Performative Aesthetics: An Exploration into DLT-Ceramic Composite Wall Assemblies

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Keywords: Material Agency, Robotic Construction Technologies, Computation, Optimization

The paper presents the early development of a novel mass timber-ceramic wall assembly that speaks to the importance of sustainable, performative and aesthetic potentials within the built environment. The work seeks to broaden the extensive body of research conducted on the robotic additive manufacturing of customized ceramic clay printing for large scale construction, exploring the possibilities of clay for its performative and formal capacity. It employs the use of an industrial robotic platform not as a device for automation, but for its ability to produce unique elements through a craft-based methodology in search of variability and specificity. Recognizing the limitation of ceramics as a load bearing material, it seeks to uncover its potential when combined with mass timber. As a result, dowel-laminated timber (DLT) is explored for its numerous advantages including structural efficiency, low toxic manufacturing processes, its inherent renewability and speed of construction. With the renewed interest in mass timber structures in recent years, we are nonetheless confronted with the realities of this unique natural material. Being both anisotropic and hygroscopic, wood's inherent moisture-storage capacity makes it susceptible to water and air infiltration, vapor migration and condensation (Gagnon et al. 2013). Whether it be dowel-laminated or cross-laminated, timber's sensitivity to moisture and its vulnerability to the elements renders itself unsuitable as a cladding application. Responding to this need, traditional cladding solutions for mass timber assemblies generally do not offer sustainable alternatives nor do they provide heightened aesthetic interest. As a result, the paper explores the production of material effects that go beyond superficiality by addressing the shortcomings of exposed mass timber wall assemblies through the development of a protective ceramic ventilated façade system that combines ornamental effects with performative criteria.

INTRODUCTION

Modern and contemporary architecture over the last decade has focused exclusively on technique and tools, with emphasis placed on "process" and thus removing itself from the fundamental task to create meaningful human experience. Architect Mark Foster Gage argues that the discipline of architecture has gone far down the road of pragmatism and practicality where the focus on aspects such as programme, context and sustainability has become so great as to leave little space for truly inspirational creativity (Gage 2016). He argues that despite current technology opening up possibilities for unprecedented bold and awe inspiring additions to the built environment, modern architecture continues to perpetuate the techno mantra of design and thus sits mute in a world of technologically enabled explosive possibilities.

The Roman architect Vitruvius (80–70 BC) highlighted beauty as one of three core dimensions of architectural design. His seminal Vitruvian triad illustrated that a building must be strong and structurally stable "firmitas", meet the functional needs of its occupants "utilitas", and appeal to their aesthetic sensibilities "venustas. However, with the arrival of modernity, many would argue that Vitruvian's "venustas" dimension has been long forgotten, where the focus in current architectural practice has shifted, favouring functional elements such as cost, performance, efficiency, building information management (BIM) and all other technical considerations.

Combining traditional materials with advanced manufacturing processes, the following research draws inspiration from aesthetic speculation in an attempt to reconcile formal explorations with sustainable and performative outcomes. It embraces technological advancements, beyond its utilitarian rewards, to brazenly explore the potential of aesthetics through the development of performance-driven surface qualities that address key environmental criteria, all the while producing enhanced architectural spaces.

BACKGROUND

Dowel Laminated Timber (DLT) and Mass Timber

Dowel Laminated Timber is a mass timber product that speaks to the potential of timber construction as a renewable, sustainable and high-performing building material. DLT consists of solid wood panels utilizing dowels to friction fit pre-milled boards, requiring no glue or metal fasteners. It utilizes standard dimensional lumber which is more efficient to procure compared to laminated stock and has low manufacturing costs due to the automated production cycle that requires no glue or nails. Compared to cross-laminated timber (CLT), it has greater structural efficiency for one-way spans due the directionality of the fibers that extend across the primary direction. The elimination of the adhesives in DLT also reduces its overall environmental impact. Due to its prefabricated assemblies, DLT significantly reduces site installation time while the manufacturing and production of panels can occur throughout the entire year thus resulting in significant socio-economic benefits to regions where construction seasons are short.

Despite its multiple performative and sustainable benefits, DLT panels require protection nonetheless from the external environment. The choice of cladding material has important implications for the energy performance and durability of the overall structure. According to the US edition of the CLT Handbook, key performance requirements for the enclosure of mass timber assemblies include the prevention of water intrusion and the control of heat flow, air flow, and moisture flow. This can be accomplished by using drained wall systems and air barriers, placing rigid insulation to the exterior of the panels and preventing moisture and water penetration (Gagnon et al. 2013). Typical cladding systems for mass timber panels include vinyl and wood siding, cement board, stucco and brick. Although the performative gains vary depending on the selected system, they are limited in terms of their formal potential and aesthetic sensibility. The majority of CLT cladding alternatives consist of a siding material that typical have high embodied energy and do not embrace or compliment the natural qualities and carbon storing capabilities of wood. The exploration into clay bodies and the potential of integrating a ceramic cladding system to an existing mass timber structure, one that is both performative and intricate, provides a novel and exciting research trajectory yet to be explored.

Ceramics/Ventilated Façades

The use and transformation of clay into a ceramic material dates back 29000 to 25000 BC. Beginning in 1840, this material, better known as terra cotta, was incorporated into architectural façades and proved to be a useful material in protecting 19th century iron and steel structures from fire (Bechthold et al. 2015). By the 20th century, architects such as Frank Lloyd Wright and Louis Sullivan employed ceramic elements on a multitude of projects utilizing its potential as a rainscreen system capable of protecting the assembly from the elements. In 1984, the first ceramic ventilated façade was developed by Thomas Herzog in Munich and was further advanced by Renzo Piano on a series of projects in Paris that utilized a ventilated terra cotta façade system (Bechthold et al. 2015).

A ventilated façade is a system that utilizes a ventilated chamber between the insulation and outer screen resulting in a continuous convection current that rises from the bottom of the assembly. The system has the ability to improve the energy efficiency of a building by improving thermal comfort, leading to a reduction in heating and cooling costs while both improving the acoustic performance of the façade and preserving the integrity of the structure. Typical ceramic ventilated façades consist of a substrate wall, insulation panels, ceramic cladding and a metal substructure. Despite the level of technological progress resulting from state of the art ceramic cladding systems, their implementation in mass timber construction is nonexistent or uncommon at best. However, wood's unique characteristics, it's inherent moisture-storage capacity and resulting predisposition to mold growth, decay, and dimensional changes provides an opportunity to explore the potential of a novel wall assembly that incorporates the benefits of mass timber construction with ceramics. The development of a ceramic ventilated façade system specific to mass timber assemblies could provide the required protection where it is most needed, in the prevention of moisture, water penetration and condensation that occurs throughout the lifecycle of a hygroscopic living material such as wood.

Clay/Robotic Fabrication

Working with clay is an age-old practice, one in which the artisan works closely with the material, getting to know its properties and capabilities in an intimate manner. The invention of the pottery wheel around 3000 BC introduced technology as a means to bring fourth greater possibilities in forming clay. Through a traditional understanding of the material properties, merged with an in-depth knowledge of 3D digital processes and tools, an extensive body of research has emerged that focuses on ceramic-based 3D printing innovation. Through the work of Ron Rael and Virginia San Fratello of Emerging objects (Rael, San Fratello 2018), Jenny Sabin of Sabin Design Lab (Sabin et al. 2014), Martin Bechthold (Bechthold 2014) or the inspiring work coming from the IAAC (Dubor et al. 2018), a new understanding of architectural ceramics is brought forward revealing the unhindered potential for design explorations.

The development of architectural ceramics can be performed though a variety of different manufacturing processes. They follow a similar sequence requiring; the creation of the clay body, shaping, drying, firing and post-processing (Bechthold et al. 2015). Due to the gained efficiencies and cost reduction purposes, common fabrication techniques include extrusion, slip casting and plastic-pressing, all of which involve the use of dies and molds in order to mass produce a high-volume of identical, repetitive units. The use of robotic technologies within the body of this research provides an opportunity to depart from automated fabrication processes to a craft-inspired approach capable of producing individually unique custom units. This framework provides numerous advantages within the context of this research. Each ceramic façade module can be designed separately, where surface elements can be manipulated and optimized for performative criteria (e.g. thermal, airflow, etc.) according to its exact position in relation to environmental data. Secondly, within the complete scope of a project, modules that intersect with openings such as door frames, windows, etc. can be adapted and produced without necessitating the development of custom molds which are prohibitive in terms of cost. Corner conditions can also be easily resolved where modules can be 3D printed in their entirety to accommodate any angle.

METHODS

DLT Fabrication

The research begins with the development of a DLT panel (Figure 1). The material used in this research was standard Spruce-Pine-Fir (SPF) dimensional lumber reclaimed from several design-build projects conducted in the previous year. Although DLT can accommodate panels up to 12’ wide and 60’ long using 6” to 12” boards that are structurally finger jointed, the final prototype represented a sectional moment of a larger DLT panel measuring 3’ x 2’ using standard 2x4 material. Visual defects were marked and cut out prior to running the boards through a planer/jointer ensuring consistency in board thickness. The lamellas were clamped and pressed where ¾” diameter holes were drilled into the wide face of the board allowing for the dowels to be inserted. As the dryer dowels accumulate moisture with the surrounding lumber, they expand to create a secure friction fit connection with the lamellas.

One advantage of DLT is the ability to incorporate surface profiles in the boards allowing for the integration of acoustic materials or service conduits. This provided an opportunity to integrate a surface profile that would act as the connection detail to the ceramic 3D printed module. The intent was to develop a system that would eliminate the need for any mechanical fasteners (consistent with the production of DLT), it would lock the ceramic model in place and would allow for the placement of a continuous air barrier between the DLT panel and ceramic module. The inclusion of an air barrier membrane would prevent air from escaping through the DLT wall assembly and compensate for any gaps that could potentially exist between the boards.

Robotic Clay Extrusion

Several clay extruders were employed to facilitate the research (Figure 2). Earlier versions utilized a worm gearbox with a high torque stepper motor to extrude the material through a 3D printed nozzle. The ball screw driven extruder only allowed for continuous extrusion and provided unreliable results due to an inability to mitigate for material inconsistencies. With the emphasis placed on controllability and scalability to assist in the development of intricate larger assemblies, a second cavity type extruder was developed using a dual system of pressurized air and auger to move the clay forward through the print nozzle. The benefits of the auger system included the ability to accurately manage the flow of material and provided enhanced print quality however limitations in size and scale still remained. Accordingly, a third extruder was acquired (LDM WASP extruder) and retrofitted to the Kuka robot which provided greater torque and extrusion control translating to greater predictability of the printed artifacts.

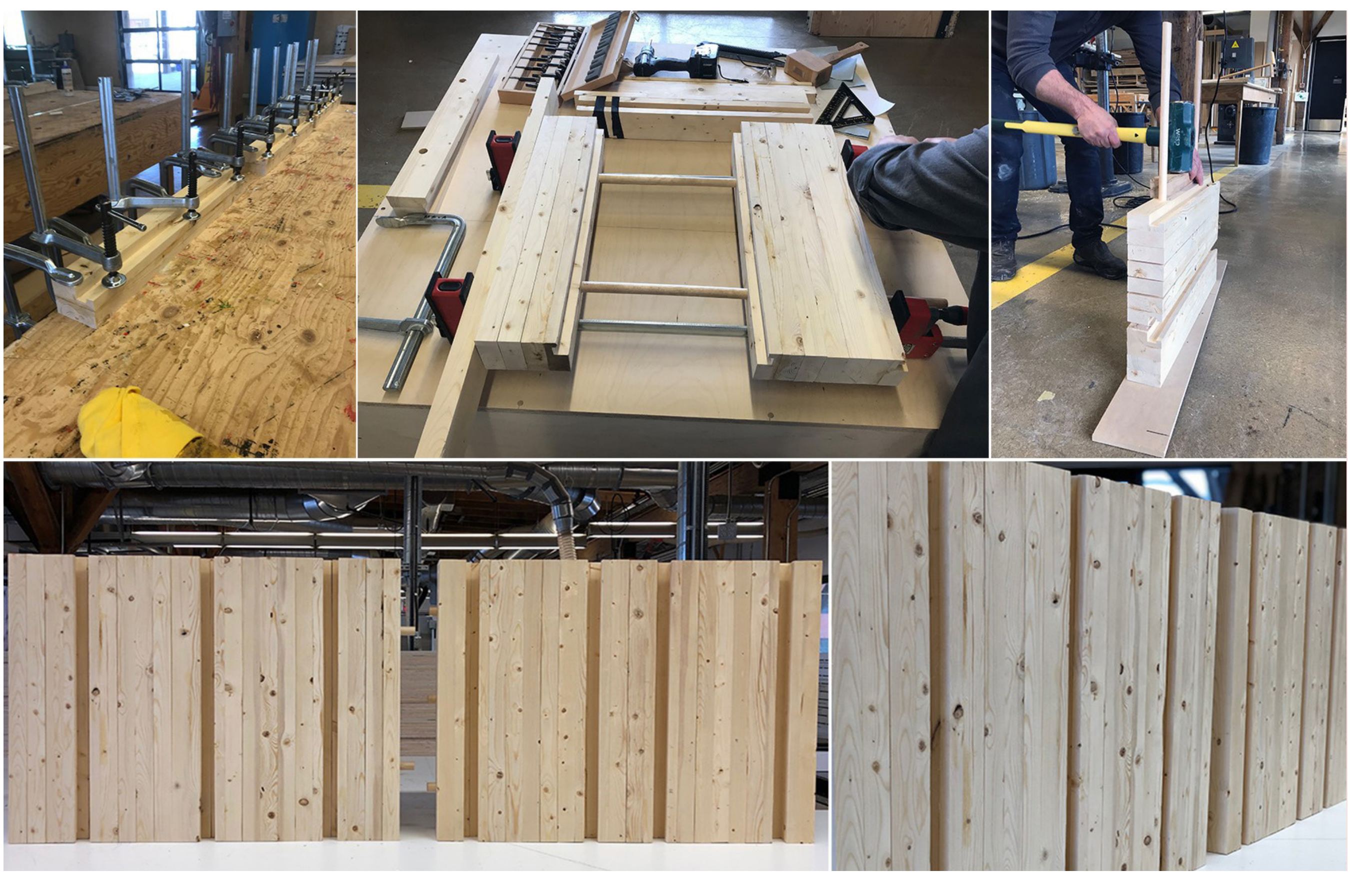

Figure 1. DLT Panel Fabrication Process and Final Prefabricated DLT Panel. Image by author.

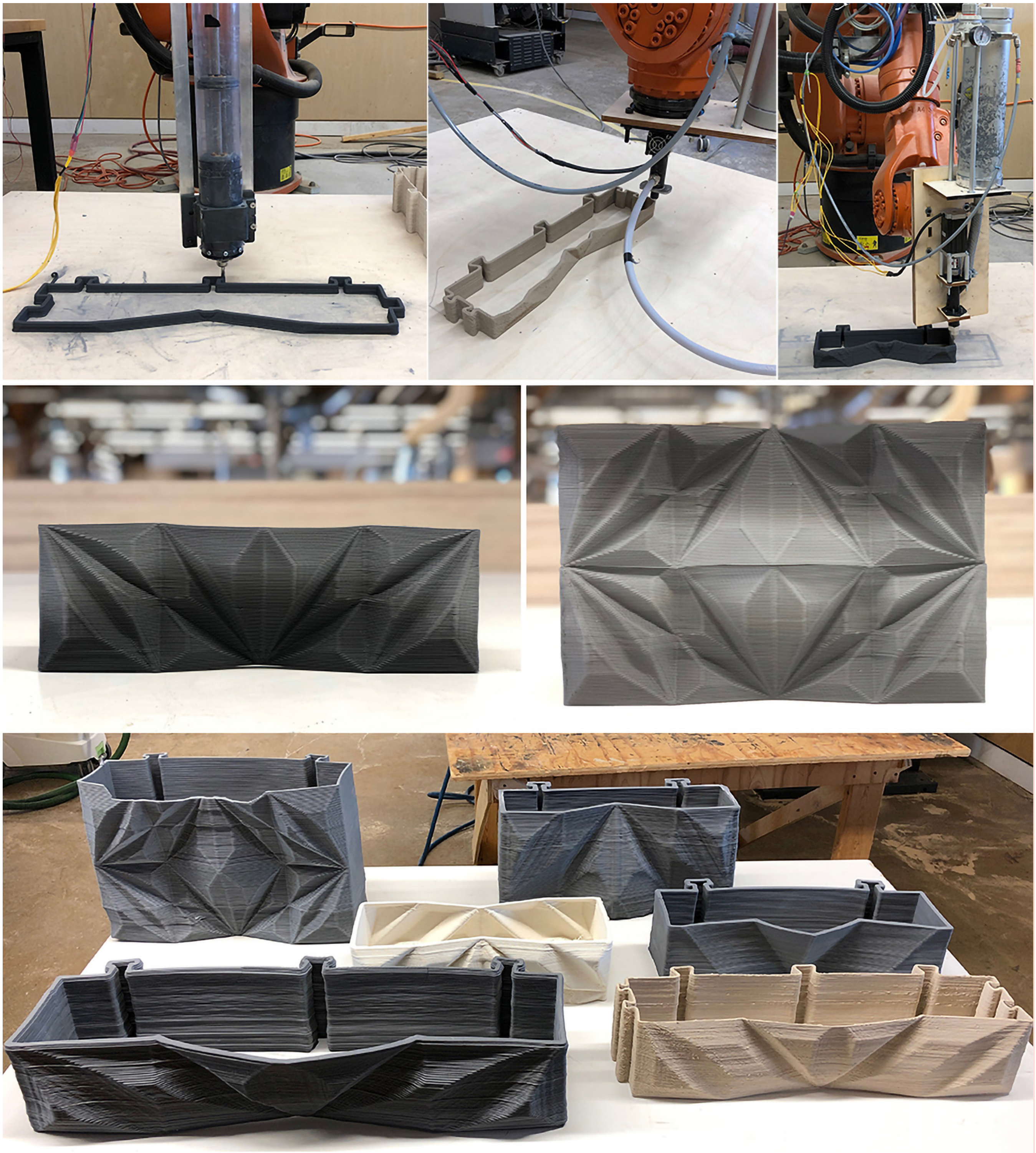

Figure 2. Ceramic prototypes exploring extruder, material and design limitations. Image by author.

Experiments were conducted using 4 to 6mm nozzles. The intent of the experiments was to gain a better understanding on the implications of air pressure and motor control variability, nozzle size, canister volume and material composition in order to extend potential design possibilities (Figure 2).

Design Development

The objective of the experiment was to develop a timber-ceramic composite wall assembly that could address performative criteria through its ornate and intricate surface qualities. A series of hollow cavity façade modules were designed to test the feasibility of producing a successful 3D print. The consistency of the clay was critical in determining the overall size of the module. Clay with higher water content would collapse under its own weight yet a mix that was too stiff would have difficulties flowing through the extruder. In order to embed ornate elements into the overall geometry, an exploration into the allowable cantilevered angle and protrusion distance was required to successfully translate the digital model into a physical artifact. This was dependent on the width of the extrusion bead, speed of extrusion as well as the 3D printed layer height. These factors also governed the level of detail that could be achieved as well as the predictability of the intended geometry. A minimal extrusion width and height would result in greater geometric detail however would add significant printing time and result in very thin and brittle wall cavities.

Using subdivision surface modeling processes and optimized daylighting and energy modeling simulations, a series of ornate geometries were designed to facilitate the production of hollow cavity façade modules that could respond to thermal conditions. The design began with the development of a simple faceted geometry. The geometry would undergo a series of transformations, through additional subdivisions and extrusions, responding to sun path diagrams that were generated using LadyBug; an open source environmental plug-in for Rhino. The goal of each subsequent transformation was to minimize solar radiation in the summer and maximize the gain in the winter. This directly informed the orientation and positioning of mesh elements and guided the overall surface morphology towards the generation

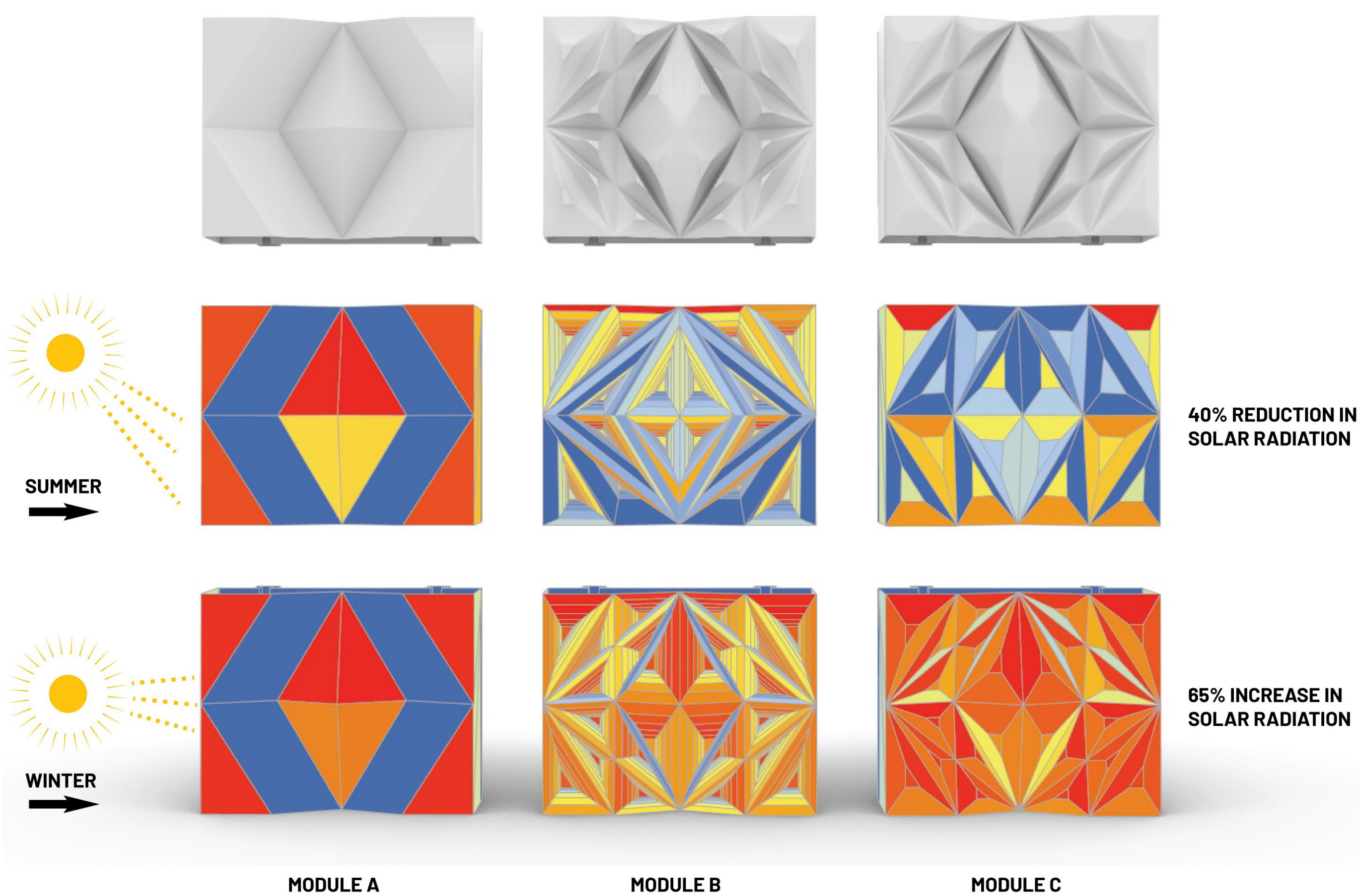

Figure 3. Surface Morphology through subdivisional transformations informed by solar radiation levels. The goal was to find a balance between ornament and performance. Compared to module A, module C provided a 40% reduction in solar radiation over the summer and a 65% increase over the winter. Image by author.

of surface qualities that were both ornate and performative. (Figure 3)

RESULTS

A series of physical prototypes were developed to explore the potential of a novel DLT/ceramic composite wall assembly. The DLT wall, which is exposed to views in the interior, can be used as both a structural bearing and shear wall. When combined with a hollow cavity ceramic module, it acts as a ventilated façade system employing both passive solar and passive natural ventilation strategies

Passive Solar | Thermal Mass

The articulation of the faceted geometry, informed by solar exposure data, addresses the opportunity for thermal optimization through passive solar strategies. The faces of the geometry are angled perpendicular to the sun path during the winter months, when sun is at its lowest altitude. The thermal mass of the ceramic façade module acts as a storage system capable of absorbing and storing the sun's heat energy and releasing it throughout the evening when temperatures begin to fall. Alternatively, during the summer months, when the sun is at its highest position, the faceted cantilevered elements act as solar shading device blocking the sun's heat energy and keeping the building's thermal mass in the shade. Ceramics, similar to concrete, have a high thermal mass and therefore are capable of resisting rapid temperature fluctuations. The material desires to stay at a stable temperature therefore when shaded will maintain cooler temperatures for longer periods. Similarly, though building energy simulations, DLT has been proven to have effective thermal mass properties to help moderate heating and cooling energy consumption compared to light frame construction (Gagnon et al. 2013). The passive solar strategies resulting from both the DLT and ceramic's thermal mass coupled with the introduction of an open air chamber within the cavity would greatly assist in lowering overall building energy use and enhancing occupant comfort. Compared to other typical siding applications, the proposed DLT-ceramic assembly would provide far greater thermal mass performance due to the clay/ceramic's high density, high heat capacity, thermal conductivity and thermal lag which corresponds to the rate at which heat is absorbed and re-released by the material. Further analysis and simulations are required in order to precisely determine the thermal benefit of the proposed DLT-ceramic assembly.

Passive Ventilation Strategies

The proposed ventilated façade system has the potential to provide structural and thermal advantages to the building.

- Structural

The hollow ceramic modules provide an air cavity that protects the mass timber panels from exposure. Openings are designed into the ceramic modules located at the bottom of the façade to allow the air to enter the cavity. As this air heats up, it moves upward and assists in eliminating moisture, preventing mould and helping to prolong the structural integrity of the DLT.

- Thermal

The air corridor between the DLT and ceramic module has significant thermal benefits. Known as the stack effect, the air surrounding a heat source becomes less dense and rises thus allowing the cooler air to move in and replace it. During the summer months, the presence of the insulation on the outside wall coupled with the airflow inside the cavity create an insulated layer removing the heat transfer to the indoor environment and thus reducing the thermal load on the building (Figure 4). In the winter months, solar radiation on the ceramic façade would heat up the cold air within the air space. The ability to close the openings would assist in maintaining inside room temperature as the layer of warm air present inside the cavity would act as further insulation (Figure 4).

Continuity of the insulation is critical in reducing thermal bridging and protecting the DLT and air barrier membrane from extreme temperatures. Rigid exterior insulation is positioned within the ceramic module while maintaining the open cavity air chamber. However, to maximize the thermal benefits, the design will need to be to revisited in order to provide a continuous insulating layer across the DLT eliminating the thermal break that currently exists at the intersection of each ceramic module.

CONCLUSION AND FURTHER DEVELOPMENT

The paper presents the very beginning of a research trajectory that focuses on the potential of mass timber as a renewable, sustainable and high-performing building material via the development of a novel DLT ceramic composite wall assembly. The research merges traditional methods of making with robotic fabrication processes towards the continued development of a performative ventilated façade system (Figure 5).

A 3D printed hollow-cavity ceramic module attempts to overcome the shortcomings of exposed mass timber by providing a protective layer that speaks to both performative and aesthetic sensibilities. The ceramic cladding serves to protect the building from the elements while the integration of an air space seeks to improve the indoor climate through the stack effect. More importantly, the work attempts to revive ornament through performative qualities that give equal importance to functional and aesthetic criteria in order to evoke experiences that can only lead to more thoughtful and successful architectural spaces. It attempts to generate a discourse on aesthetics, making and technology, not as a superficial exercise but one that has the potential to be performative yet inspiring, pragmatic yet experiential.

The studies presented in this paper, although in their early stages, attempt to reveal the potential implications of a robotically driven DLT-ceramic composite wall assembly. Additional research efforts are currently underway in order to validate the findings and provide empirical results on the benefits of the proposed DLT-ceramic composite building enclosure in comparison to more traditional mass timber assemblies. The continued research will focus on the performative potential of additional geometric configurations achieved through robotic 3D printing and on the

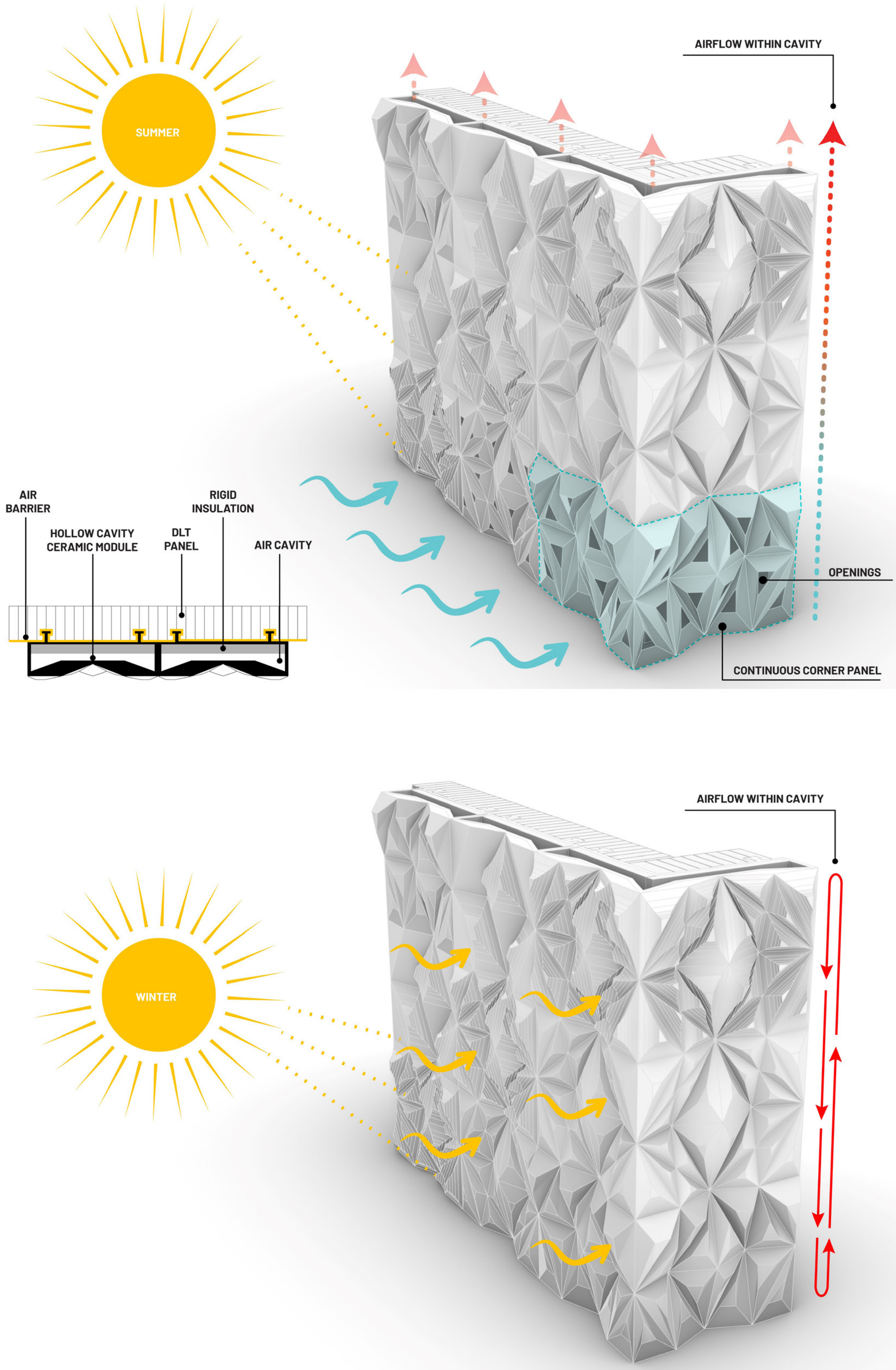

Figure 4. In the summer, the openings allow warm air into the chamber creating an insulated layer against heat gain and exhausting the hot air through the top cavity. In the winter, the sun heats the cold air in the chamber acting as an additional insulation layer. The openings at the bottom are closed to maintain a sealed cavity. Image by author.

development of a connection detail facilitating the continuous placement of insulation to eliminate thermal bridging. Further computational modeling and energy simulation will be required to validate the thermal and fluid dynamic behavior of the airflow and the structural performance of both the ceramic connection detail and overall module. Finally, the development of an active system capable of controlling the openings based on climatic and diurnal cycles is required in order to authenticate the thermal benefits achieved throughout the seasonal changes.

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Figure 5. Work-in-progress prototype of a DLT-ceramic composite wall assembly. Image by author.