run.

29 "Sanitary Ware Brand JOMOO Pioneers China's Smart Home Development," Computer Technology Journal, 2019, 34.



Fig. 3.44
Photo of glaze robot, Image by Betta Sanitaryware.

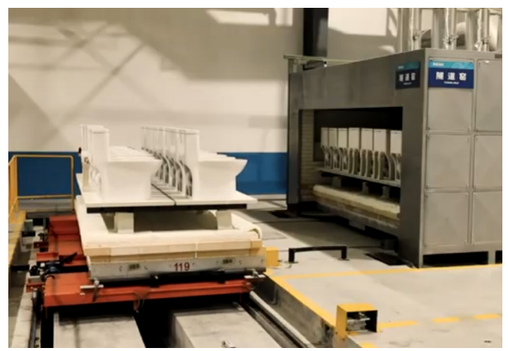


Fig. 3.45
Photo of kiln cart, Image by Betta Sanitaryware.

VALUES OF BUSINESS

Toilet manufacturing facilities' main priority is meeting the market demands of large scale production, where efficiency and consistency are essential. Clients expect a standard product delivered within the shortest time possible. Standardization and machine-driven manufacturing allow products to be repeatedly made with predictable outcomes, while reducing the time, human labour, and cost associated with production. Digital technologies and automated systems further support this process by transferring the design information into machines and digital information. The value of this production process therefore lies in its ability to maintain consistent quality, prioritizing efficiency and repeatability over customization, variation, or human engagement with the material, product, and process.



Fig. 3.46
Photo of toilet stock prepared for shipping, Image by Fohome.

PERSONAL ARTISANS' VALUES

Workers act as machine programmers and operators rather than artisans in the toilet manufacturing facilities as most operations are standardized and automated.[30] Their roles are organized around specific stages in the production process, with decisions affecting the product primarily made by supervisors and production leads. Final inspection stages introduce the most amount of human connection with products, where workers identify imperfections to maintain quality product standards. While this requires skill and attention, these decisions are directed toward achieving a predetermined outcome rather than influencing the design of the product. The factory workers therefore contribute to the quality and consistency of the final product without obtaining a greater connection to the material or product.

30 "Sanitary Ware Brand JOMOO Pioneers China's Smart Home Development," Computer Technology Journal, 2019, 34.



Fig. 3.47
Photo of final quality check, Image by Estrella Chang.

3.3 COMPARATIVE ANALYSIS

The fabrication processes, products, and values learned from case studies reveals the values and motivations behind the craftsperson's choice of technique, drawn across a range of scales and intentions. The interviews are organized around four categories—personal values, foundations of practice, motivations for using slip casting, and production processes—to describe the methods each practitioner uses and the reasons behind them. Together, these categories describe the tensions, consequences, and potential opportunities associated with the evolution of fabrication methods and the shifting role of human involvement in contemporary design.

PERSONAL VALUE

The case studies show a contrast between locations that choose the method of slip casting, and those that use it because it is necessary to achieve their desired outcome. Larger companies, such as Ludowici and toilet manufacturers, choose slip casting because it suits the production of toilets and large-scale architectural features. Its ability to produce repeatable, consistent, thin-walled, hollow forms while capturing intricate curves, edges, and details makes it well suited to these applications. In contrast, smaller experimental practices use slip casting to explore the material and process itself, allowing clay properties, technique, and personal expression to influence the resulting forms.

Material understanding underpins many of the practices studied. Hopkins and Ludowici are interested in both the provenance and properties of the clay they source. They push the clay to fully use its strengths and limitations, so the fabrication process responds to the material. Stein is interested in how materials respond to new technologies, using the close relationship between material, process, and maker to treat fabrication constraints as opportunities for experimentation and variation. Toilet manufacturers gain material understanding to create a production process that performs reliably. Control over the fabrication process, grounded in material understanding, remains essential across all scales and methods, from analogue processes to digital workflows.

Participants similarly identify material knowledge as central to craftsmanship and generally consider themselves craftspeople, either explicitly or through their demonstrated practices. Hopkins identifies as a craftsman by reintroducing handmade qualities through randomness and deliberate variation, while valuing the physical traces of hand-tool processes left in the finished object. Stein similarly identifies as a craftsperson, maintaining control over material properties while using his knowledge of clay and process to direct technological tools and fabrication decisions. Similar to Hopkins' appreciation of the traces left by the hand, Stein values the final artifact as a record of its creation, with the marks of machine and technological processes remaining visible in the finished form. This aspect of hand interaction is not observed in practices where direct clay manipulation is not integral to production, such as large-scale factories. Regardless, both craftsmanship and digital fabrication retain underlying value, as their material knowledge allows them to maintain control over the process while incorporating variation and achieving new design goals. Hopkins' and Stein's emphasis on incorporating traces of the processor informs this research by shifting the value of the hand from direct material manipulation and visible traces in the final form toward intentional interventions that introduce variation, judgement, and individuality into a repeatable process.

Although employees in the toilet manufacturing facilities retain specialized process knowledge, production decisions and innovation remain embedded within the machinery and standardized procedures. As a result, material knowledge has largely been transferred to digital technology, while the remaining human knowledge is limited to operating specific stages of production. The factory's use of terms such as "employees," "labourers," and "operators," rather than "craftspeople," further reflects the functional role assigned to workers within the production system. Ludowici values craftsmanship and specialized process knowledge, maintaining traditional clay-working practices while integrating machinery and digital technologies to support rather than replace skilled labour. This hybrid approach uses machinery for consistency and efficiency while relying on skilled workers to make informed decisions, adapt processes, and customize pieces to meet client requirements. Employees develop expertise through continuous learning, allowing the facility to meet customized design demands while refining its methods through experimentation and experience.

The approach to information gathering differs between the larger facilities and smaller-scale practices, as factory leads responsible for business and marketing at large facilities are interviewed rather than individuals directly engaged with the clay and fabrication process. As a result, the information gathered on personal values is more reflective of business priorities than individual material connections, providing insight into how craftsmanship is valued and understood within larger production operations.

FOUNDATION

Worker engagement is shaped by how tools are integrated into the fabrication method rather than by the tools themselves. Hopkins continually refines his use of tools as extensions of human operations to maintain control over material and process, questioning how much intervention can be removed before the result no longer reflects his intended outcome. Although Ludowici operates at a larger scale and incorporates machinery and digital technologies, human knowledge remains the foundation of its design process. Machinery replaces physical labour while skilled workers retain control over design and customization. Digital technology further expands production capabilities and design opportunities, while custom slip casted designs remain guided by craftsperson knowledge. While toilet manufacturers transfer knowledge into machines to repeat an established process, Stein uses technology as a means of experimentation and discovery. Stein's designs are shaped by both the capabilities and limitations of his tools, but the craftsperson remains responsible for interpreting these conditions and directing the process. The key difference between Stein's work and toilet manufacturers is Stein's decisions evolve alongside the machine processes, while in mass-production toilet facilities, human knowledge is primarily transferred into the system before production, allowing machines to execute production independently.

The product's goals and requirements shape the relationship between physical operations and knowledge. When production requires ongoing adaptation through design changes, experimentation, or customization, flexible tools and processes are necessary. The key distinction is therefore between processes in which human judgement continues to shape the outcome and those in which knowledge is embedded in digital technology for repeated execution.

The time constraints of toilet manufacturing, combined with its linear production process and tightly controlled stages such as drying and kiln firing, encourage embedding knowledge in digital technologies to support consistent, efficient production and expand manufacturing capacity. Even within this structure, workers remain responsible for tasks requiring physical judgement and evaluation, particularly where outcomes cannot be fully predicted by the automated system, such as the quality control stage. This stage, performed manually by workers, is present in both Ludowici's practice and toilet manufacturing facilities. This raises questions about where craftsmanship resides within highly automated production, whether it is diminished through the reduction of direct material engagement or reshaped through the knowledge, judgement, and care required to operate and oversee these systems. Examining this relationship supports this research's goal of understanding how craftsmanship can be maintained and valued as fabrication methods continue to evolve.

MOTIVATION

Each company's motivations and market conditions largely shape the difference in approach. Introducing machine and digital technology is a good business decision when the return on investment is high. The large-scale manufacturers studied respond to high market demand by incorporating machine and digital technologies to reduce production time, labour, costs, and energy consumption. Ludowici faces limited competition because they create architectural features that no other local company produces, and toilet manufacturers produce a universally essential product that will never lack demand. This difference in market demand shapes their production priorities: toilet manufacturers face greater time and cost pressures and prioritize efficiency, standardization, and high-volume production. In contrast, Ludowici's specialized market allows greater investment in customization, experimentation, and craftsmanship. Although operating at a smaller scale, its success is supported by a different value structure that prioritizes customization, human involvement, and specialized expertise over production volume. Similarly, at a smaller scale, time and cost play a less significant role in shaping Hopkins' and Stein's production processes. Hopkins and Stein do not produce slip casted objects for profit, but rather for discovery, innovation, and expression of interests. This suggests that as production becomes increasingly profit-driven, efficiency can take precedence over the value of craftsmanship. All case studies demonstrate the ability to move beyond traditional practices and explore innovative approaches after gaining control over the material, suggesting that craftsmanship is not dependant on production scale or existence of technology, but by the continued presence of human judgement within the fabrication process.

PRODUCTION

Both Hopkins and Stein demonstrate that maintaining authority over design decisions enables greater customization in slip casting, but this flexibility can require additional labour and process complexity - challenges that large-scale manufacturers prioritize avoiding. This decision within practices reveals a trade-off between craftsmanship and production efficiency.

Even with machines and digital technology introduced to reduce labour and process complexity, method and material limitations persist. This leads many larger-scale practices to a hybrid method of hand, machine, and digital tools. The hybrid method practiced at Ludowici allows different fabrication techniques to compensate for one another's limitations, enabling outcomes that could not be achieved through a single method. This process therefore demonstrates how technological advancement can build upon existing craft knowledge to develop new methods of production. Maintaining knowledge among workers also extends beyond preserving craftsmanship, supporting collaboration, adaptability, and informed decision-making throughout production.

CONCLUSION

The case studies explore the importance of craftsmanship in each contemporary slip-cast ceramic practice, across a range of scales, methods, and tools. Each practice's production process and values are compared to identify the attributes that sustain craftsmanship involving decision-making, material knowledge, and developed skill across different scales and methods. Across the case studies, craftsmanship is maintained through adaptability, being able to iterate, refine, and alter a process in response to changing requirements. This adaptability depends on material and process knowledge, which allows fabricators to recognize the capabilities and limitations of slip casting and adjust their methods accordingly. Digital technologies and contemporary tools prove most effective when designed as extensions of the human operator, expanding the capabilities of the process while maintaining the craftsperson's ability to direct and adapt it. These attributes are identified as "design goals" in the following sections of this thesis, as they are used in the development of the designs for design tests.

04 | METHODOLOGY

4.1 CASE STUDIES INFORMING DESIGN GOALS

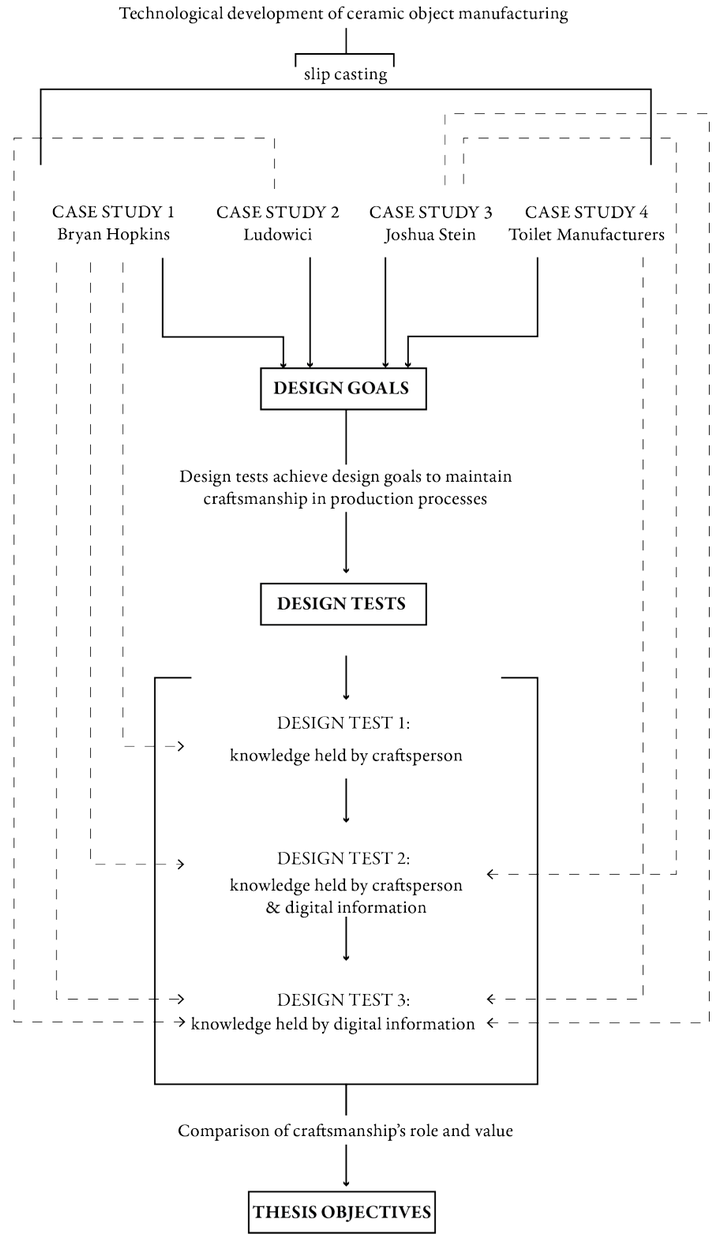
The case studies identify several consistent attributes that support the craftsman's ability to make decisions and develop skills, while establishing a rationale for the selection and application of slip casting as the material and fabrication method, informing the design goals. These attributes include the ability to efficiently customize and vary a design while making use of the material and process advantages of slip casting. These design goals establish a defined structure for the thesis and narrow the scope of the investigation to ensure that the proposed designs respond directly to the research objective of understanding the role and value of craftsmanship in contemporary fabrication. The design goals remain consistent across varying methods and tools, from hand fabrication to machines and digital technologies.

DESIGN GOALS

1 ADAPTABILITY	2 EFFICIENCY	3 ADVANTAGES
• Ability to customize and vary the form produced.	• Lowest production time • Most affordable production and consumption	• Advantages of material properties utilized • Advantages of method utilized: ▪ use of hand tool ▪ use of machine tool; largest scale possible ▪ use of digital tool

Fig. 4.1

Table of design goals, Illustration by author.



identifies influencing case studies

Fig. 4.2

Diagram of design structure, Diagram by author.

DESIGN GOALS

ADAPTABILITY

A design has the potential to scale up while supporting variation if it is produced through digital technology and machinery. Large-scale slip casting is limited by the inability to modify plaster molds after fabrication, as traditional resin and plaster molds are typically designed for a single form and lifecycle. The objective is to achieve variation in outcomes using a single mold, while maintaining the efficiency and consistency of the slip casting process.

Traditional slip casting relies on physical manipulation by hand and the continuous judgement-making process by a person, making large-scale production labour-intensive. Digital fabrication shifts the energy used in traditional production toward overseeing the process, adapting designs, and making informed decisions based on the capabilities of the machine and material. The preferred design method enables customization while maintaining the responsiveness and care associated with craftsmanship, as accommodating individual requirements requires judgement, decision-making, and attention to the outcome.

EFFICIENCY

It is essential to maintain efficiency in time, cost, and material use as variation, customization, and production scale increase. The preferred design method is therefore the most efficient, or the only way to achieve the final object.

The production processes consider how to efficiently respond to market demand. Large scale production facilities such as Ludowici and the toilet manufacturing facilities demonstrates how they achieve efficiency through standardization, as time and cost constraints limit the production of customized work, and therefore opportunities for human engagement with the material, product, and process. To explore efficiency as a means of supporting variation and customization rather than eliminating them, time and cost constraints are temporarily removed from the design tests.

MATERIAL AND METHOD ADVANTAGES

Rather than introducing digital technology solely to increase efficiency, the case studies explore how principles of craftsmanship guide the application of digital fabrication technologies. The case studies identify material understanding and process exploration as key principles of craftsmanship. To investigate these principles, slip casting is selected for its material and fabrication advantages, including its ability to produce thin-walled, lightweight forms with reduced processing, drying, and firing times. The method of slip casting is selected before the design outcome is developed, reversing the conventional sequence in which a fabrication method is chosen to suit a predetermined design. Distinct slip casting design tests separate hand and digital processing methods to discover where human knowledge and judgement remain essential.

Gaining control over the fabrication process requires understanding clay's behaviour. While machines can provide consistency and precision, material knowledge existing in the machine makes it difficult to respond promptly to the unpredictability of clay and changing environmental conditions. Clay is affected by temperature, humidity, airflow, water content, composition, additives, forming methods, drying conditions, firing conditions, and geometry. Hand processing allows material reactions to be recognized and addressed promptly, accommodating unpredictable changes during fabrication, but making consistency in the final design outcomes difficult to maintain. The objective is therefore to maintain consistency in production outcomes and enable controlled adaptability.

4.2 DESIGN TESTS

Three design tests examine how craftsmanship is maintained by implementing the design goals through methods progressing from traditional craft to contemporary slip-cast fabrication. Design Test 1 uses analogue tools and traditional manual methods, Design Test 2 combines analogue and digital tools, and Design Test 3 relies exclusively on digital tools for automated production. Conducting design research provides first-hand experience of the relationship between material and process knowledge.

Designing and producing a slip casted screen system provides a way to evaluate the research through practice. While theoretical investigation and literature establish a foundation for understanding fabrication method, direct engagement with the clay and production process reveals the practical constraints, opportunities, and design implications that cannot be understood through theory alone.

Three design tests examine how changes in method, tools, and scale affect the distribution of knowledge within fabrication, drawing on Schindler's waves of production technology.[1] Isolating these variables allows comparison between analogue processes, where knowledge is held by the craftsperson, with digital processes, where knowledge is increasingly embedded within tools and digital information. Each design test results in an object whose form reflects how the design goals, fabrication methods, and digital technologies interact throughout the design process. The role and value of craftsmanship within each fabrication method is then compared through the presence of decision-making, material knowledge, and skill development, based on subjective experiential observations gathered throughout the design tests.

1 2007_Schindler_Information-Tool-Technology, 1.

	DESIGN TEST 1	DESIGN TEST 2	DESIGN TEST 3
where design knowledge is held	craftsperson	digital information	digital information
location process knowledge exists	craftsperson	craftsperson	digital information
Tools	analogue	analogue and digital	digital
digital technology in process	no	form generation	mold production
relationship to Schindler's waves of processing technology	hand-tool technology	⟷	information-tool technology
pre-existing physical form	yes	yes	no

Fig. 4.3 *Diagram of artifact tests,* Diagram by author.

DESIGN TEST 1 - KNOWLEDGE HELD BY CRAFTSPERSON

The craftsperson holds knowledge of design and process through direct engagement with hand tools (hand-tool technology).

Design Test 1 will be an analogue process using hand tools exclusively, mimicking a traditional practice where the craftsperson controls all manual processes. The physical design will be sourced from existing patterns, providing a tangible reference to observe and understand the intended outcome before creating a slip cast replica.

The following describes how the design concept is developed by applying the three design goals:

Design goal 1 – Adaptability

To achieve variation in each screen using a single plaster mold, the key-locking system that traditionally holds separate plaster mold pieces together in the exact same place will be eliminated. This enables the ability for the craftsperson to adapt the plaster mold assembly and adjust the scale and patterns, also providing opportunities for client involvement in customized work. Using hand tools to trim and refine details will be the final post-processing stage, adding another layer of variation.

Design goal 2 – Efficiency

The method of removing keys will achieve variation in the most efficient way for analogue processing. Production time and material use will also be reduced because the plaster components remain reusable rather than becoming obsolete when designs change.

Design Test 1 will explore the balance between achieving the thinnest possible form and the largest feasible scale at which a rectangular screen system can be produced as a single form. The overall dimensions of the screen's length and width will be increased until failure occurs. Achieving the thinnest possible form will reduce material consumption, supporting greater material efficiency.

Design goal 3 – Material and method advantages

Achieving a thin form will also take advantage of the method of slip casting. Consistent thickness can be controlled as the slip follows the plaster form exactly, resulting in a screen that can be viewed and experienced from either direction. Meeting the objective of a thin form will make achieving translucency possible, allowing light and shadow to pass through the screen. Slip casting also captures small, precise details, so Design Test 1 will replicate small textures collected arbitrarily from the surrounding environment.

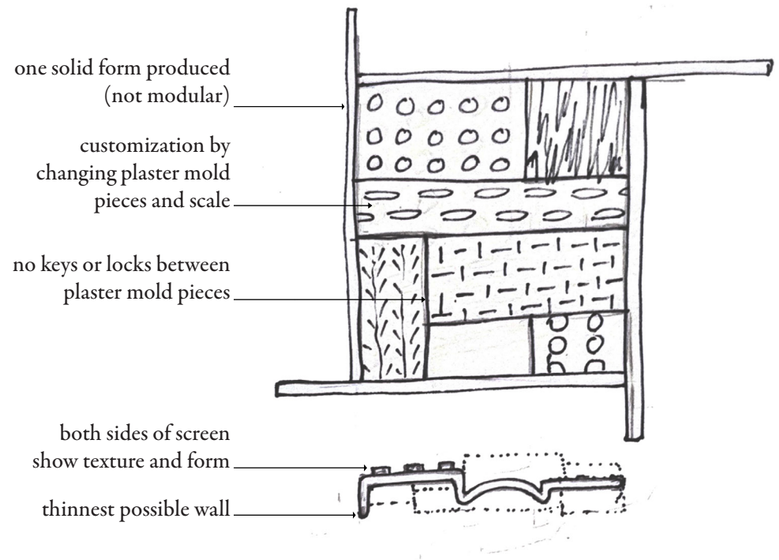


Fig. 4.4

Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages, Diagram by author.

DESIGN TEST 2 –
KNOWLEDGE HELD BY CRAFTSPERSON AND DIGITAL INFORMATION
Digital information holds design knowledge, while the craftsperson holds process knowledge.

Design Test 2 explores the transition from hand-tool technology to information-tool technology by using both hand tools and digital tools in the production process. Design knowledge will be transferred to the machine through digital information, separating this from processing knowledge that will remain in the craftsperson.

In Design Test 2, machine tools will be used to replace hand tools in design creation, using digital modelling to create a 3D plastic printed positive form. Then, hand operations will be used to complete the process of production, creating a multi-part plaster mold cast around the printed pattern. Using digital technologies for design creation expands design possibilities and allow models to be physically produced as tangible references for evaluating the intended outcome before slip casting.

The following describes how the design concept is developed by applying the three design goals:

Design goal 1 – Adaptability

Hand tools will be used for post-processing to create variation in each screen module. The locking system of the modular screen will be created by removing one side of a cylindrical connector with a knife, forming a corresponding recess, and allowing adjacent pieces to interlock during the assembly of the screen. Although each module will share the same base geometry, rotating and reversing individual pieces will create variation in the overall assembly, producing a varied final composition using a single repeated form.

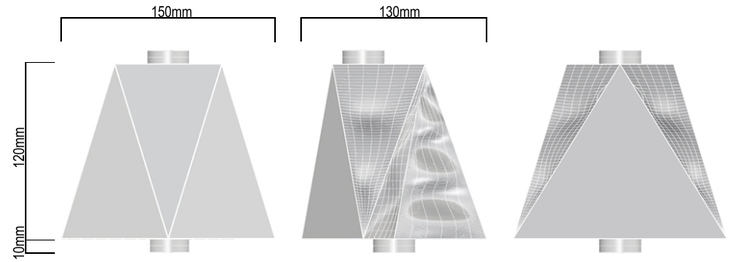
Design goal 2 – Efficiency

Hand post-processing to achieve variation will also improve material efficiency by eliminating the need for a new plaster mold for each design iteration. Additionally, production efficiency for customized designs can be achieved by using digital workflows, as complex objects are possible to digitally design and print in positive form.

Design goal 3 – Material and method advantages

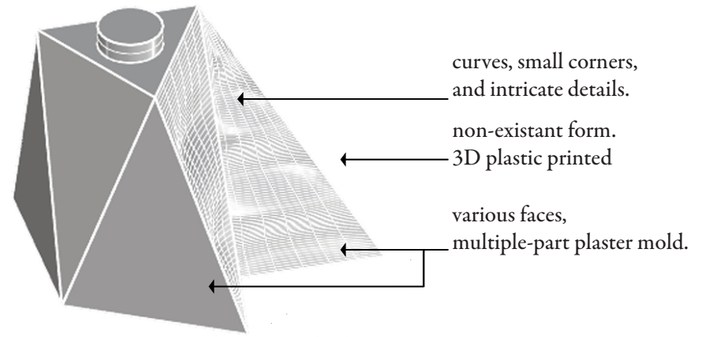
Slip casting allows for small details, curves, sharp edges, and three-dimensional forms with designs on all faces to be produced, so this design test will leverage these material advantages. Slip casting will be the only method to achieve the design outcome in a single, complex, and hollow form.

Modularity will be introduced in this design test to demonstrate the advantages of digital design, which will allow the assembly of highly detailed and intricate forms to be tested virtually before physical fabrication. Modularity inherently supports adaptability and efficiency design goals by enabling customization of the assembled form while allowing the overall scale to be increased.



poured as single, hollow form.

all faces of form have design.



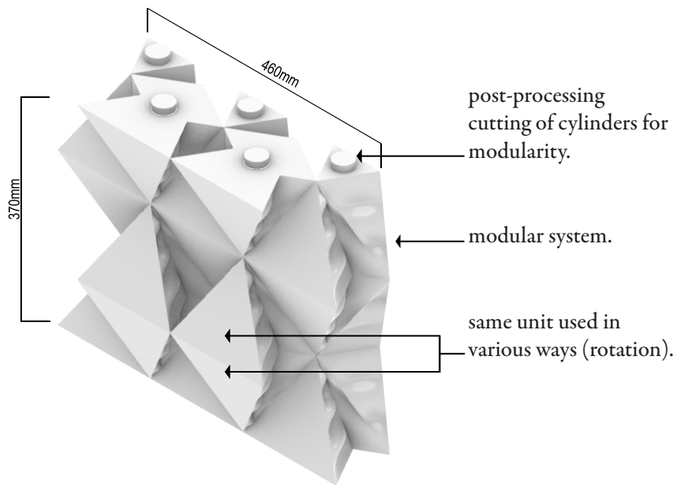


Fig. 4.5

Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages, Diagram by author.

DESIGN TEST 3 - KNOWLEDGE HELD BY DIGITAL INFORMATION

Digital information holds knowledge of design and process (information-tool technology).

Design Test 3 will use machines and technology as the foundation, with knowledge existing as digital information transferred from the human mind. This design test will explore how digital fabrication can introduce adaptability and maintain consistency in the mold-making process within contemporary slip casting. Rhino software will be used to develop the digital design, and an AXYZ CNC router will translate it into physical form.

Design Test 3 will be a modular, slip casted privacy screen system composed of 28 individually fabricated modules assembled into a complete screen 3' in width and 6' in height. These dimensions are selected to produce a screen large enough to be experienced at a human scale and to demonstrate the modularity of the system and repetition in production.

The following describes how the design concept is developed by applying the three design goals:

Design goal 1 – Adaptability

An AXYZ CNC Router will be used to fabricate the plaster mold, supporting material and time efficiency while enabling customization and fabrication at an increased scale. This workflow eliminates the need for an intermediate physical positive, allowing complex digital geometries to be machined directly into plaster. Using a CNC router will enable the design to be adapted and re-cut into the plaster mold to accommodate variations.

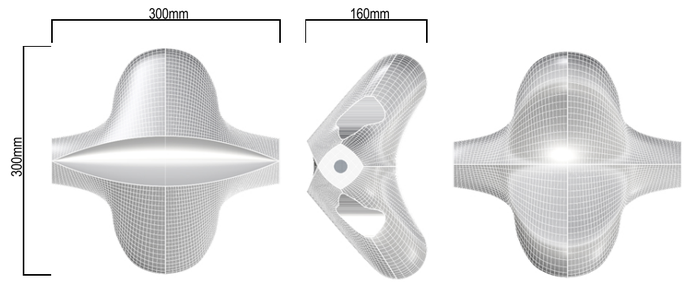
Design goal 2 – Efficiency

Machining directly into the plaster block will allow a single mold to accommodate design variations, pushing the limitations of traditional slip casting and improving time efficiency in mold production and material efficiency through reduced plaster waste. Introducing digital and machine workflows will also reduce human physical labour in the production process, increasing efficiency and enabling larger-scale production. The ability to create larger individual modules means that less pieces need to be created to fill the required screen system dimensions.

Design goal 3 – Material and method advantages

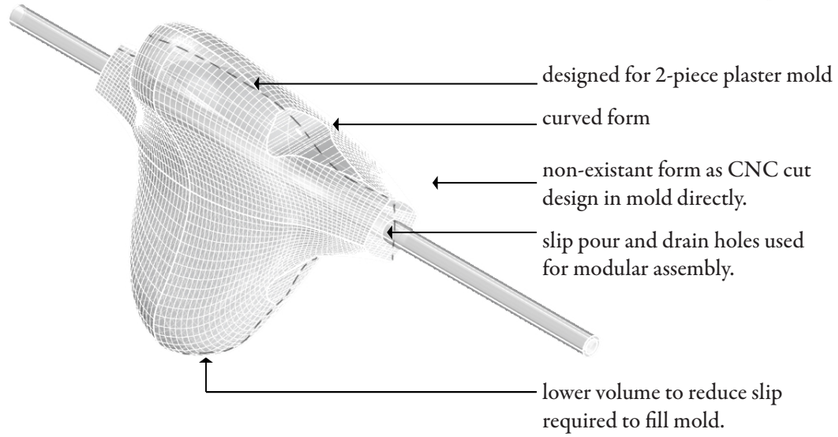
The tooling paths of the CNC router will directly inform the design process, allowing the technology itself to become a factor in shaping the resulting form. The form designed using human knowledge will be digitally modelled and cut directly into the plaster mold through a generated CNC toolpath. The designed form will take advantage of slip casting and the digital fabrication workflow by making small, precise details, and curved geometries. The physical form produced through the machine's interpretation of digital information will be shaped by the selected tool bits and toolpaths.

Design Test 3 will also use the opening required for pouring and draining slip as a design opportunity, incorporating it into the modular assembly by running steel rods through the holes to act as the assembly method.



poured as single, hollow form.

all faces of form have design.



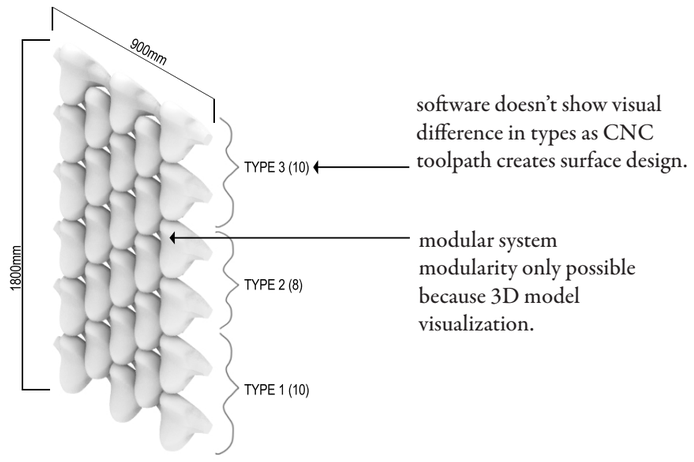


Fig. 4.6

Diagram of concept design and how design meets design goals of adaptability, efficiency, and material and method advantages, Diagram by author.

4.3 DESIGN METHOD

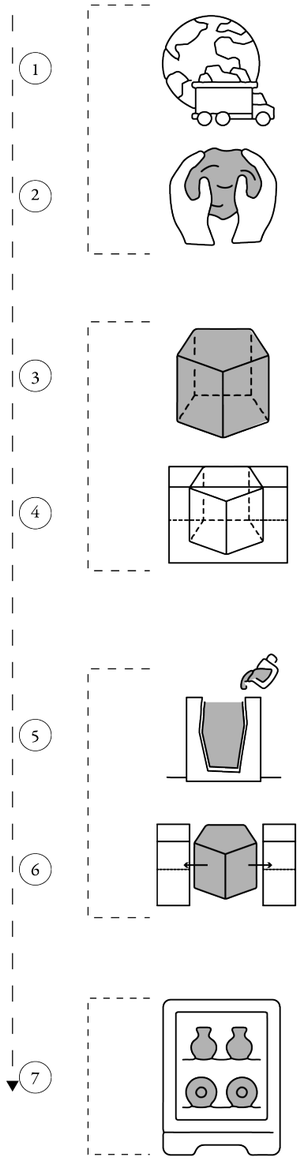


Fig. 4.7

Diagram of slip casting workflow,
Diagram by author.

WORKFLOW

The basic process of a slip casting workflow includes:

1) Sourcing clay

2) Processing clay to a workable slip casting material

3) Developing a design

4) Creating a mold based on the design
   Selecting the material for mold creation

5) Pour slip in mold and drain after clay layer is formed in mold
   Determine the time the slip remains in the mold.

6) Release the clay from the mold
   Determine the time before the clay is released from the mold

7) Dry and fire the clay objects

Clay sourcing and processing, drying, firing, and assembly are stable variables within this thesis research. Alterations to the method occur solely in the design, mold creation, and casting process.

DESIGN – SCREEN

This research focuses on the application of modular slip cast ceramic screens as stand-alone, non-loadbearing partitions within interior spaces. This way, their architectural expression can be investigated without the structural and environmental constraints associated with exterior building envelopes. As Pallasmaa states, "architecture provides an essential bridge between abstraction, symbolic meaning, and the physical world, bringing meaning and relevance to space and place."[2] A screen system allows the design tests to focus on craftsmanship, material behaviour, and fabrication method, rather than performance-driven design requirements. Through subjective experiential observations, the craftsman, material, and method are examined to evaluate the role and value of craftsmanship across different fabrication methods.

Slip casting is used to construct modular screen system modules because it facilitates quick repeated experimentation and produces individual components that can be analyzed independently and as part of a larger assembled system. Variations in form, tolerance, and scale resulting from fabrication techniques are directly compared, revealing how specific stages of the production process influence the outcome.

2 Cristopher Bardt, "Recapturing Meaning: Toward a New Material-Based Design Theory for Architecture," Frontiers of Architectural Research 11, no. 4 (2022): 609–17, https://doi.org/10.1016/j.foar.2022.03.005.

MATERIAL AND TECHNICAL CONSIDERATIONS

SLIP BODY

Based on the case studies, Bryan Hopkins uses a low-fire porcelain slip recipe that he mixes himself. Cambridge, Ontario, where this research is conducted, is located relatively close to Buffalo, New York, making his clay resources geographically accessible to the research. Although this slip provides a more environmentally conscious clay alternative through low firing energy and locally sourced materials, producing it according to his slip recipe costs approximately $110 per ten litres, on average more than twice the cost of commercially available pre-mixed slip.

S&S Pottery Supplies is a division of the Pottery Supply House (PSH), located in Kitchener, Ontario. The cost of their pre-mixed slip is $45 per ten litres, so their slip is selected as it is the more economic choice. If this method were applied to larger-scale production beyond the scope of this thesis, Hopkins' slip recipe may provide a less environmentally harmful material option despite its higher production cost.

MOLD MATERIAL

Slip casting can be completed using plaster molds or porous resin molds with hydraulic pressurized clay injection into the molds. The hydraulic pressurized injection component is not available within Waterloo's facilities, so plaster for mold material is used.

The plaster selected for this thesis is USG No1. pottery plaster, sourced from PSH in Kitchener, Ontario. For ceramic work, pottery plaster is a good material to work with opposed to other plaster types because it is made of extremely fine particles that allow extreme precision in detail. Its high-water absorption also makes it effective for slip casting, while its ease of mixing and workability simplify mold fabrication. Most importantly, pottery plaster is the most common mold material used in traditional practices and is compatible with machinery and digital tools for contemporary workflows. This plaster is chosen for consistency in all the tests.



Fig. 4.8

Photo of pre-mixed slip sourced from S&S,
Image by author.



Fig. 4.9
Photo of USG No. 1. Pottery Plaster,
Image by author.

LIMITATIONS

FACILITY

The tools and processing space available at the University of Waterloo School of Architecture's facilities (UW), where all design research was conducted, represent the first limiting factor.

The workshop at the school is predominantly set up for woodworking, with machinery and equipment for wood processing. Wood processing tools, such as a table saw, a handheld circular saw, a drill with drill and driver bits, and the CNC Router, are available to create plaster mold formwork.

In the workshop, there is a plaster processing workbench. This plaster processing area provides four coddle boards and clamps, bowls, spoons, a sifter, a pitcher, a surform file, plasticine, an insulated container with an incandescent light bulb for melting plasticine into a workable material, an agitator to reduce bubbles in plaster, and surface area to process materials. The slip casting process makes use of the mixing equipment from the plaster mold process. Further tools required are rubber bands, trimmers, and mold release agent. The tools available allow for maximum flexibility, with the only restrictions on processing being the tool dimensions and designs that can be produced.[3]

There is also a clay lab within the school of architecture that acts as a clay processing workspace. This room is separate from the workshop, so the clay materials are not impacted by other material operations occurring in the same space. This facility provides heat guns for drying, drying racks, drying boards, slip stirring equipment, and a kiln for firing. The hand tools available are sculpting tools, sponges, cutting wires, and detail tool sets.

3 2007_Schindler_ Information-Tool-Technology.



Fig. 4.10 *Photo of workshop,* Image by author.



Fig. 4.11 *Photo of workshop plaster bench and tools for plaster mold creation,* Image by author.

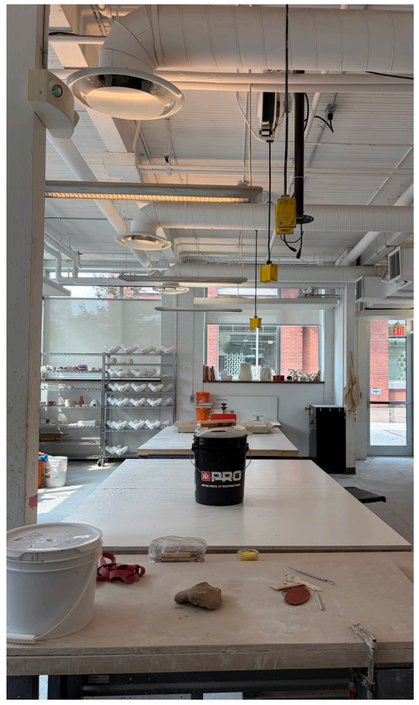


Fig. 4.12 *Photo of Clay Lab,* Image by author.



Fig. 4.13 *Photo of clay lab workstation tools for slip casting,* Image by author.

TOOLS

Digital Modelling Software

The tools available for digital fabrication are programs such as Rhinoceros 3D with extensions such as Grasshopper to create coded scripts. The resulting codes provide instructions for how the machinery operates and processes clay material. These programs are compatible with the school's software and digital technology.

3D Plastic Printer (FDM)

The 3D plastic printer available is a Bambu Lab P1s. This printer has a maximum limitation in bed size of 256mm (x-axis) x 256mm (y-axis) x 256mm (z-axis).

The available filament printing materials are Polylactic Acid (PLA), a hard plastic, and Thermoplastic polyurethane (TPU), a flexible, rubber-like plastic.

The printer deposits linear tubes of plastic that fuse together, so the print's resolution shows the trace of the fabrication process based on the nozzle diameter and layer height selected. The final object is also impacted by the machine's inability to achieve a smooth surface independently, requiring post-processing where a smooth finish is desired.

The object's form is also limited by tool constraints. Each printed layer acts as the foundation/support for the following printed layers such that slopes and overhangs may require bracing.

CNC Router

The school's CNC router is an AXYZ CNC Router. This router is limited by a bed size of 3048mm (x-axis) x 1524mm (y-axis) x 200mm (z-axis). The main constraint is the maximum material height of 200 mm in the z-direction. Available tool bits range from 1/8" to 1/2" in diameter, and end conditions include flat and ball ends. Tool bits vary in length, so tool height and spindle head are design considerations to prevent collisions with the material being cut. The CNC router can cut wood, foam, polyurethane modelling boards, PBLT Precision Board High Density Urethane Foam, and plaster.

Kiln

Due to modern machinery, slip casted objects are commonly fired in an electric kiln, allowing for more dependable results and control than pit firing or wood firing. UW allows access to its electric kiln, so this thesis uses it for firing clay.

The kiln available at the school is the Euclid's CF-255 front-loading electric ceramic kiln. This kiln has maximum dimensions of 610mm width x 610mm depth x 690mm height. The kiln shelves can be used and have a maximum length of 558mm and a width of 279mm.

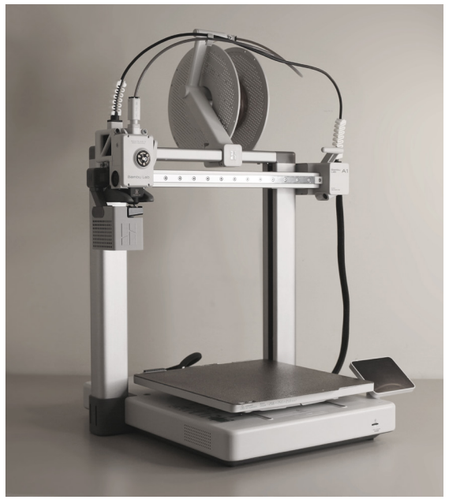


Fig. 4.14

Photo of bambu lab P1s 3D plastic printer,
Image by Ulyana Bunina.

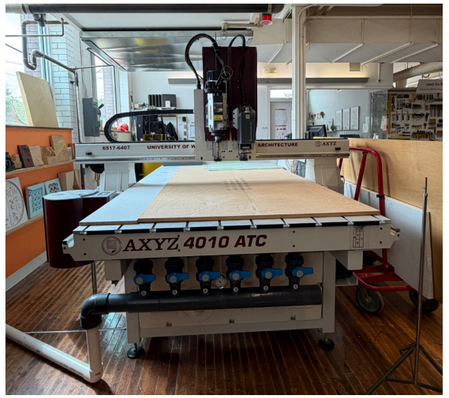


Fig. 4.15

Photo of AXYZ CNC router,
Image by author.



Fig. 4.16

Photo of Euclids CF-255 front-loading electric ceramic kiln,
Image by author.

05 | RESULTS

5.1 DESIGN TESTS

DESIGN TEST 1 – KNOWLEDGE HELD BY CRAFTSPERSON

The craftsperson holds knowledge of design and process through direct engagement with hand tools (hand-tool technology).

Fig. 5.1

Photo of final form for Design Test 1,
Image by author.



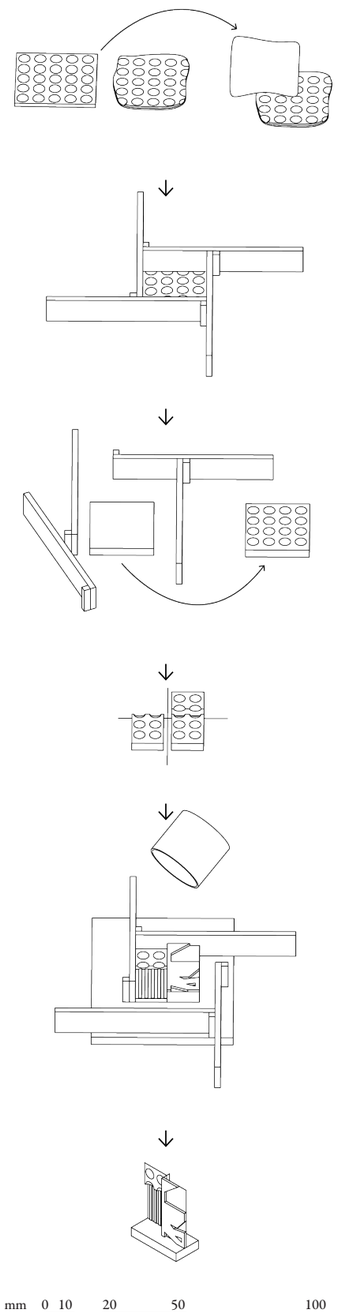


Fig. 5.2 *Diagram of design development,* Illustration by author.

A reusable ceramic pattern is created by pressing a clay slab into a found-object texture and bisque firing it. Plasticine is then pressed into the ceramic pattern to reproduce the texture and shaped into the desired form. This process allows the texture to be replicated while the form can be adapted for different mold configurations.

Coddle boards then frame the formed pattern, and plaster is poured over it to create the final mold.

The plaster molds for this design took 72 hours to dry fully before being able to slip cast with them.

The plaster pattern is cut into pieces of varying sizes, with their dimensions determined by the desired final form and arrangement of patterns rather than a fixed grid. This process is repeated to create multiple patterns with varying textures, which are then assembled into a single screen.

The plaster pieces are arranged into a rectangular form and coddle boards frame the assembly for slip casting. This approach allows for customization by giving the craftsperson discretion over the selection and arrangement of varied patterns within the screen. The mold is rotated during drainage to prevent drip marks from forming along the surface. Trials show that approximately one hour provides the best balance between safe form removal and reducing cracking.

The thin screen is then braced and dried gradually to further control shrinkage and cracking. Once dry, hand tools are used to clean the edges and remove marks left by the draining slip. The sequence of transferring the pattern from positive to negative and back to positive is essential to accurately reproduce the original object's texture rather than creating a reversed impression.

Plaster mixing directions and ratios:

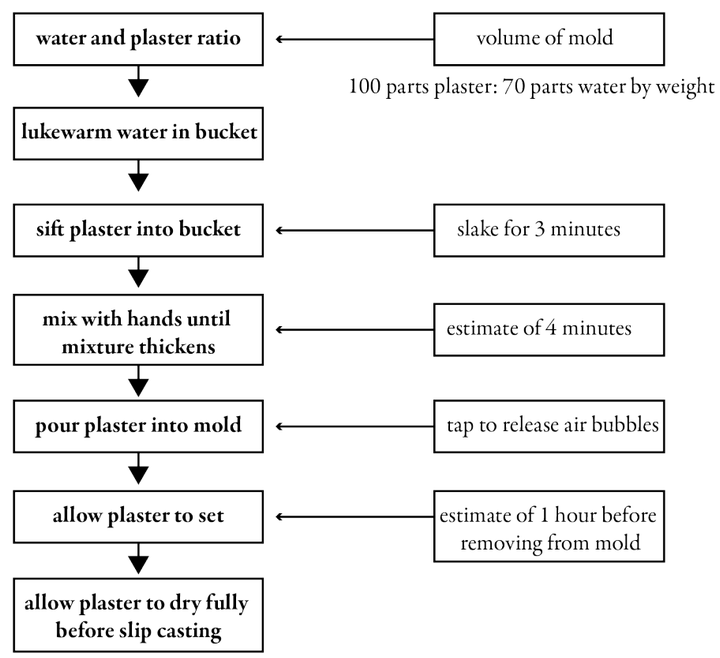


Fig. 5.3

Diagram of plaster mixing directions, Illustration by author.

Wait time for slip before draining:

TRIALS	TIME BEFORE DEAINING	RESULTS	ADDITIONAL NOTES
Trial 1	15 minutes	unsuccessful	
Trial 2	20 minutes	unsuccessful	
Trial 3	30 minutes	successful	Wall thickness 1/4". Unstable plaster mold assembly
Trial 4	20 minutes	successful	Wall thickness 3/16"
Trial 5	15 minutes	unsuccessful	

Remaining pours using trial 4 results, waiting 20 minutes before draining for 3/16" wall thickness.



1 Fig. 5.4 *Photo of gathered textures printed in clay,* Image by author.



2 Fig. 5.5 *Photo of plasticine taking texture of fired clay,* Image by author.



3 Fig. 5.6 *Photo of formwork prepared for plaster mold creation,* Image by author.



4 Fig. 5.7 *Photo of measurements for cutting plaster,* Image by author.



5 Fig. 5.8 *Photo of plaster blocks being cut,* Image by author.



6 Fig. 5.9 *Photo of plaster coddle boards prepared for slip,* Image by author.



7 Fig. 5.10 *Photo of slip after mold was drained,* Image by author.



8 Fig. 5.11 *Photo of slip casted piece after removal from mold,* Image by author.

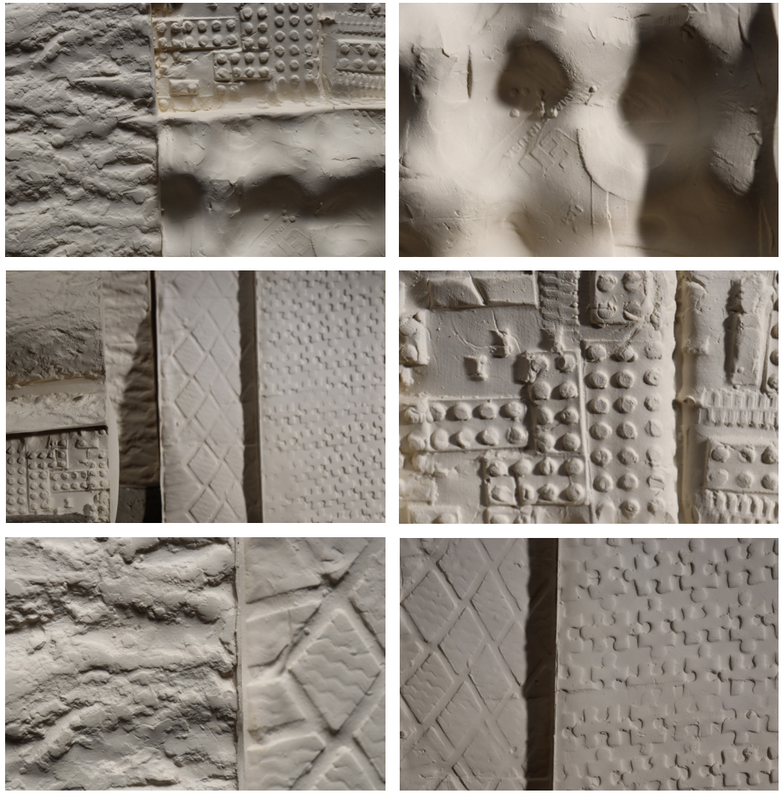


Fig. 5.12

Photo of slip casted piece assembled with base,
Image by author.

Fig. 5.13

Collage of texture and depth achieved in final forms,
Image by author.



LIMITATIONS

The scale is limited by weight of form and thinness of slip-cast piece. Because this method relies on human labour, the fabricator needs to be able to lift the mold assembly to pour the slip out. A plug would not work with this technique as there would be a hole left in the screen where the plug is removed and the slip is drained. As the slab's surface area increases, more slip is required to cover it, resulting in a larger unsupported mass during lifting and flipping. If the goal of this screen is thinness, the scale is also limited with brittleness of the pieces. The thinner the pieces are, the greater the likelihood of cracks and breakage. The edges where the plaster pieces differ in height also creates breaking points with thin slip casted pieces. Upon drying, plaster blocks obstructing the direction of shrinkage put strain on the clay. A reduction in the thickness of clay increases this risk of cracking.

The design is also limited because the textures are the only distinguishing feature from one design to the next, therefore the design freedom and customization rely on the textures chosen. There is also a limit to the textures available because they are all extracted from existing objects. Imagined designs are not part of the scope of this method as that would add an additional step.

EVALUATION – How design met design goals

Design goal 1 – Adaptability

This design process began with a method to achieve detailed textures in the screen, but the actual design of the screen with chosen textures, heights, and form was a product of the process. Through adapting the assembly and creating new plaster textures, an unlimited number of patterns could be achieved. The number of plaster blocks in one assembly, the textures chosen, the height difference between plaster blocks, how each plaster piece would meet the others, and the final scale were discovered through production.

Because the method was fully driven by human manipulation and knowledge, alterations to the production process could be incorporated as material and process knowledge developed through fabrication. Repeated assembly of the plaster pieces and slip casting revealed how different configurations affected the outcome, including gaps between pieces, edge angles that contributed to cracking, and patterns that transferred effectively. The vertically cut, right-angled plaster pieces provided no slope to prevent undercuts, making small inaccuracies prone to creating gaps or cracking during removal. Complex textures, such as tree bark, similarly created undercuts that made clay release more difficult. These observations informed subsequent adjustments, including switching and rotating pieces to achieve more successful slip casts. The drying process was also modified to reduce cracking and warping, with later tests incorporating improved bracing of the plaster pieces during drying.

By avoiding the use of keys to achieve variation, customization was also introduced because the plaster blocks could be assembled in any chosen pattern. Another layer of customization and variety was introduced in the post-processing stage with trimming, smoothing, and clean-up using hand tools. Customization could be introduced through this technique; however, its trial-and-error nature made it difficult to guarantee a specific design outcome for a client. Customization was also constrained by the textures available for collection, as the method relied on gathering and reproducing existing surface patterns.



Fig. 5.14

Photo of final screen,
Image by author.

Design goal 2 – Efficiency

The intention of the thin screen was to take advantage of the method of slip casting, where form could be experienced on either side of the screen. The design goal outlined the potential for a thin clay layer to express texture and form clearly on both sides. The desired thinness to express the design on both sides could not be achieved, so one side of the screen system resulted less interesting than the other. To improve this design, an enclosed form like Hopkins' cups could be produced so both sides of the screen could be experienced similarly. Although the clay thickness achieved does not provide translucency, its reduced thickness decreased material use and shortened drying and firing times, contributing to both material and time efficiency.

Time efficiency was reduced by the additional steps required in this process, which exceed those of traditional slip casting. Traditionally, a single plaster mold is created from a form and used to produce exact replicas. This process required additional steps to exchange existing textures into reusable molds for variation in the assembly.

This variation in assembly added adaptability, but it was limited by the fixed plaster pieces once the plaster set. Creating a new design required restarting the process with newly cast plaster pieces. This process was more efficient than traditional practices though, because variation could be achieved without having to re-cast a new mold each time. This method did not change the plaster pieces themselves, rather the assembly pattern so the casted piece was different.

Design goal 3 – Material and method advantages

The process shaped the final design by revealing limitations and failures within production. As the craftsperson began to understand the materials used, alterations in the pattern, thickness, or process can be changed as the human was the physical tool operator and designer. Post-processing by hand with trimming and sponging rough edges was an advantage of this hand-tool method of fabrication because if there were any errors in process, human recognized these areas and fixed the piece before it was fired.

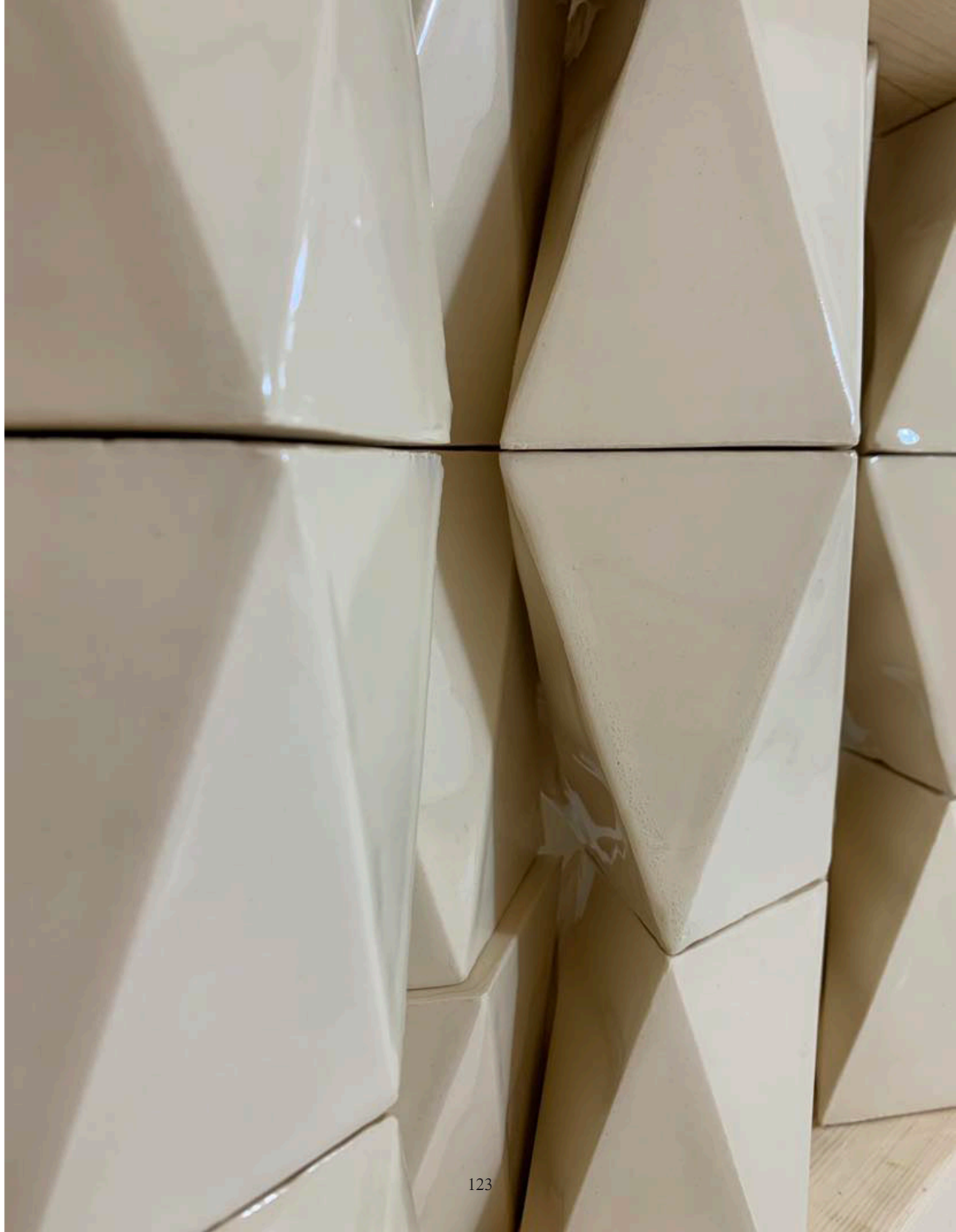
For example, pursuing thinner forms introduced the potential for structural weaknesses that made the pieces more susceptible to tearing under stress. As the clay dried to a leather-hard state within the plaster mold, it shrank and became caught in the mold's right-angled undercuts, causing the cast pieces to tear. Warping was also a concern, as the unsupported screens deformed as they dried. Closing the form would address these issues by increasing structural stability and reducing exposed brittle edges that could chip or snap under their own weight.

DESIGN TEST 2 – KNOWLEDGE HELD BY CRAFTSPERSON AND DIGITAL INFORMATION

Digital information holds design knowledge, while the craftsperson holds process knowledge.

Fig. 5.15

Photo of Design Test 2,
Image by author.



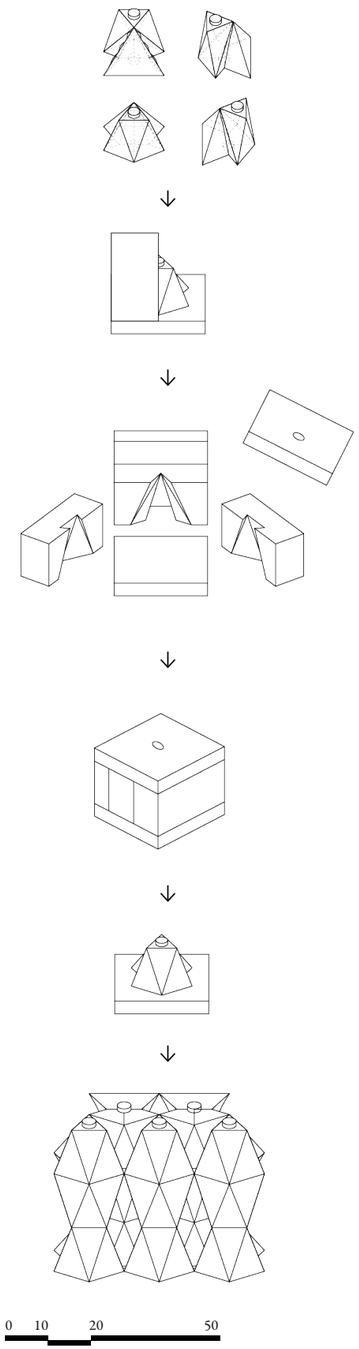


Fig. 5.16 *Diagram of design development,*
Illustration by author.

DESIGN DEVELOPMENT

The design is digitally modelled and 3D plastic printed at full scale, allowing a new form to be developed and tested as a complete modular assembly before fabrication.

The completed form is then used to produce a six-piece plaster mold, with the number and arrangement of sections determined by the geometry and location of overhangs to ensure each piece can be removed without catch-points. Each section took 72 hours to completely dry before being able to slip cast with them.

Keys are incorporated into the mold to ensure consistent alignment during assembly, unlike the last design that introduces variability with the lack of keys. Providing keys gives the craftsperson greater control over adaptations by establishing a consistent and repeatable variable within the process.

The dried plaster pieces are assembled, and slip is poured into the mold. This process highlights technology's ability to expand design possibilities and establish controlled fabrication parameters. During slip casting, the mold is rotated while draining to prevent excess slip from collecting in corners and along edges, supporting a more consistent wall thickness.

Testing established a minimum removal time of approximately one hour and 45 minutes, demonstrating the importance of process-specific timing and material knowledge. Once removed, the pieces are refined using a sponge and hand tools to smooth surfaces and clean seams.

Post-processing introduces an element of craft and variability, as each module is individually modified by removing top/bottom cylinders to create the connection required for assembly. This demonstrates how human judgement and manual intervention can remain important within a digitally informed fabrication process.

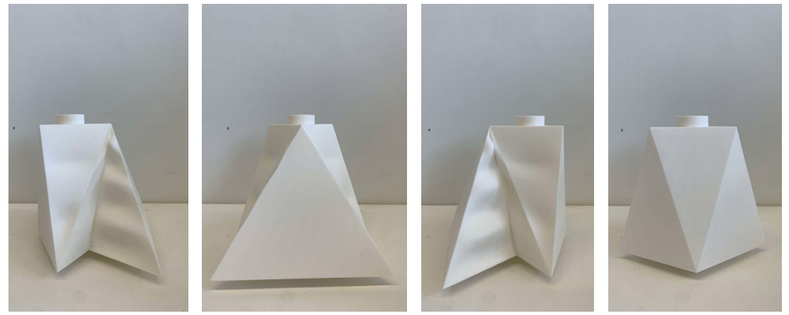


Fig. 5.17

Collage of 3D plastic printed design,
Collage by author.

Wait time for slip before draining:

TRIALS	TIME BEFORE DEAINING	RESULTS	ADDITIONAL NOTES
Trial 1	30 minutes	successful	Wall thickness 1/4"
Trial 2	20 minutes	successful	Wall thickness 3/16"
Trial 3	15 minutes	unsuccessful	

Remaining pours using trial 2 results, waiting 20 minutes before draining for 3/16" wall thickness.



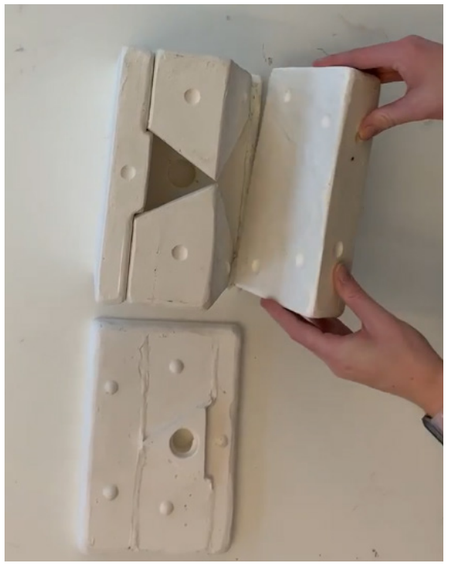
1 Fig. 5.18 *Photo of 3D plastic printed object,* Image by author.



2 Fig. 5.19 *Photo of plaster mold created from 3D printed object,* Image by author.



3 Fig. 5.20 *Photo of plaster mold section creation,* Image by author.



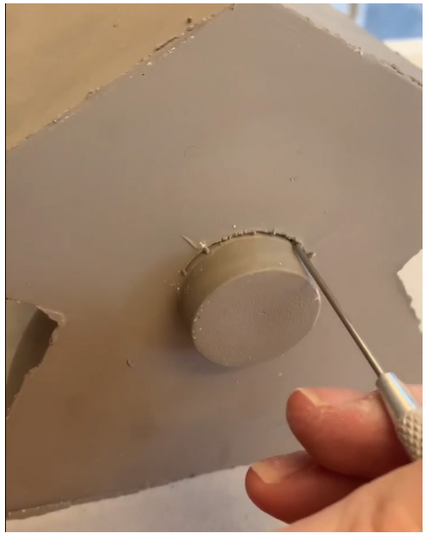
4 Fig. 5.21 *Photo of plaster mold assembly,* Image by author.



5 Fig. 5.22 *Photo of plaster mold assembled to pour slip,* Image by author.



6 Fig. 5.23 *Photo of slip-casted object during un-molding,* Image by author.



7 Fig. 5.24 *Photo of post-processing for attachment,* Image by author.



8 Fig. 5.25 *Photo of kiln fired module,* Image by author.



Fig. 5.26 *Photo of modular system - front side,* Image by author.

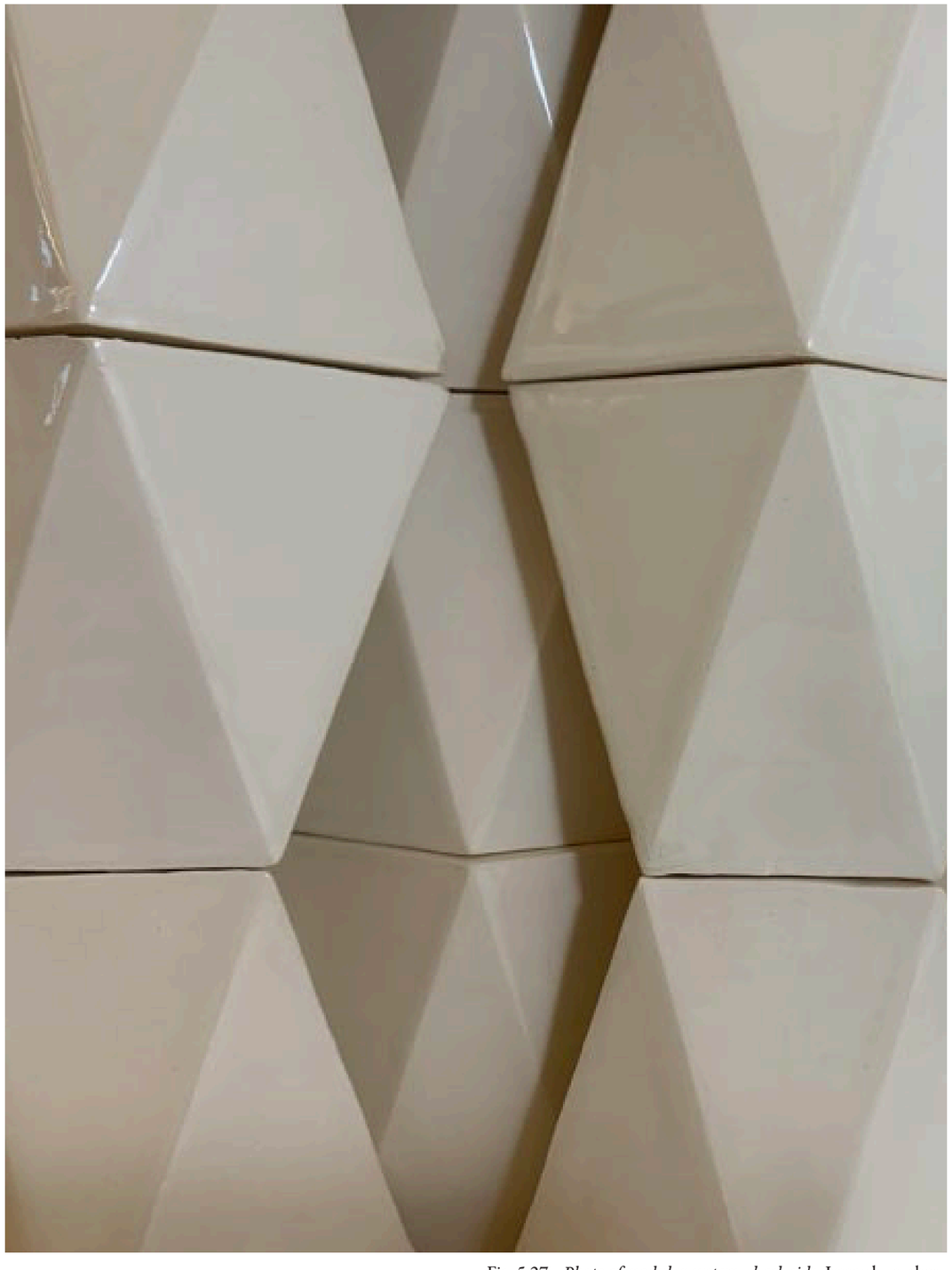


Fig. 5.27 *Photo of modular system - back side,* Image by author.

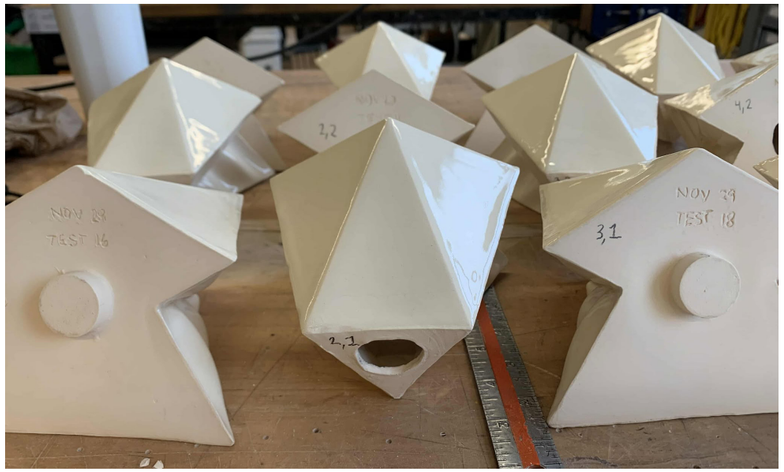


Fig. 5.28

Photo of modules for screen, Image by author.

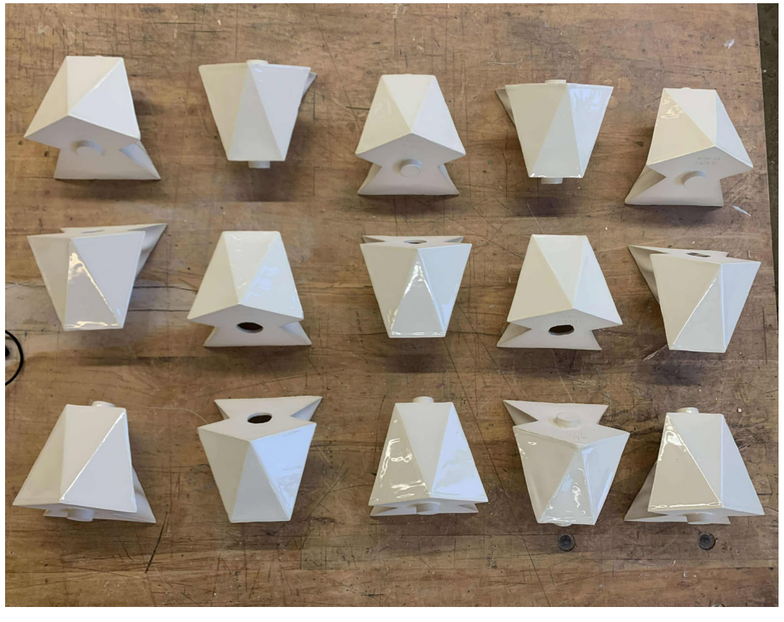


Fig. 5.29

Photo of modular system unassembled, Image by author.

LIMITATIONS

The limitations in design exist due to the printing process. The bed size restriction is the first limitation in scale of design, as the individual module could only be as large as the bed size available. Then, large overhangs or intricate details are restricted to the plastic material lamination from one layer to the next and the nozzle size. Similar to the first design, the scale of each module is also restricted by the weight a human operator can carry. The molds need to be flipped to drain the slip, so a much larger scale needs a machine to assist with the manual labour.

Sanding after the design is printed is an important step because the 3D plastic printer leaves traces of the machine that are copied with the plaster mold and slip. This design has small corners, so sanding is almost impossible to reach into these small areas and achieve a smooth surface. The process of sanding also risks slightly altering the final design form. If the small, lined details of the plastic printer are left, the slip would not release as well from the plaster mold.

Because this is a complex plaster mold created using hand-processing, it is more susceptible to errors in fabrication and assembly. Given the research timeline, there is insufficient time to refine the mold and achieve a precise interlocking fit.

Some of the pieces do not have a flat bases because they maintain their two plugs on top and bottom of the modules. These pieces can not be removed from the mold and dried flat, so gravity loads cause slight warping of the forms.

EVALUATION – How design met design goals

Design goal 1 – Adaptability

The modular system was intended to turn out exactly like the 3D software designed modules, but upon fabrication and assembly in the modular system, the physical form was different. A difference was observed between the digital design and the physical form in the tolerances between the pieces. Because there were slight differences in each module, they could not be assembled in a tight fit, so there were gaps where the triangles were intended to meet. This adaptation can be viewed not as an error, but as the fabrication process influencing design decisions. Moments in the design process where differentiation occured were;

- The timing the slip was left in the mold before being drained (thickness of ceramic piece).
- The timing before the clay module was removed from the plaster mold.
- How dry the plaster mold was (thickness of ceramic walls and firmness of state of material) before removal from mold.
- The drying process and conditions (covered or uncovered drying process, temperature of room, airflow in room, stabilizing structure around form, amount of shrinkage).
- Firing conditions (where the piece was in the kiln and how it was rotated).

The workflow and its variables were adjusted throughout fabrication as more effective methods were identified and process errors were corrected. For example, the initial modules experienced warping because they were removed from the plaster mold too early. Leaving the pieces in the mold for a longer period reduced warping but resulted in differences in the overall shape between the first and later modules.

Design goal 2 – Efficiency

Variation was achieved through hand post-processing of the slip-cast pieces. However, at a larger scale, this level of manual post-processing would require significant time and human labour. Multiple molds would also be needed to allow simultaneous slip-casting operations. While the initial 3D-printed mold provided an efficient way to achieve customized designs, the subsequent production process remained similar to the analogue workflow of Design Test 1, limiting scalability.

The number of fabrication steps had been reduced from Design Test 1, but was still equivalent to the number of steps in a traditional workflow. The only difference was that, instead of sourcing an object to be cast, digital technology and machines produced a design, enabling design freedom.

Design goal 3 – Material and method advantages

The material advantages of slip casting, including the ability to achieve curvature and sharp edges, were successfully demonstrated, enabling a unique design outcome within the slip-casting process. The use of a multi-part mold allowed undercuts to be incorporated, reducing limitations on design freedom. Although the design was digitally modelled, the plaster mold was assembled manually. As a result, minor human error prevented the mold pieces from fitting together perfectly, creating catch-points and slight irregularities where the plaster pieces meet.



Fig. 5.30

Photo of modular system assembled, Image by author.

DESIGN TEST 3 - KNOWLEDGE HELD BY DIGITAL INFORMATION
Digital information holds knowledge of design and process (information-tool technology).

Fig. 5.31

Photo of modular system assembled for Design Test 3,
Image by author.



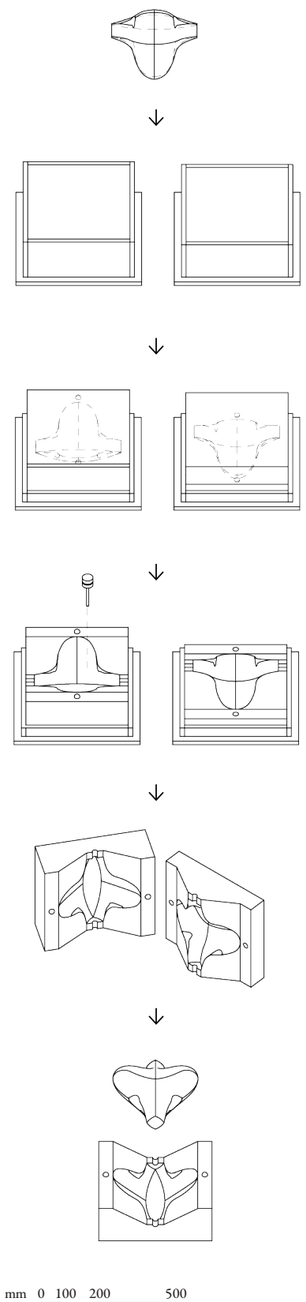


Fig. 5.32 *Diagram of design development,* Illustration by author.

DESIGN DEVELOPMENT

The design is digitally modelled to test the modular system before fabrication, allowing the craftsperson to refine scale, tolerances, attachment points, and complex connections.

The geometry is developed specifically for a two-part mold without undercuts, requiring each half of the module and the necessary tolerances to be accounted for when determining the plaster block dimensions.

Testing directly on the CNC router is completed to determine the appropriate plaster moisture level for machining, balancing the need to avoid wet plaster interfering with the equipment with excessive dryness producing harmful dust. The tests demonstrate that large plaster blocks dry unevenly, leading to the use of staged machining with additional drying time between operations.

Once adequately dried, the blocks are securely repositioned for machining, and the CNC toolpaths are digitally established with parameters including tool dimensions, tolerance, end conditions, cutting path, and speed. The toolpath is the same for both sides of the plaster mold, but the stock dimensions and cutting surface change. The success of the CNC processing depends on understanding and adapting to the physical behaviour of plaster.

Once fully dried, the mold sections are aligned and fastened together for slip casting.

After producing the desired number of modules, the same plaster molds are re-machined using a modified toolpath to generate a new design. By re-wetting the plaster and returning it to the CNC at the same origin point, variation can be introduced through changes to the machining tool and stepover rather than through any additional digital modelling. This process is significant to the thesis because it demonstrates how technology can become an active design tool, with machine parameters and fabrication conditions directly generating variation and customization rather than simply reproducing a predetermined design. The fired modules are then assembled within a frame using horizontal steel rods that pass through the openings created during slip casting, demonstrating how process-driven features can also contribute to the final assembly.



Fig. 5.33 *Photo of plaster block pre-roughed and prepared for CNC router, using 3.5lbs water and 5.14 lbs plaster,* Image by author.



Fig. 5.34 *Photo of plaster block pre-roughed and prepared for CNC router, using 1.7lbs water and 2.43 lbs plaster,* Image by author.

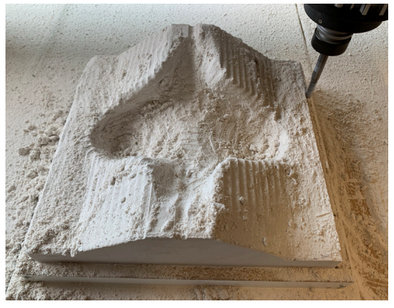


Fig. 5.35 *Photo of dryness cut test after 72 hours of drying. Result is too wet with liquid forming as cuts occured,* Image by author.

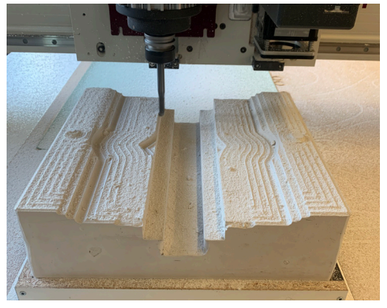


Fig. 5.36 *Photo of dryness cut test after 166 hours of drying. Result is top layer too dry and bottom layers are too wet,* Image by author.

TOOLPATH SETTINGS

These two scripts are only cut once for the first type because it is the initial block forming cut. After this, only inner form shape is re-cut.

TYPE 1

Entire operation time; Part 1 - 1hr:23mins. Part 2 - 1hr:3mins. Foundational settings are set up in RhinoCAM. The variables that changed based on design type are the tool, cut region, and stepover distance of the tool based on the percentage of the tool diameter.

ROUGHING PASS
Region; Entire surface.
Tool; Foam Ball mill ½" Long
Stepover; 75%
*Getting rid of material.

FINISHING PASS 1
Region; outer faces (plaster meeting plaster).
Tool; Foam Ball mill ½" Long
Stepover; 10%
*Last pass to make the plaster meeting faces smooth so they meet in a tight fit.

FINISHING PASS 2
Region; Inner faces (form shape)
Tool; Foam Ball mill ½" Long
Stepover; 70%
*Tool and stepover create a design in form. Large tool bit and large stepover leave big ridges.

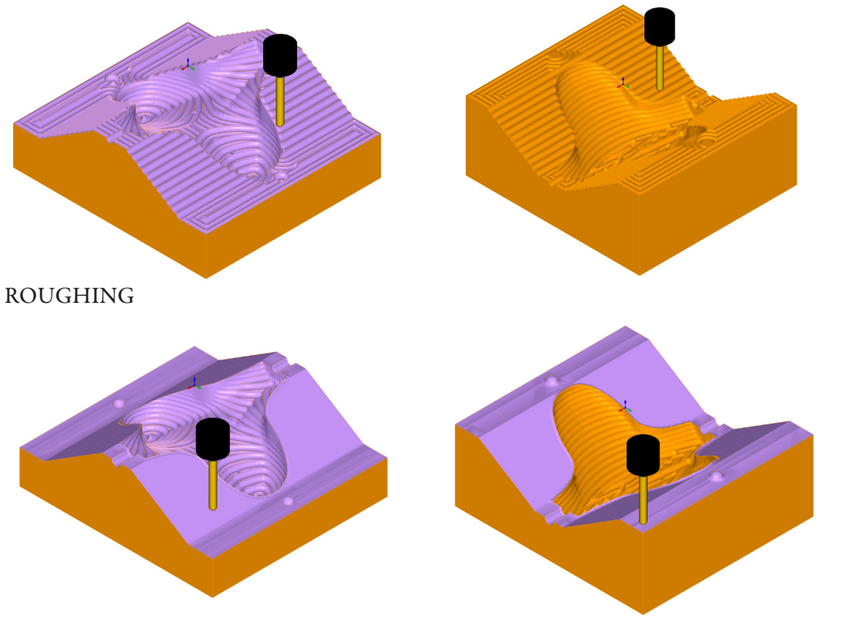


Fig. 5.37

Diagram of RhinoCAM simulation of plaster block cuts for type 1,
Illustration by author.

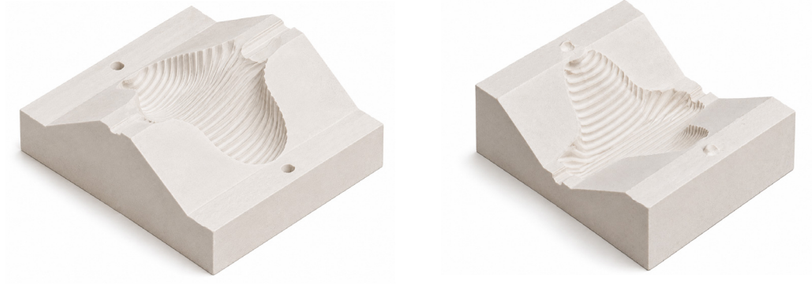


Fig. 5.38

image of plaster mold cut for type 1,
Image by author, edited using AI tools.

TYPE 2

Entire operation time; Part 1 - 7mins. Part 2 - 5mins.

FINISHING PASS
Region; Inner faces (form shape)
Tool; Foam Ball mill ¼" Long
Stepover; 50%
*Tool and stepover create a design in form. Small tool bit and smaller stepover leave small ridges.

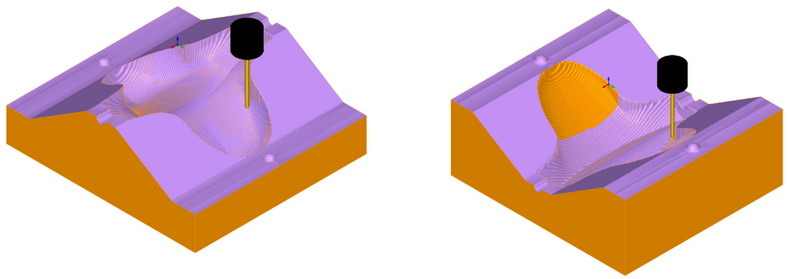


Fig. 5.39

Diagram of RhinoCAM simulation of plaster block cuts for type 2,
Illustration by author.

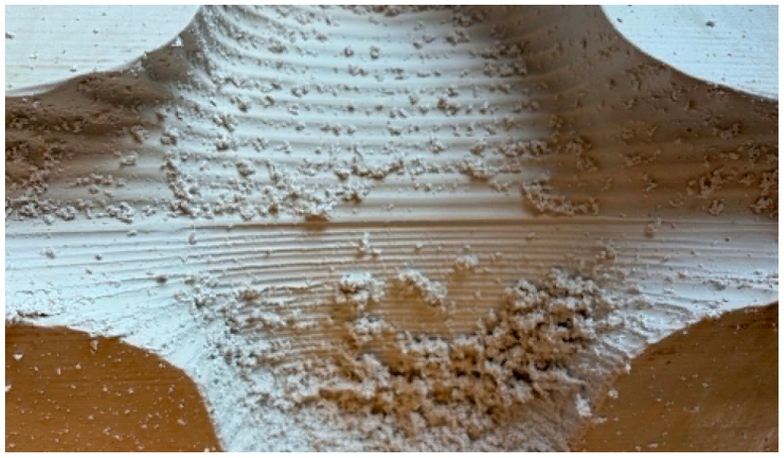


Fig. 5.40

Photo of plaster block being cut on CNC showing type 1 transform into type 2,
Image by author.

TYPE 3

Entire operation time; Part 1 - 42mins. Part 2 - 38mins.

FINISHING PASS
Region; Inner faces (form shape)
Tool; Foam Flat mill ¼" Long
Stepover; 10%

*Tool and stepover create a design in form. Flat tool bit and small stepover leave smooth surface. Minor hand smoothing in post-processing to finely smooth form required as curved surfaces leave toolpath.

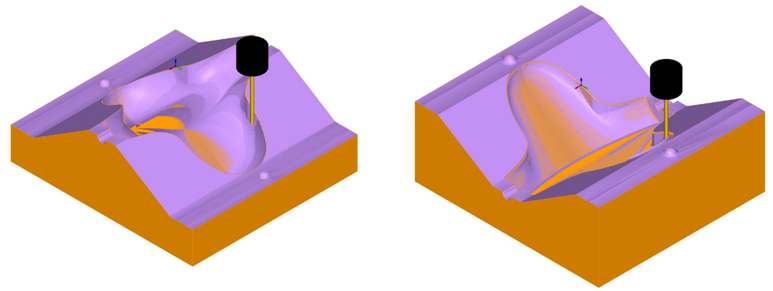


Fig. 5.41

Diagram of RhinoCAM simulation of plaster block cuts for type 3,
Illustration by author.

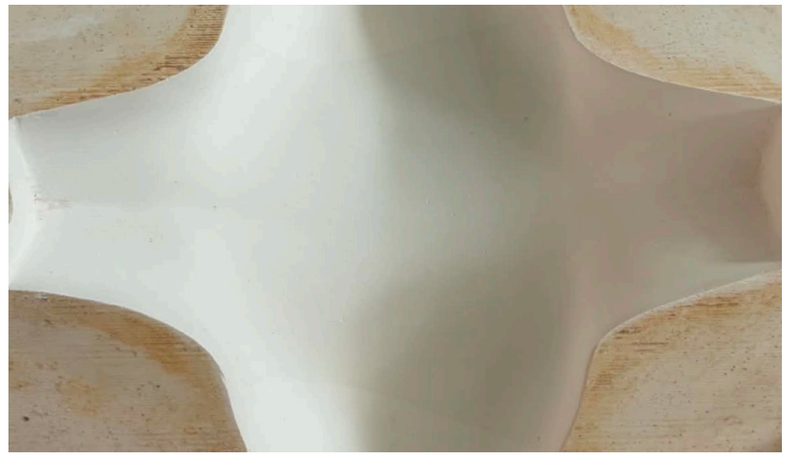


Fig. 5.42

Photo of plaster block showing type 3,
Image by author.

Wait time for slip before draining:

TYPE 1

	TIME BEFORE DRAINING	TIME BEFORE OPENING MOLD	RESULTS	ADDITIONAL NOTES
Trial 1	13 minutes	1 hour	unsuccessful	-wall thickness 1/8". -Clay is too wet when released from the mold. Plaster mold is too wet still. -A release agent is needed between the plaster pieces and between the clay and plaster for the form. -slip is pressing mold apart, so a tighter clamp is required
Trial 2	10 minutes	4 hours	unsuccessful	-Cracks when released from mold as it is stuck to the sides. The plaster mold CNC pattern left tall, sharp edges that cuts through the clay rather than forming an even wall. These edges need to be sanded down.
Trial 3	15 minutes	12 hours	successful	-Cracking when removed from mold.
Trial 4	15 minutes	9 hours	successful	-Cracking after removal because of gravity weight on leather-hard piece.
Trial 5	20 minutes	13 hours	successful	-wall thickness 1/4" -Not as much cracking. Thicker walls, more drying time, and structure to hold form while drying reduces the cracking.
Trial 6	12 minutes	10 hours	successful	-Bad cracking

*Trial 5 is the most successful, so all following pours are done using trial 5 times.

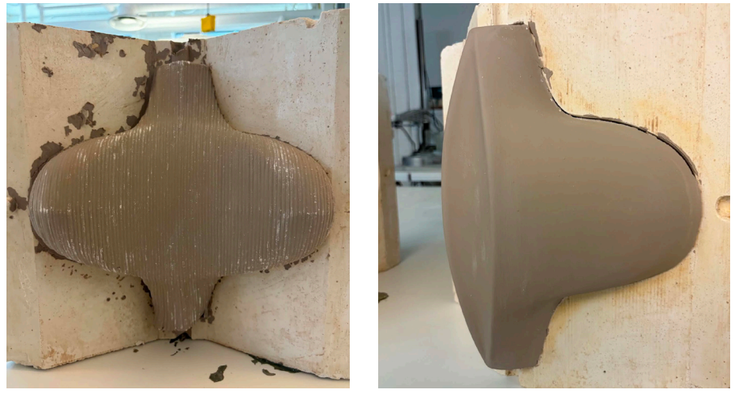


Fig. 5.43

Photos of type 2 plaster block on left and type 3 on right after opening mold,
Image by author.

TYPE 2

	TIME BEFORE DRAINING	TIME BEFORE OPENING MOLD	RESULTS	ADDITIONAL NOTES
Trial 1	20 minutes	12 hours	unsuccessful	-Plaster mold is still too wet. Clay wall is not as thick because the mold was too wet, so water was not absorbed into plaster as well. Wait 48 hours before re-pouring. -Edges are directly 90 degrees, so catching slightly with CNC path. Edges are sanded, leaving the connection point smooth with no pattern.
Trial 2	20 minutes	12 hours	successful	*Plaster halves are not lined up correctly because alignment was off when re-cutting on CNC. There is no way to correct this.

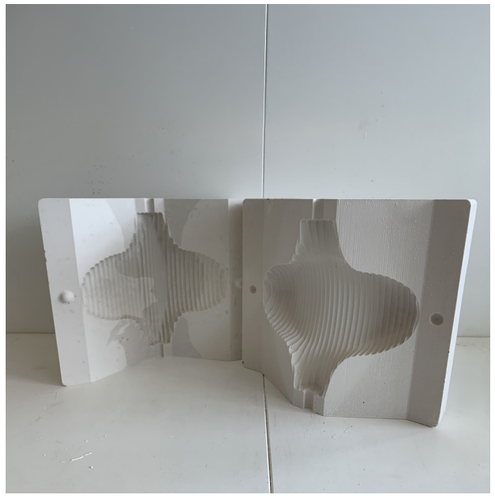
*Trial 2 is the most successful, so all following pours are done using trial 2 times.

TYPE 3

	TIME BEFORE DRAINING	TIME BEFORE OPENING MOLD	RESULTS	ADDITIONAL NOTES
Trial 1	20 minutes	12 hours	successful	-More imperfections were seen on the surface from air bubbles in the mold and release agents clumps because the surface is smooth. The pattern does not hide anything.

*Trial 1 is successful, so all following pours are done using trial 1 times.

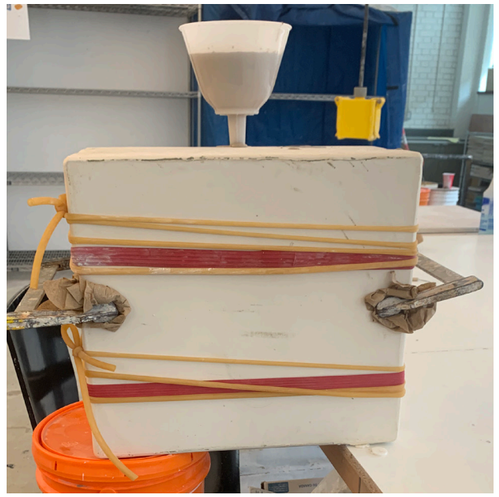
The mold is too large to flip, so a hole is in the top for pouring the slip and plugged the bottom for draining. As the mold is draining, it is rotated so slip is not stored in the edges of the mold.



1 Fig. 5.44 *Photo of plaster blocks type 1,* Image by author.



2 Fig. 5.45 *Photo of plaster blocks assembled,* Image by author.



3 Fig. 5.46 *Photo of plaster blocks with slip before being drained,* Image by author.



4 Fig. 5.47 *Photo of slip casted object being removed from plaster mold,* Image by author.



5 Fig. 5.48 *Photo of modules in kiln to be fired,* Image by author.



6 Fig. 5.49 *Photo of module being assembled on steel rod,* Image by author.



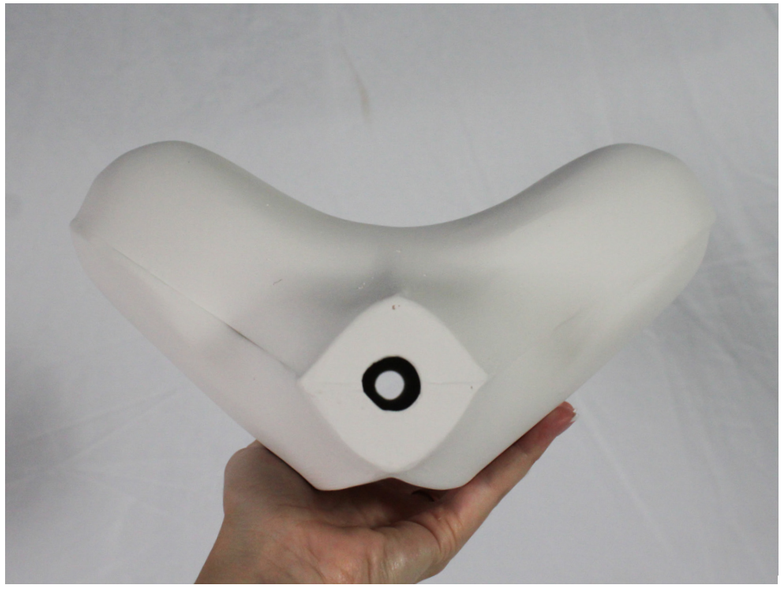




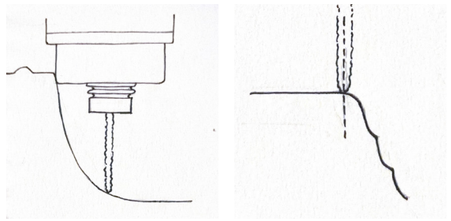
Fig. 5.50
Collage of modular system,
Collage by author.

LIMITATIONS

Slip casting imposes design constraints based on the properties of clay and the requirements of the fabrication method. Forms with curved geometries and sufficient structural support tend to produce more successful casts, while long, flat spans are more susceptible to warping during drying due to gravity. Similarly, undercuts cannot be incorporated into the design of the plaster mold, as the mold sections must be removed without damaging the cast form. For this study, the design is intentionally limited to geometries that can be produced using a two-part mold, avoiding interior corners that require additional mold sections. While more complex geometries could be accommodated through a CNC-fabricated multi-part mold, limiting the design to two parts establishes a specific constraint through which the capabilities and limitations of slip casting can be examined.

The CNC router also limits the design in overall scale and tool depth. The plaster blocks need to be under the maximum gantry height of the CNC router, and cut depths need to be shallower than tool lengths. The cutting tool also influences the design, as its diameter limits the level of detail that can be achieved. Features must be sufficiently large to accommodate the tool, while tight internal corners and angles greater than 90 degrees are difficult to produce due to the tool's diameter and geometry.

The final pass on the CNC router is the finishing pass. A ball-end bit is used; therefore, when the tool leaves the plaster mold, instead of exiting in the z-axis, it leaves a radius so the operation can end with the center of the tool on the toolpath line. When the two sides of the mold are joined, there is a small seam on the plaster, and therefore on the ceramic pieces too.



left to right

Fig. 5.52

Diagram of maximum cutting depth due to tool length, Illustration by author.

Fig. 5.53

Diagram of radius in plaster due to tool leaving mold, Illustration by author.

It is difficult to achieve a successful level of dryness of the plaster molds when the plaster blocks are larger. The moisture is removed from the outside in, so identifying when CNC cutting is possible is difficult. Plaster is also brittle, so chipping and wear on the plaster over time is inevitable.

This method requires the plaster molds to be re-cut on the CNC router to achieve a new design. Once the mold is re-cut, it cannot revert to the original form. If the original design is needed again, the mold has to be re-cut from a new plaster block.

When the form is re-cut, the exact same origin is difficult to find. This makes the consecutive slip casted forms slightly off the original origin, causing a larger seam. This is the limitation of using machine, technology, and hand manipulations.

Fig. 5.51 *Photo of form achieved and toolpath variation,* Image by author.

Design goal 1 – Adaptability

The CNC-based module-creation workflow met the design goals while improving material and time efficiency compared to traditional methods, which require additional processing steps. However, this method limited the ability to virtually test the complete modular system before fabrication, requiring the final assembly and design to be tested physically. Although the modules could be modelled digitally, variations in CNC toolpaths—particularly stepover distance and tool geometry—altered the resulting surface without requiring changes to the Rhino model. While RhinoCAM could simulate portions of the machining process, the complete positive cast and assembled system could not be visually represented until the slip cast modules were physically produced. As a result, the full range of toolpath variations was only revealed when the modules were cast and assembled into the final screen. This reintroduced an element of unpredictability characteristic of traditional slip casting, where the final form is not fully known until it is physically produced.

The physical labour involved in executing this design could be fully replaceable by robotic arms for material transfer and hydraulic systems for slip casting. As seen in case studies with toilet manufacturers, this technology and machinery was already used. The parts of the process that machines or technology have not replaced to date are virtual design creation and post-processing work, such as trimming or correcting errors. In a factory operation, they work through many mistakes and refine the design. This thesis speculates on technology's capacity to replace human knowledge in processes that require continual adaptation to new designs and challenges. Even though digital workflows were used, the method relied on material understanding to guide decisions and adaptations when variations such as plaster mold re-cuts occurred.

Design goal 2 – Efficiency

The CNC router was used to improve efficiency and expand design potential during initial mold fabrication. Unlike Design Test 1, where textures were limited to forms existing in the surrounding environment, digital fabrication allowed custom textures and forms to be developed specifically for the design. Design Test 2 demonstrated this expanded potential by using 3D-printed plastic positives, while this method further increased efficiency by eliminating the additional step of creating a positive and cutting the design directly into the plaster. Cutting the design directly into the plaster also provided greater control over fabrication and reduced opportunities for error, as manual intervention in Design Test 1 introduced inconsistencies that would otherwise be avoided through a fully automated process. Precision in plaster mold creation is increased by replacing manual fabrication processes with machine-controlled production.

However, small catch points and sharp edges that disrupt the uniform clay wall were not always apparent in the digital simulation and only became evident through physical testing. This occurred during the initial slip casting tests, where imperfections in the CNC-cut plaster mold caused by human modelling errors led to casting failures and required hand sanding to correct. Although the mold could be re-machined, hand finishing was more efficient in this case. This hybrid approach allowed the fabricator to determine the most appropriate combination of machine and hand operations. Regardless of the tools employed, in an operation where design includes variation and change, human knowledge of the material and process remains necessary to identify problems and make informed adjustments.

Design goal 3 – Material and method advantages

An unexpected finding was that the CNC router was particularly well suited to creating slip-casting molds. Because the tool bit moves along the orthogonal X, Y, and Z axes, it cannot produce undercuts within the plaster mold, aligning well with the geometric requirements of slip casting mold creation. Undercuts can unintentionally occur when plaster molds are created by hand, and even minor undercuts can prevent a slip-cast piece from being successfully removed from the mold.

The CNC router was also advantageous for plaster mold creation because the design remained digitally defined and did not rely on manual physical manipulation. This allowed the same mold to be reproduced with a high degree of consistency. A limitation of the CNC router was its dimensional capacity, as the fixed gantry restricted the maximum height of the mold. The design process considered the maximum available CNC bed height, along with variations in end conditions and bit diameter.

Design Test 3 accounted for tolerances and shrinkage based on the previous design tests and the advantages of the digital workflow. The screen system was designed with hidden joints and rounded meeting points to accommodate minor inconsistencies without making tight-fitting edges appear as design errors.



Fig. 5.54
Photo of modular system assembled,
Image by author.

06 | DISCUSSION

6.1 OUTCOME OF DESIGN TESTS

The degree to which each design meets the design goals assesses how effectively craftsmanship is maintained across varying slip-casting methods through maintaining decision-making, material knowledge, and skill development. By comparing differing fabrication methods—one where knowledge is held primarily by the craftsperson, and others where this knowledge is embedded within digital technologies—this research examines how craftsmanship is maintained or transformed through technological shifts. This comparison demonstrates the persisting value of human knowledge and judgement in contemporary fabrication, particularly in understanding the material, adapting to a process's limitations, and making informed decisions throughout production. Rather than replacing these qualities, digital technology can create new fabrication opportunities when used alongside the maker's knowledge and judgement.

Design goal 1 – Adaptability

Customization and variation require an understanding of how the clay and slip casting process can be manipulated, meaning that knowledge must remain accessible to the craftsperson. Although these design tests explore slip casting processes requiring clay body and process knowledge to refine each method, the introduction of variation and customization into the design further requires an understanding of how the clay and casting process could be adapted. The introduction of new tools across design tests also creates new design limitations that need to be understood, such as the respective tooling bed size constraints of the 3D plastic printer in Design Test 2 and the CNC router in Design Test 3. While design limitations could be digitally defined in technology to prevent failures, they restrict customization and the range of possible outcomes. Some efficiency is intentionally sacrificed to allow greater customization and design freedom, maintaining opportunities for human judgement and intervention identified as important to craftsmanship through the case studies.

Design goal 2 – Efficiency

If technology can become the entity that retains knowledge, performing the physical tasks traditionally carried out by humans, then what is the value of keeping humans involved in the process? To examine the value of human involvement, the fabricator's perspective provides firsthand insight into how decision-making shapes both the production process and the final outcome, enabling informed decisions that improve design efficiency and reduce production time. Many decisions made throughout production reflect personal preferences, creative expression, and responses to the specific conditions of the production environment. Other decisions respond to method or material requirements that affect efficient achievement of the design goals. Design Test 3 shows the need for human involvement, where a shortage of slip requires adaptations to the production process, including rotating the mold during casting to achieve consistent wall thickness and introducing hand-tool post-processing to refine the final form. These adaptations demonstrate that efficiency does not rely on technological advancement alone, but on the fabricator's ability to apply judgement and respond to changing circumstances. A hybridized method is therefore used to combine the efficiency and consistency of digital fabrication with the adaptability and responsiveness of human intervention.

Design goal 3 – Material and method advantages

After developing the designs through research-informed design goals, the slip casting method is further shaped by both the limitations and capabilities of the tools used throughout the fabrication process. A limitation of the chosen casting methods is the reduced control that results from allowing clay material and machine agency to influence the design. Slip casting inherently involves uncertainty, as the outcome cannot be assessed until approximately 12 hours after casting. When the clay or the extended slip casting process is given greater agency, such as in Design Test 3 when the CNC router is used to create variation and the final design is not fully resolved before execution, unexpected outcomes arise (such as catch-points from machine toolpaths) resulting in failed casts. However, transferring process knowledge and control to machines and digital technologies increases efficiency and enables consistent replication, customization, and variation at larger scales. This suggests that control is not necessarily achieved by eliminating uncertainty, but by establishing a clear location of knowledge and decision-making within the production method. This location may shift between the human and technology but must remain clearly situated in one place at a time.

OUTLOOK

Christoff Schindler pioneered the term "information-tool-technology", which describes processing techniques in which computer-aided manufacturing (CAM) performs physical and intellectual labour.[1] Now, digitally enabled production with Artificial Intelligence (AI) designs and fabrication processes are possible. AI paired with robotic machinery, can make judgements and perform processes, reducing the need for human involvement informing designs, and leaving less room for small discrepancies in design and production.

However, human knowledge introduced into the design process shifts the focus from simply achieving a design outcome to pursuing excellence in its execution, as humans have the unique ability to care. AI can make judgements, but they are informed by input data and do not account for human experience, intuition, environmental perception, creativity, or the social and situational contexts that shape human judgement. Because AI knowledge is shaped by the information provided by its creators and users, its capacity to generate creative outcomes remains dependent on the information it receives, rather than the creativity and judgement developed by the craftsman through making. Juhani Pallasmaa describes craftsmanship as a way of thinking through the manipulation of materials.[2] Technology can process information and generate responses, but it cannot think like humans with consciousness, self-awareness, emotional experiences, or beliefs. Maintaining process knowledge within digital technologies while retaining the craftsman's oversight allows the fabricator to monitor the workflow, apply judgement, and adapt the process when necessary. This hybridization demonstrates the continued value of craftsmanship within contemporary production by combining technological efficiency with human knowledge and decision-making.

1 "2007_ Schindler_ Information-Tool-Technology," 17.

2 Juhani Pallasmaa, The Thinking Hand: Existential and Embodied Wisdom in Architecture, AD Primers (Wiley, 2009), 52.

6.2 FUTURE DIRECTIONS

There are machines and technologies available that reside outside the scope of this thesis research. For further investigation, it would be beneficial to discover the capabilities of these tools within the fabrication process.

Robotic arm:
A team at the University of Pennsylvania develops dynamic approaches to slip casting that introduces variability using a single mold for architectural expression.[3] They use a 6-axis articulated robot that rotates throughout the solidifying process of slip casting to introduce variability in the module forms. This aligns with the research focus, using new technology to introduce variability and break the limitations of current methodologies.

Automated high-pressure casting machines with synthetic resin:
This machinery was introduced to increase the efficiency of casting processes for mass production, as resin molds have greater durability and high-pressure casting reduces processing time. While this technology improves production efficiency, it also eliminates direct human involvement in this stage of the process, as the operation becomes repetitive and machine-controlled. If this machinery and resin material are available for further design tests, it would provide a more accurate representation of current and future opportunities within casting technologies and production methods.

For this investigation, a screen system is used as a means of materializing the research findings and conclusions into a physical artifact. The next step in this research would be the application of these methods to façade systems, where the potential of customization and variation could be explored alongside the precision, repeatability, and scalability enabled by slip casting. This would also allow observation of the physical objects existing in architectural environments to see how people interact with them.

Looking beyond the scope of this research, the continued development of automation and artificial intelligence raises further questions about their implications for craftsmanship, production, and the future role of the maker. As digital fabrication and AI continue to advance, future systems may have the ability to generate and optimize architectural components by integrating predefined constraints related to clay properties, fabrication methods, and available tools into the design process. This investigation could build upon observations from toilet manufacturing facilities that have implemented 5G cloud manufacturing technologies, where AI is used to track and optimize production processes. Minimizing human intervention would allow future research to examine how design outcomes and production decisions change when human judgement is removed from the process.

Such an investigation would further examine the role of human consciousness, experience, emotion, and personal values in design decision-making. By comparing human-directed and AI-driven fabrication, the research could identify what automation gains and what may be lost when these qualities are removed, providing further insight into the role and value of craftsmanship within increasingly automated production.

3 "Robotic Approaches to Dynamic Slip Casting | MSD-RAS," accessed October 25, 2024, https://ras.design.upenn.edu/project/robotic-approaches-dynamic-slip-casting.

Through this research, analogue and digital forms of fabrication are examined to understand the role and value of craftsmanship in contemporary production while considering the demands of efficiency. The final screen system is shaped by the limitations and capabilities of the available tools and technologies, but human judgement, material knowledge, and decision-making remain integral to its development. This investigation began with the intention of demonstrating the value of handcraft, but the research journey revealed that craftsmanship does not need to be limited to manual production. Digital and automated fabrication can offer valuable opportunities for contemporary production, such as design opportunities and efficiency, while still maintaining the qualities associated with craftsmanship, provided that human knowledge and judgement remain engaged in the process.

Craftsmanship can therefore persist through the integration of digital fabrication technologies, not by resisting technological advancement, but by maintaining a meaningful relationship between the maker, material, and process. While this investigation examines this relationship through slip casted ceramic fabrication, the method offers a broader perspective for architectural fabrication, demonstrating how human knowledge can continue to influence the production of other materials, forms, and spaces, as fabrication technologies continue to evolve.

6.3 INTERPRETATION OF RESULTS

The results of this thesis is interpreted based on the success of attaining the thesis' objectives. The role of craftsmanship is assessed through the relevance of decision-making, clay material and process knowledge, and skill development within contemporary production processes, studied through the lens of slip cast ceramics. The value of craftsmanship within contemporary fabrication is evaluated based on findings from case studies, design test outcomes, and anticipated developments in contemporary fabrication.

Objective 1) Understanding the role of craftsmanship in contemporary fabrication

Pallasmaa's emphasis on embodied knowledge is challenged within mass-production facilities,[4] such as toilet manufacturing, and in Design Test 3, where direct physical manipulation of clay is limited and human knowledge is instead transferred into the machine and production process. The concern that material and process understanding may become disconnected aligns with Sennett and Pallasmaa's view that craftsmanship depends on material understanding, embodied knowledge, and informed judgement.[5] While these qualities can exist without direct physical engagement with clay, separating human and material risks diminishing the personal connection that allows knowledge, intuition, and care to develop through making. This raises the question of why preserving this connection remains valuable within contemporary production methodologies.

In alignment with Richard Sennett's definition of craft, each design test demonstrates the development of skill through practice, reflection, and iterative problem-solving. Craftsmanship is therefore expressed through method rather than the specific tool or mode of production. It is not defined by physical manipulation alone, but by the human knowledge guiding material decisions and processes. However, when production becomes repetitive and no further development is required, this knowledge can become embedded within the system rather than retained by the individual. In contrast, customized production requires continuous adaptation, where the craftsman must understand material properties and process limitations to make informed decisions. This demonstrates craftsmanship's role in contemporary fabrication not through the act of making alone, but through the human ability to respond, evaluate, and improve throughout production.

4 Juhani Pallasmaa, The Thinking Hand: Existential and Embodied Wisdom in Architecture, AD Primers (Wiley, 2009), 51.

5 Richard Sennett, The Craftsman (Yale University Press, 2008); Pallasmaa, The Thinking Hand.

Objective 2) Investigating the value of craftsmen in contemporary fabrication

The greatest consequence of losing craftsmanship may not be the quality of the final object, but the transformation of the individual involved in its creation. As knowledge becomes transferred from the individual to the system, the craftsman's role in shaping the process is reduced. Craftsmanship is valuable not only because of the objects it produces, but because of the person it creates.[6] Through engagement with material and process, craftsmen develop care, patience, resilience, judgement, creativity, and a unique design language. Since craftsmen shape architecture, and architecture shapes society, the separation between maker and making risks reducing not only the care embedded in products but also the character developed through the process of creation.

Sennett's statement, "Craftsmanship names an enduring, basic human impulse, the desire to do a job well for its own sake",[7] suggests that craftsmanship is more than just a production method, it is a method of existing in the world. He argues that making and thinking cannot be separated, as thinking within the making process cultivates values that extend beyond production and contribute to society. Throughout the design tests, the process of making decisions and developing production methods fosters problem-solving skills, discipline in responding to clay properties, respect for the material and workspace, patience, care in handling the final product, and perseverance. Cultivating these skills is valuable not only for the architectural spaces shaped through thoughtful production, but also for the society that experiences and inhabits these environments. Craft is a means of making the values, knowledge, and judgement of the craftsperson visible within the work.

While technology and machines can increase efficiency, they cannot replicate judgement shaped by self-awareness, experience, emotion, and personal values. Through the physical production of the three designs, decisions evolved through material responses, external influences, and personal interpretations beyond the initial design goals. Interviews with craftspeople reveal a similar understanding, where the value of their work lies in the decisions made throughout fabrication that give it individual character. In contrast, discussions with business and marketing teams emphasize organizational outcomes rather than the personal reasoning embedded within the production process. Human judgement also extends beyond creative decision-making to deciding how and when to use technology.

Building on the finding that technological advancement is often driven by the pursuit of greater efficiency, the research demonstrates that increased automation does not necessarily result in greater efficiency. In some cases, the fastest, simplest, or least costly solution is manual intervention, resulting in a hybridized production process. Across the case studies, workers use their judgement to determine when manual intervention is more efficient than automated processes. Even within highly automated toilet manufacturing facilities, tasks may be completed by hand when doing so is faster than re-machining. The same principle emerges during the fabrication of Design Test 3, where hand tools are used to correct minor CNC errors rather than repeating the machining process. This demonstrates that efficiency relies not on automation alone, but on human judgement to evaluate and adapt the fabrication process.

6 Jonathan Crary, *24/7: Late Capitalism and the Ends of Sleep* (Verso, 2013).

7 Sennett, *The Craftsman*, 9.

The English Arts and Crafts Movement emerged in England in the 1880s, following the rise of industrialization and mass production for efficiency.[8] This revolution stems from anxieties about machines taking over handwork, so it advocates a return to traditional craftsmanship and pre-industrial social values. Prior to industrialized production, information was passed on by humans teaching humans, so bonds were created between people and craftsman-specific tips and techniques were shared, shaping culture and society with the learned skills and values.

In 2026, more than a century later, similar concerns regarding the loss of craftsmanship have emerged alongside advancements in machinery and digital technology. However, the continued value placed on craftsmanship over the past century demonstrates its enduring significance within society. This research concludes that craftsmanship remains essential not because it preserves traditional methods of making, but because it preserves the human qualities developed through engagement with material, process, and decision-making. Craftsmanship can therefore exist within contemporary fabrication methods by embedding material knowledge, adaptability, and human judgement into the design process, ultimately shaping the built environment.

This research began with the assumption that technology could offer new opportunities for craft, tradition, and product development. Through the investigation, craft and tradition are found to offer much to technology, opportunity, culture, and architectural environments.

8 Monica Obniski, "The Arts and Crafts Movement in America - The Metropolitan Museum of Art," June 1, 2008, https://www.metmuseum.org/essays/the-arts-and-crafts-movement-in-america.

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APPENDICES

A INTERVIEW QUESTIONS

B ADDITIONAL FIELD RESEARCH

C ADDITIONAL FABRICATION DESIGN DEVELOPMENT

APPENDIX A
INTERVIEW QUESTIONS

Methodology

- Walk me through the process of production.
  - What objects/products do you create,
  - What is your method of working, and why do you work this way? What drives this method?
  - Would you choose to work a different way if there was nothing limiting you? Have you faced limitations in your work due to your method of working?
  - How use of much do you contribute the hands, technology (digital creation), and machine in the creation process? Would including the tools you haven't been using add any benefit to your work/products?
  - How did you start using this method of production? Tell me the history of how you got to where you are today.
- What would your definition of "hand craft" in ceramics be?

Adaptability

- I'm focusing on slip casting with my work, so could you see slip casting fitting into your fabrication process in any way? What is the scale of your work? Would the method of production you're working with be able to change scale at all? Do you have the ability to take on larger/smaller orders or larger/smaller products?
  - Do you have experience with slip casting? If so, what are your thoughts on the success of this technique and when do you think it could be used? What are its advantages? Have you seen it done on larger scales?
  - Do you have experience with plaster molds? If so, what are your thoughts on the success of this technique? Have you seen it done on larger scales?
- Are you able to customize orders?
  - How much can be changed in terms of your method of production and the products you produce? o How often do you change/add new products?

Market

- Who is your target market for the products? Who buys these products and why are they the consumer?
  - Where are your pieces used?
- What does your network look like?
  - Are you in contact with other potters, suppliers, manufacturing companies, designers, architects...
  - Is there any other contacts that you would be able to point me to that may be able to contribute to this conversation as well?

Values

- What values do you hold with your product creation?
- Where do you source your materials from? Are you able to share what major resources you require for production
- Do you feel connected with the work you produce in any way?

ETHICS CLEARANCE

UNIVERSITY OF WATERLOO

Notification of Ethics Clearance to Conduct Research with Human Participants

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Principal Investigator: Fiona Lim Tung (School of Architecture)

Student investigator: Candace Haddy (School of Architecture)

File #: 47298

Title: Developing a hybridized methodological approach to terracotta modular screen fabrication

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The Human Research Ethics Board is pleased to inform you this study has been reviewed and given ethics clearance.

Initial Approval Date: 03/31/25 (m/d/y)

University of Waterloo Research Ethics Boards are composed in accordance with, and carry out their functions and operate in a manner consistent with, the institution's guidelines for research with human participants, the Tri-Council Policy Statement for the Ethical Conduct for Research Involving Humans (TCPS2 2022), the Ontario Personal Health Information Protection Act (PHIPA), and all laws and regulations of the province of Ontario (as applicable). Additionally, CREB operates in a manner consistent with the International Conference for Harmonization of Technical Requirements for Pharmaceuticals for Human Use (ICH) Guidance E6(R2): Good Clinical Practice , the International Organization for Standardization of Good Clinical Practices (GCP) as set out by ISO 14155 - Clinical investigation of medical devices for human subjects, Part C, Division 5 of the Food and Drug Regulations, Part 4 of the Natural Health Products Regulations, Part 3 of the Medical Devices Regulations. Both Boards are registered with the U.S. Department of Health and Human Services under the Federal Wide Assurance, FWA00021410, and IRB registration number IRB00002419 (HREB) and IRB00007409 (CREB).

Expiry Date: 04/01/26 (m/d/y)

Multi-year research must be renewed at least once every 12 months unless a more frequent review has otherwise been specified. Studies will only be renewed if the renewal report is received and approved before the expiry date. Failure to submit renewal reports will result in the investigators being notified ethics clearance has been suspended and Research Finance being notified the ethics clearance is no longer valid.

Level of review: Delegated Review

Signed on behalf of the Human Research Ethics Board



APPENDIX B

ADDITIONAL FIELD RESEARCH INFORMATION

CASE STUDY 1: BRYAN HOPKINS

LIMITATIONS

The firing process is a self-imposed limitation for the pure white results that Bryan wants to achieve. If he used an electric kiln, the results would be a blue/grey tint in the white clay.

PRODUCTS

Bryan's work has shifted in design and products over time, with the development of his most recent work beginning with boredom. To make products that would be profitable with little exertion of energy, he began producing cups and vases. The evolution began when he got bored of the simple procedure and decided to cut up the plaster pieces into smaller pieces with no keys. He was inspired by Kayla Stein, a student at Alfred that he met at a craft show in central New York, who didn't use keys in the modular casting system to slide the pieces around during slip casting. The same thing, being bored of this process, led him to test an increase in scale, resulting in bowls.

"The texture in my pieces was introduced when my son was young. He didn't want a cup with two handles, he wanted a cup he could grip that looked like what his parents used. So I added textures for grip into the vessels. This has evolved and developed into the products he makes today; vessels, cups, bowls, and even light fixtures. The light fixtures were inspired by the properties of the clay, being translucent."

Bryan has not tested the extents of scale possible because of his goal of producing household items. He wants his work to be intimately scaled and used commonly. The home and the use of the products inspires a lot of the products he produces.

VALUES OF BUSINESS

Although Bryan Hopkins is doing business with his pieces, his goal is not income. He explains that his wife has a good position making enough income for them to live comfortably, so he has the freedom to do what he would like with his craft. This allows research and innovation to drive his method, creating objects that please him as an artisan rather than something that is guaranteed to make a sale. His boredom and life circumstances brought him to where he is at now, producing homeware and unique affordable objects.

Objects that are accessible to a broader range of individuals over solely art collectors or upper-class citizens is a value Bryan holds in his business structure. Porcelain is a posher product, usually only consumed by upper class individuals, so Bryan strives to break this trend by creating regular household objects such as glassware, dinnerware, or lamps that are priced fairly. Although his mugs are accessible, they remain thin glass with the appearance of being fragile and precious. He likes this because it makes people slow down and contemplate their actions with the object.

He places himself in the buyers' shoes to see the value in his work as well. He notices people gravitate to randomness and uniqueness. People can relate to pieces that visibly involve the human hand, a concept that Bryan relates to the Japanese concept of Wabi and Sabi – finding beauty in imperfection.[1]

VALUES INHERENT TO CLAY

To discover natural clay, Bryan spent some time during the pandemic digging and processing his own clay. He worked with clay from Grand Island and produced some architectural work. This was an important step as a ceramicist for personal learning, but the clay deposit he used didn't contain the natural properties he admired in the New Zealand clay for his current work. For his current work, Bryan mixes his slip using his own slip recipe to achieve very specific goals he's addressed as 'the structure of how work'. This way he can isolate components and experiment with reducing or increasing specific functions. Prior to making his own slip, he imported clay from Australia that contained components from England, Spain, and India. Until this stopped being produced, making his own recipe was never important to him. But this shift in production led Bryan to ethical considerations with acknowledging his carbon footprint.

The clay Bryan used to purchase was shipped wet to the West Coast, theN trucked to New York, so the carbon emissions would include emissions from the boat's and vehicle's fuel use. So when he started making his own clay he tried to use as many local resources as possible. His clay materials are predominantly from the United States, with stains from a company in Canada called Spectrum. The one exception is the clay he gets from New Zealand in powder state, so the same weight being shipped lasts him longer, slightly reducing the carbon footprint. Even the process of mining clay produces a large carbon footprint, but while Bryan can't avoid that, he can be conscious of reducing his footprint where possible.

Finally, Bryan fires at his ceramic studio, which is 60% nuclear, 30% coal, and 10% hydro. If he could fire at home with an electric kiln, he could buy into the hydro and wind grid and fire relatively clean. This is a limitation of his situation, but in the future this is a step Bryan, or other ceramicists using his work, could adopt to make the process even cleaner with sustainable energy sources and low carbon emissions.

CONNECTION WITH ARCHITECTURE

Bryan's work has an innate connection with architecture and Bryan acknowledge this stating that he wasn't initially inspired by architecture, but the resemblance to European Brutalist architecture was remarkable. Louis Kahn's stair and cantilevered details were later inspiration to Bryan, adding wood grain textures into his library. The process of casting concrete in wood formwork is a similar process and final appearance to Bryan's work, just on a larger architectural scale. This led Bryan to the conclusion, "this effect is like someone took my work and made it into a real building, which I would love to see".[2] This connection to architecture already exists and the visual effect and response from customers is very positive, so this statement is encouraging in the success of my thesis, making slip casted screen modules, and I will use the success in experimentation of Bryans work to achieve this.

1 Boyé De Mente, Elements of Japanese Design (n.d.).

2 Hopkins, "Interview Bryan Hopkins," 1."issued":{"date-parts":[["2025",3,24]]},"locator":"1","label":"page"}],"schema":"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}

The studio space Bryan works in is covered in sketches depicting the elevation views and plan view with dimensions of the vessels he creates. He makes a plan before beginning so he can work out his design flaws in 2D before creating an object in 3D that may fail.

Bryan speaks on the opportunity of using slip casting on an architectural scale, highlighting the benefits of this method and material. Slip casting is known for uniformity, so repetition on a mass scale is possible. Fine details are also able to be achieved as the slip goes into every small crevice created by the textures on the plaster molds. The slip material you're working with you have less control over due to the complex properties in clay, but Bryan experiments with chemistry to have more control over the material.

CASE STUDY 2: LUDOWICI

FACTORY PRODUCTION

The process of production is similar for all of their manufacturing processes and products, except slip casting that will be explained in the next section. I will explain the general process of factory production at Ludowici, and when specific about products, I will explain their roof tile production as that is the largest part of their business.
A client can either choose a standard product from their catalogue of products, or they can do a custom tile from a historic tile they're matching. The client chooses the profile and the colour. Hydraulic presses are used for many of the factory's standard roof tiles, with long lasting metal dies for exact replicas. To create these dies, it costs thousands of dollars which is a fee added on to custom profiles. One hydraulic press machine can produce a range of pieces just by changing the die attachment. Once a profile is chosen, eagle view scans of the roof are performed to have a record of the area requiring tile. This way they know the exact quantity of tiles needed. Ludowici works closely with the roofers to confirm the amount of tiles required and possibility of using the profile requested. This allows them to create a quote, adding 5-10% for a breakage buffer that can be kept as attic stock for replacement if needed.

MATERIALS

Fireclay is a sedimentary mudstone that got its name from having the ability to resist high temperatures.[3] One person works outside, using a front-end loader to mix one part to four-part ratio of shale and fireclay. Sometimes recycled clay from jitney bins (their bin system for clay mistakes) will get mixed in as well. Once mixed in the correct ratio, the front-end loader dumps the mix into large bins inside the factory.

The rolling hills in New Lexington, Ohio were carved out during the ice age, depositing all the required minerals for clay in the soil. The entire system uses these rolling hills to their advantage, beginning the process at the top of a hill and using gravity to move clay around the factory.

The mixed clay gets dumped into a hopper that dispenses the required amount mechanically. The raw material is moved by a belt system that transfers it to a grinder. While the raw material passes through the grinder twice, barium carbonate is added and mixed in. Barium Carbonate is a preventative measure for effervescence, the white crystalline deposit comprised of soluble salts that leaves streak marks on the clay body.[4] Ludowici is currently experimenting with adding grog to the mixture to reach a lower consistent amount of shrinkage and preventing cracking when the clay is fired. Currently their pieces shrink 12.5%, but with the right amount of grog, they can consistently and dependently reach 8.5% shrinkage.

The belt then drops the clay mixture into a crusher. The crusher is large stones that break down the rocks in the mixture to form a powder. 16 grit screens allow any material that has reached this powder form to pass through and be sent to the floor for use. The screens contain a magnet that will take out any metal or undesirable materials from the clay before passing through the screen and reaching the floor. This is a cyclical process through the crusher and screens commonly 5 or 6 times before all of the material reaches the powder state.

3 "Mpf_ fireclay," n.d.

4 "Efflorescence," accessed April 25, 2026, https://digitalfire.com/glossary/efflorescence.

There are hoppers that sort and store 30 tons of material each, ready for use. Some of the bins are fed to pug mills to make the raw material into slugs. The slugs will be used for presses, extruded into setting mud for the tiles to sit on, or extruded into thicker pieces for supports to help it keep shape.

TOOLS

The tools used for production are a mix of old and new machinery and technology. The two hydraulic presses, also known as RAM presses are from two different eras of factory production. The old 'A press' has been in use since the 1940's when the factory began full operations again after the war. It is a machine that allows more force, consistency, and time than hand presses can provide. The new 'Merando press' does the same operations as the old machine, but additional technology is added to automate the process of production more and remove the need for human operations. Trimming, scoring, and finishing work can be deciphered from standard deliverables input into the press, and coded operations. The hydraulic extruder is an old mechanized system that has remained the same since the beginning of operation.

The roof scans also make the process more efficient by being able to drone scan the area, slope, and roof hip and ridge conditions, so an exact calculation on amount and angle are provided to the production team. The glaze sprayer is also digitized, spraying glaze in a coded pattern onto the tiles. Some of these process are capable of being fully automated, but it is not worth the investment unless it is a substantial increase in output or reduction in employees required.

Some tiles are sent to the testing room after firing to ensure the warranty on strength and water absorption is validated. The weight of the tile is measured before sitting in water and after sitting in water for 24 hours. A low water absorption is required, with Ludowici consistently under 1%. Then for the breaking strength, they place a tile under a compression system that reads how many pounds per square inch it takes to break a tile. Ludowici is consistently around 550 pounds/sq.in.

LIMITATIONS

The limitations in this large operation still share similar constraints to smaller operations such as Bryan Hopkins' work. The limitation in scale is due to the machinery, tools available, and possible human force. The presses and extrusion die have a scale constraint as the machinery is only fabricated to a certain scale, as well as the belt that carries the clay is limited in width. Large format profiles are challenging because they need the equipment suitable to the size required, causing them to turn down certain projects. If hand pressing is done, the human artisan will need to be able to manipulate the plaster molds and remove the piece after creation with their strength. Then the carts, spray booths, kilns, and belt tracks are scaled to accommodate the maximum size of pieces created, so upscaling beyond what they've created is not feasible. They will accommodate projects if the cost and time frame will profit the company, but even with accommodations, the scale can only be so large due to the machinery, tools, and human force available.

The capacity of the factory is another large constraint. They have a minimum size of project they will take on because of the changeover process and testing required for new

profiles. Then if there's too many orders requiring a certain manufacturing process, they will look into their other tools and techniques available so they can be using all of their operations at the same time. Even with this organization technique, they have a limited amount of methods, machinery, and people available. So new projects will be scheduled out for when machinery becomes available, as they strive for capacity to be consistently at 100%. Currently they can produce 4.5-5 million pieces per year, with an extension to their factory currently being built that will expand the capacity to 7 million pieces per year. This was a business decision as the investment of an estimate of 14 million dollars for structure, cars, additional setters, and outfitting housing 2 more kilns will increase their business and net profit will be greater. Ludowici will challenge certain limitations if their business will be profited with the decision.

The business at Ludowici is successful in how they're currently operating, so they have not invested a lot of time and funding into research and development. For this, the two ceramic engineers, Jeff and Dave, have certain limitations to the extent of innovation they can do. This is the current business model, but similarly to the available machinery, they could expand this department if a profitable project becomes available.

The final limitation is in the advantages and disadvantages of certain ceramic processing techniques. For example, their project 'gate of harmonious interest' required hollow, lightweight ceramic forms because their old ceramic pieces failed due to the assembly required. They were not slip-casted, so the heavy pieces were fastened with mortar where moisture could cause breakage. Machine or hand pressed pieces, extrusion dies and slip casting are all unique processes to eachother and have certain strengths that affect the final form. This is important to keep in mind when Ludowici decides what technique is best to create a project.

MACHINE RAM PRESS

For complex pieces, sections are created on a press mold, then they're stitched together by scoring and slipping the joints by hand. Other times, some post-processing manipulation and finishing need to be performed. Trimming, and adding holes is required for some tiles. Other tiles need to be smoothed out or scored to achieve the correct style and aesthetic.

Ludowici uses old and new presses, alternating based on style of tile and capacity of the machine. They have been using the old press, called the 'A-press', since the 1940's. Their historic tile is still created on this press because of the aesthetic style based on a strong influence of hand production. 17 people are required to be working on this line, as it is a mix of machine and hand processing. The machine extrudes the clay in the pug mill, presses it in a plaster mold, and rotates the ceramic piece to the other side of the machine where someone can remove it from the mold and place it on the line on setting mud to hold the form. There is someone that loads the clay in the pug mill, unloads it, works the slab, trims the pieces, adds holes, and does any finishing work.

The new press, called the 'Merando press', is one of the most efficient lines they have. It can run with only 4 people as tasks have become more automated using machine and digital inputs. They have a loader, quality testers and monitors for the pieces. The results are the exact same, except the hand-made quality with certain imperfections and

uniqueness in scoring or trimming is removed with every piece exactly the same. The speed of production increases, resulting in higher net profit for the company because the capacity of this machine is 30 000 pieces/day. Transferring the pieces, trimming, scoring, and finishing work is now all automated.

Bishops palace has many ram pressed tiles as the entire roof is being redone, only containing decorative roof components that are slip casted. The pitch of the roof constantly changes and there are cones that have graduated tiles. The same shape needs to get slightly smaller and shorter as it goes up the cone. It is not standard how much smaller as it is based on the circumference of the cone, which is information achieved through scanning the roof.

Beginning with the Plaster molds, the craftsmen take the detailed drawings of the roof pitches and make plaster molds in mold boxes that fit on the presses. When less copies of the same mold are needed and changeovers occur frequently, plaster is a lot more efficient in terms of creation time and cost for production than metal molds. When the ceramic shapes are all pressed, the plaster mold can be broken out of the box and replaced with the next shape.

To make the plaster mold, the craftsmen form plasticine acting as the positive final form and cast it into plaster. More modernly and because they invested in this tool for slip casting, they will model the positive digitally and 3D plastic print it for plaster mold casting.

Then they create a saddle, which is a mock-up of the roof made in their workshop that is the exact pitch of the roof to be able to test the fit of the final tiles.

HAND PRESS

For hand pressing, they create plaster molds. The clay is placed in the plaster mold and a jackhammer pounds it down tight to the plaster. When the desired thickness its achieved, the clay is smoothed out and packed with hands, then a needle with a desired depth is placed in the clay to ensure it is evenly the correct thickness.

For custom roofs where the pitch changes constantly, a sheet is produced that states the exact pitch at certain locations. The craftsmen use cut blocks made of plaster to set pressed tiles on to score and slip them together to specific angles. The shipping document identifies the pattern and matching pieces so the roofers can perfectly place the tiles.

Bishops palace also contains some hand pressed pieces such as the ball under the hippocampus feet. They could be slip casted, but due to availability of spaces they are testing hand pressing as an alternative method. This contains an extra step using hand processing to score and slip the two sides together and smoothing it out to create a seamless sphere.

EXTRUSION

The extruded tiles are flat forms with a profile. A seamless extruded chain of clay is pushed through the die with high pressure forced air. The clay is hydraulically cut, then skilled craftsmen correct any imperfections, post process with holes if required, and stitch pieces together if required.

These pieces are the least expensive as minimal work is required by hand after the machine processes the tiles completely.

DRYING

After the pieces are removed from the plaster molds, they are moved to carts on drying tracks and moved to the hot room. The hot room maintains temperatures of 90-130 degrees Fahrenheit. The shrinkage is 13¼% for slip-casted objects, so the size difference between wet and dry pieces looks substantial. The pieces take 36 hours to dry completely as there was more water retained in the slip than packed clay.

FIRING

The pieces are always fired once, with glazes already on the greenware for efficiency. The tunnel natural gas kilns are constantly running as there is always carts in queue to be fired. The kiln in 350 feet long by 30 feet wide and can fire 7 million pieces per year. The tunnel kiln reaches 2200 degrees Fahrenheit, corresponding to cone 6. 24 hours later, the pieces are removed from the backside of the kiln. The water acts as an insulator, heating up and evaporating, then you can control the air flow movement.

FACTORY PRODUCTS

Ludowici began as a terracotta roof tile factory. They now create roof tiles, roof accessories, ceramic flooring tiles, and wall cladding. These are all created with either extrusion die for flat pieces like slate tiles, hydraulic press mold for pieces with curvature such as the barrel tiles, or by hand pressing for most custom roofs that don't have a standard form used throughout the entire project. Ludowici's floor tiles are standard dimensions, but can range in shape.

When the slip-casting facility is not required for method-specific projects, it is used to produce other ornamental details are typically hand-pressed and manually stitched together. Because the same plaster molds can be used for both press and slip-casting, the choice is determined by the design. Slip casting extends the mold's lifespan but requires longer drying and release times before the piece can be removed.

VALUES INHERENT TO CLAY

Ludowici's perspective of innovative materials for the future is sustainable materials used in architecture. Their business model is founded on the use of a natural resource and promoting a product that will last a lifetime. And even after 75+ years of use, there is an afterlife with reuse of the material.

The terracotta tiles are predominantly produced using a single, local, natural source. Their company began with this value as a byproduct of using clay as their only material in production and have maintained this value in parallel with maintaining the production process they began with. They produce all their products without common clay additives such as petroleum-based materials, sand or silica, cementitious materials, unproven synthetic materials, or surface sealers.[5]

5 "About Ludowici | Terracotta Tile | Ludowici Roof Tile."

VALUES OF BUSINESS

This job is also unique because the factory is in the middle of New Lexington, Ohio, a small village in Southeastern Ohio with a population of approximately 4400 people. The workers are rooted in the history of the town, many of which are related or connected to each other and the community. The factory supports this community and the workers support each other.

Due to the length of time and effort put into each project and piece, they maintain a higher product cost than competing roof products. The factory tour also helps explain why the cost is higher to clients, but the fact that their products are good quality, durable and long lasting with a warranty, sustainable with a low carbon footprint and made of natural materials, the cost is self explanatory and justified. The upfront cost is higher, but the cost of maintenance and lifetime of product makes it worth the investment.

The value of sustainability is portrayed in their LEED and ISO compliance certifications, which larger companies greatly value in their product sourcing. The material that takes up such a large portion of their buildings represent their company and their companies' values.

Although the production process has remained the same, upon enlightenment of environmental impacts due to business decisions, they have evolved or strictly maintained certain methods. They now prioritize renewable energy, water recycling, and waste reduction in their manufacturing process. Rather than using coal for their kilns, they decided to use natural gas as it is the cleanest way to fire ceramics. They also no longer use toxic chemicals such as cadmium in their glaze recipes.

Throughout the production process, when the clay is in greenware state, they save and reuse any pieces that have errors by reprocessing the clay from the beginning of the cycle back into its powder form. Once the clay has been fired, if there are errors they will use jitney bins as the glazed pieces can't be reprocessed in the production line. The jitney bins will be reused for French drains, driveways, exterior pathways or gardening, or aggregators for strong road bases. When clay roofs are replaced, the old tiles can be recycles in the same way. If there are small piles of leftover terracotta tiles, they'll sell off small batches for less money or donate tiles so they can all be used.

The values inherent to slip casting attracted Ludowici to evolve their production processes to incorporate this method as well. Slip casting produces a hollow, lightweight object that maintains a great deal of detail. These values can't be achieved in other methods of fabrication to the same extent or quality in an efficient manor, so for projects such as Gate of Harmonious Interest it was worth evolving. The past detailed objects on the gate such as the bodies of the phoenix, tiger, and lion had broken off pieces because water had deteriorated it and the weight was too heavy. The new slip casted objects are lightweight, hollow, and fastened together with bolts so water damage won't occur. There wasn't an alternative method to complete this project with the specific requirements of weight and detail, and there will be similar projects that require these specific properties inherent to this method.

INNOVATION

Over the years, their company has evolved by adding new gas-fired kilns in 1960 rather than the beehive circular kilns and the roof system that moved terracotta tiles through smokestacks for coal firing. These were sustainably conscious decision, but also required updates in their tools due to inefficiency. Their material refinement process is 90% machine operated with equipment from the 1940's, but it still works perfect for their needs. They have put time and money into maintenance and additions of stones, belts, and cables, but there is no benefit in updating equipment because the ancient tools still work.

If the demand for terracotta roof tiles in the United States went up, they would invest in more machine and technology for automation. Terracotta roof tiles in the US is 2% of the roofing market, so although they are one of only three companies that produce it, the demand is not as high as it used to be in the US. As a comparison, in Europe terracotta roof tiles make up 80% of the roofing market, so their production process is for greater demand. This means two things; they are fully automated, but they also don't have the ability to do custom work.

New technology and machinery they have considered adopting is a CNC machine and 3D clay deposition modeller. In Europe, they produce plaster mold boxes for lots of changes in design by layering plaster on top of existing plaster and using a CNC to create the new design rather than breaking out the plaster each time. This would save Ludowici time and material, but it is a large upfront cost to initially change this process. They would be a company that would adopt new machinery and technology for experimentation if cost and market requests weren't factors.

CASE STUDY 3: JOSHUA STEIN

He also taught at the California College of the Arts, Cornell University, SCI-Arc, Milwaukee Institute of Art and Design, and currently at Woodbury University, with a passion for challenging the thought processes of new architects. His education was in architecture at the University of California Los Angeles where he worked predominantly with digital fabrication.

PROJECTS

SLIP SCREEN

The design projects, 'Upscaling – In Foam Falls Function' and 'Tectonic Horizons' manifested in Stein's Slip Screen project. His project is explained as, "a component-based skin system designed to integrate historic glazed terra-cotta tile façade systems of the late 1800's with parametric performance-based, digitally fabricated slip-cast modules".[6] Stein designs a slip screen system for architectural application because of the advantages of the clay material and form based on slip-casting process of fabrication such as evaporative cooling with a porous module, trombe wall ability with closed modules, visual perforation or shading, and ornamental qualities. To imagine the entire assembly of these modular units on the façade, a digital software created the precise forms required for the plaster molds. Stein then used the three-axis router to carve directly into the plaster molds, eliminating the step of creating an original positive form.

This was his largest scale of slip-casted forms for architectural application. He has proven for this application to be possible and profitable, but due to the range of different modules required and complete this slip screen, mass production is not possible, and production of large quantities Is a time-consuming process.

VALUES INHERENT TO CLAY

Clay is a complex, stochastic material, which is what intrigued Joshua to experiment with clay rather than other materials. The complex properties of clay is what Joshua predicts intimidated architects that were interested in digital fabrication upon its inception. Joshua states, "they were scared of all the outside factors that would ruin the ease of translation or manifestation of what we have on our screen with what we can get in our shop".[7]

Clays properties such as its ability to take on forms, water absorption, state and size based on temperature, low permeability and ability to withstand extreme temperatures create challenge upon manipulation for mass duplication but are desirable properties for architectural application with freedom in design possibilities, external use in weather, and thermal strengths Joshua highlights in his slip screen project.[8]

6 "Slip Screen - RadicalCraft," accessed April 9, 2026, https://radical-craft.com/Slip-Screen.

7 Stein, "Interview Joshua Stein," 10."issued":{"date-parts":[["2025",7,25]]},"locator":"10","label":"page"}],"schema":"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}

8 Nyle C. Brady and Ray R. Weil, The Nature and Properties of Soils, Fifteenth edition, global edition, Pearson Global Edition (Pearson, 2016), 332.

CASE STUDY 4: THE TOILET

PRODUCTION

The mixture passes through industrial sieves to separate the larger particles from the liquid clay before it's stored. The liquid clay is stored in tanks until it is ready to be used. When they're ready to make a toilet, the clay is transported to the molding machines using pipelines.

PRODUCTS

The large factories produce solely toilets, but they aren't in competition with thousands of competing operations, so they are able to make a good profit on one product. Their toilet lines all range in style resulting in the need for a variety of molds produced and larger facility to house the various molds. Because there are so many steps involved in production, the facility is spread out over an area averaging 200 000 square feet for larger production facilities such as TOTO or Kohler.[9] To be specific, TOTO's new factory in the United States is one of the larger operations that spreads 363,393 square feet and produces 300 000 toilets annually in that facility alone. JOMOO's factory in comparison produces 600 000 toilets annually due to a larger facility and their digitally operated 5G cloud manufacturing center that operates and oversees their entire operation.[10]

9 "Toto Opens New Toilet Factory in Georgia | ASSEMBLY."

10 JOMOO Kitchen & Bath, How Are Toilets Made?

APPENDIX C

ADDITIONAL FABRICATION DESIGN DEVELOPMENT

DESIGN 1 – KNOWLEDGE HELD BY CRAFTSPERSON

1) A negative mold of a found objects pattern is created by pressing a slab of clay into the positive texture. The clay slab containing the desired pattern is laid flat and bisque fired in a kiln so this pattern can be re-used.
2) Plasticine is used to press into the ceramic pattern and represent the positive form.
3) The plasticine slab is molded around a form or laid flat to take the desired form for the plaster mold. Plasticine is used so that the slab containing the pattern can take any shape, then be re-used for another plaster mold without adhering to the plaster material.
4) Wood Coddle boards are used to create a frame around the plaster mold.
5) Plaster is mixed and poured to cover the pattern and fill the box void created.

   which allow the texture to be replicated while the form can be adapted for different mold configurations.

   PLASTER MIXING DIRECTIONS AND RATIOS

   Design 1 plaster molds took 72 hours to dry fully before being able to slip cast with them.

6) After plaster has set, the plaster piece is removed from the mold framing and the plasticine is released from the plaster.
7) The plaster pattern can be divided and cut into smaller pieces.
   - There was no set dimensions or planned pattern behind the decision to divide the plaster piece. The dimensions were influenced by the size of the final form and number of varying patterns I chose to place in the screen.

*The process from step 1-6 is repeated for any amount of patterns. The plaster blocks ranging from all different patterns and dimensions are used in a single screen.

8) Plaster pieces of varying dimensions are assembled to create a rectangle. The base of the plaster blocks is a plaster slab so if there are any cracks or seams, the base will stop the slip from escaping the assembly. Plaster coddle boards are used to frame the edges of the plaster pattern assembly.
9) Slip is poured to fully cover the plaster pattern pieces.

   Wait time for slip before pouring it out:

   - Test 1; 15 minutes before draining.
     Results; unsuccessful,

   - Test 3; 20 minutes before draining.
     Results; unsuccessful.

   - Test 3; 30 minutes before draining.
     Results; Successful, wall thickness ¼”

   - Test 4; 20 minutes before draining.
     Results; Successful. Wall thickness 3/16”. Previous example had unstable plaster mold assembly.

   - Test 5; 15 minutes before draining. Previous example had unstable plaster mold assembly.
     Results; Unsuccessful.

Remaining tests using test 4 results, waiting 20 minutes before draining for 3/16” wall thickness.

10) The mold is flipped over to pour the slip out. As the mold is draining, it is rotated so drip marks aren’t running along the pieces.
11) Once the clay is leather-hard and can maintain its form, the plaster mold is removed.

    After testing, the successful removal time from the molds was after 1hr, but piece is still very malleable. Any longer and cracking occurs.

    The clay screen is braced to dry fully over a few days. The slip casted screen is thin, so drying with intermittent plastic covering to control the process will not take as long as pieces created using other methods of ceramic fabrication.

12) Clean up of piece with hand tools. Clean up of the path the slip took when it was poured out.
13) Once fully dried, the pieces are fired.
    Bisque fired at cone 06 in an electric kiln. No glazing required.
14) The fired pieces are assembled with a base so they can stand up.

*If this sequence wasn’t used of positive to negative pattern, the final product would be a negative print of the pattern rather than identically replicating the actual objects pattern.

DESIGN 2 – KNOWLEDGE HELD BY CRAFTSPERSON AND DIGITAL INFORMATION

1) Design is 3D-modelled and iterated in Rhino 3D software. The modular design is tested as an entire assembly within this software.
2) Design is 3D plastic printed at the same scale it was modelled in. After the piece is 3D plastic printed, it is sanded slightly so the lines of the printed layers aren't shown in the plaster mold.
3) The number and arrangement of the plaster mould sections are established after the design is complete, with parting lines determined by the location of overhangs. To allow the plastic prototype to be removed once the plaster has set, this geometry requires a six-piece mould.
   *For steps on how the plaster was mixed, refer to Design 1; Design step 5.

   a) The 3D plastic form is divided by marker lines into 6 sections. These sections are divided based on where a plaster form could be removed from the form without catch-points upon removal.
   b) A plasticine wall is built along the separation line, so only one section of the 3D form is exposed in the mold. Left one inch of tolerance around the form to pour the plaster into and have thickness to the mold. Created a semi-circle in the plasticine to form one half of a key so the plaster mold will always assemble in the same position.
   c) Pour the plaster and let it fully dry before creating the next section of the plaster mold.
   d) To prevent the plaster parts from bonding to eachother, use Vaseline as a mold release agent on the exposed area of plaster.
   e) Create a new wall with plasticine within the mold form to only allow one isolated area of the form to be casted.
   f) This plaster pour will fill in the positive semi-circle key hole created. Ensure all faces of the plaster mold have keys created.
   g) Repeat these steps until all sections of the plaster mold are poured. One section should have a hole for the slip to be poured and drained from, created using a plasticine tube.
   h) After all the plaster mold pieces are created, the 3D plastic form is removed from the center and irrelevant to any further steps in the process.

Time before plaster removal; Design 2 plaster molds took 72 hours each to dry fully before being able to slip cast with them.

4) The plaster mold is assembled and secured together using elastic bands.
5) Slip is poured into the plaster mold hole.

   Wait time for slip before pouring it out:

   - Test 1; 30 minutes before draining.
     Results; Successful, wall thickness ¼"

   - Test 2; 20 minutes before draining.
     Results; Successful, wall thickness 3/16"

   - Test 3; 15 minutes before draining.
     Results; unsuccessful.

Remaining tests using test 2 results, waiting 20 minutes before draining for 3/16" wall thickness.

The mold is flipped over to pour the slip out. As the mold is draining, it is rotated so slip isn't stored in the corners and edges of the mold.

6) Once the clay is leather-hard and can maintain its form, the plaster mold is removed.
   After many tests, the successful removal time from the molds was after 1hr45mins minimum.
   The pieces were smoothed with a sponge and trimmed on seams with hand tools. This method required a pattern of module connections, so every piece had one cylinder cut off to create a hold where the piece below would be inserted.
7) Once fully dried, the pieces are fired.
   Bisque fired at cone 06 in an electric kiln. Glazed with clear glaze. Fired to vitrification at cone 6.
8) The fired pieces are assembled in a frame, using the ceramic modules to interlock.

DESIGN 3 - KNOWLEDGE HELD BY DIGITAL INFORMATION

1) Design is 3D modelled and iterated in Rhino 3D software. The modular design is tested as an entire assembly within this software.
2) Wood mold boxes are created to pour plaster blocks. The design was created for a two-part mold (no undercuts with a 2-part mold), so each half of module needs to be accounted for in dimensions of plaster blocks, including tolerance on all sides.
   To save material, I pre-roughed my plaster blocks with forms where I knew the CNC router would have to remove material anyways, so too much plaster wasn't used.

   For steps on how the plaster was mixed, refer to Design 1; Design step 5.

   Plaster mold 1; 1.7lbs water, 2.43lbs plaster.
   Plaster mold 2; 3.5lbs water, 5.14lbs plaster.

3) Time before plaster removal was discovered using tests. The desired level of dryness is the state between too wet where the wet plaster is getting in the machining tools, on the spoilboard, or around the room, and too dry where the plaster is creating a dust that covers equipment and can get in the machine operators' lungs. The tests were performed on the CNC with the plaster blocks:

   a) Cut after 72 hours.
      Results; too wet. Liquid forming as cutting is occurring. These pieces are very thick plaster blocks, so more time is required.

   b) Cut after 166 hours.
      Results; Top layers are too dry, bottom layers are too wet. Because this piece is so large, there is not an even dry as the CNC cuts through the piece. For best results, the CNC operations can occur in stages with drying time between.

4) Once the plaster block was dry to the correct level for cutting on the CNC, a smaller frame replaced the tall edge boards for the plaster blocks so the CNC could cut down the block, but it would still be held tightly in place.
5) The toolpath for the CNC is created and tool type, dimensions, end condition, length, tolerance, path, and speed are all set.
   Stock material is set in RhinoCAM to match the plaster block dimensions. Toolpath was the same for both sides of plaster mold, but stock dimensions and cut surfaces were different.

   TYPE 1 toolpath settings
   Entire operation time; Part 1 - 1hr:23mins. Part 2 - 1hr:3mins.
   Foundational settings were set up in RhinoCAM. The variables that changed based on design type were the tool, cut region, and stepover distance of the tool based on the percentage of the tool diameter.

ROUGHING PASS
Region; Entire surface.
Tool; Foam Ball mill ½" Long
Stepover; 75%
*Getting rid of material.

FINISHING PASS 1
Region; outer faces (plaster meeting plaster).
Tool; Foam Ball mill ½" Long
Stepover; 10%
*Last pass to make the plaster meeting faces smooth so they meet in a tight fit.

FINISHING PASS 2
Region; Inner faces (form shape)
Tool; Foam Ball mill ½" Long
Stepover; 70%
*Tool and stepover create a design in form. Large tool bit and large stepover will leave big ridges.

TYPE 2 toolpath settings
Entire operation time; Part 1 - 7mins. Part 2 - 5mins.

FINISHING PASS
Region; Inner faces (form shape)
Tool; Foam Ball mill ¼" Long
Stepover; 50%
*Tool and stepover create a design in form. Small tool bit and smaller stepover will leave small ridges.

TYPE 3 toolpath settings
Entire operation time; Part 1 - 42mins. Part 2 - 38mins.

FINISHING PASS
Region; Inner faces (form shape)
Tool; Foam Flat mill ¼" Long
Stepover; 10%

*Tool and stepover create a design in form. Flat tool bit and small stepover will leave smooth surface. Minor hand smoothing in post-processing to finely smooth form required as curved surfaces leave toolpath.

6) The blocks were each placed on the CNC and separate operations run the script from RhinoCAM to cut the desired design in the corresponding block.

7) After being cut, the plaster blocks are cleaned up using pressurized air and left to dry fully.
8) Once fully dry, the two sides of the plaster mold are assembled and fastened together with a rubber band and clamps for extra strength with the larger scale.
9) Slip is poured into the plaster mold hole.

TYPE 1 Wait time for slip before pouring it out:

a) Test 1; 13 minutes before draining, 1 hour before opening.
Results; **Unsuccessful**, wall thickness 1/8"
-Clay is too wet when released from the mold. Plaster mold is too wet still.
-A release agent is needed between the plaster pieces and between the clay and plaster for the form.
-slip is pressing mold apart, so a tighter clamp is required

b) Test 2; 10 minutes before draining, 4 hours before opening.
Results; **Unsuccessful.**
-Cracks when released from mold as it is stuck to the sides. The plaster mold CNC pattern left tall, sharp edges that cuts through the clay rather than forming an even wall. These edges need to be sanded down.

c) Test 3; 15 minutes before draining, 12 hours before opening.
Results; **Successful!**
-Cracking when removed from mold.

d) Test 4; 15 minutes before draining, 9 hours before opening.
Results; **Successful**
-Cracking after removal because of gravity weight on leather-hard piece.

e) Test 5; 20 minutes before draining, 13 hours before opening.
Results; **Successful**. wall thickness 1/4"
-Not as much cracking. Thicker walls, more drying time, and structure to hold form while drying reduces the cracking.

f) Test 6; 12 minutes before draining, 10 hours before opening.
Results; **Successful.**
-Bad Cracking.

*Test 5 was the most successful, so all following tests were done using test 5 times.

TYPE 2 Wait time for slip before pouring it out:

a) Test 1; 20 minutes before draining, 12 hours before opening.
Results; **Unsuccessful.**
-Plaster mold is too wet still. Clay wall is not as thick because the mold was too wet, so water wasn't absorbed into plaster as well. Wait 48 hours before re-pouring.
-Edges are directly 90 degrees, so catching slightly with CNC path. Edges are sanded, leaving the connection point smooth with no pattern.

b) Test 2; 20 minutes before draining, 12 hours before opening.
Results; **Successful!**

*Plaster halves aren't lined up correctly because alignment was off when re-cutting on CNC. There is no way to correct this.

*Test 2 was the most successful, so all following tests were done using test 2 times.

TYPE 3 Wait time for slip before pouring it out:

a) Test 1; 20 minutes before draining, 12 hours before opening.
Results; **Successful!**
-More imperfections were seen on the surface from air bubbles in the mold and release agents clumps because the surface is smooth. The pattern doesn't hide anything.

*Test 1 was successful, so all following tests were done using test 1 times.

The mold is too large to flip, so a hole is in the top for pouring the slip and plugged the bottom for draining. As the mold is draining, it is rotated so slip isn't stored in the edges of the mold.

10) Once the clay is leather-hard and can maintain its form, the plaster mold is removed.
Hand-tool cleanup minimally required. Seams left edge of clay, so the edge was trimmed smooth with knife and sponge.

*Once you obtain enough pieces slip casted with your toolpath, re-cut the mold on the CNC with a new toolpath (step 4-9). To do this, re-wet the mold by soaking it for 15 minutes and place the plaster block back on the CNC at the same origin point. The only change to the toolpath script should be the stepover amount and choice of tool.

11) Once fully dried, the pieces are fired.
Bisque fired at cone 06 in an electric kiln. No glaze.
12) The fired pieces are assembled in a frame, using horizontal steel rods to support modules through holes created through process.