Form-finding experimentation is the technique utilized by architects as Gaudí and Frei Otto in the conceptual design of architecture via physical modeling processes that utilized natural forces. Their models allowed negotiated design criteria to be embedded within their working methodologies. These material models thus embodied design constraints that allowed for a negotiative process in order to arrive at an architectural solution.

The Centre for Architectural Structures and Technology is an architectural research laboratory that embraces both the poetic and technical dimensions of architectural design. The work of CAST seeks new boundaries for creative thought, design, and building technology through physical explorations of materials, tools, and building methods, the study of natural law, and the free play of imagination. (http://www.umanitoba.ca/cast_building/)

Material agency here refers to the autonomous material relationships that are represented by agents (individual elements) that negotiate their conditions according to their own "decisions." The final organization model is a product of this collective behavior indirectly controlled by each element.

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WORK IN PROGRESS

PARAMETRIC PRECAST CONCRETE PANEL SYSTEM

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ABSTRACT

The framework for this research focuses on the potential of utilizing a digital toolset to engage information within a surrounding context for the purpose of creating a more intelligent precast concrete panel system. The Parametric Precast Concrete Panel System *is an ongoing research project that parametrically defines geometry for the purpose of producing formwork based on quantitative information related to issues such as environmental control systems and sound abatement, as well as qualitative information such as nonstandard variation paneling and formal composition. (Figure 1)*

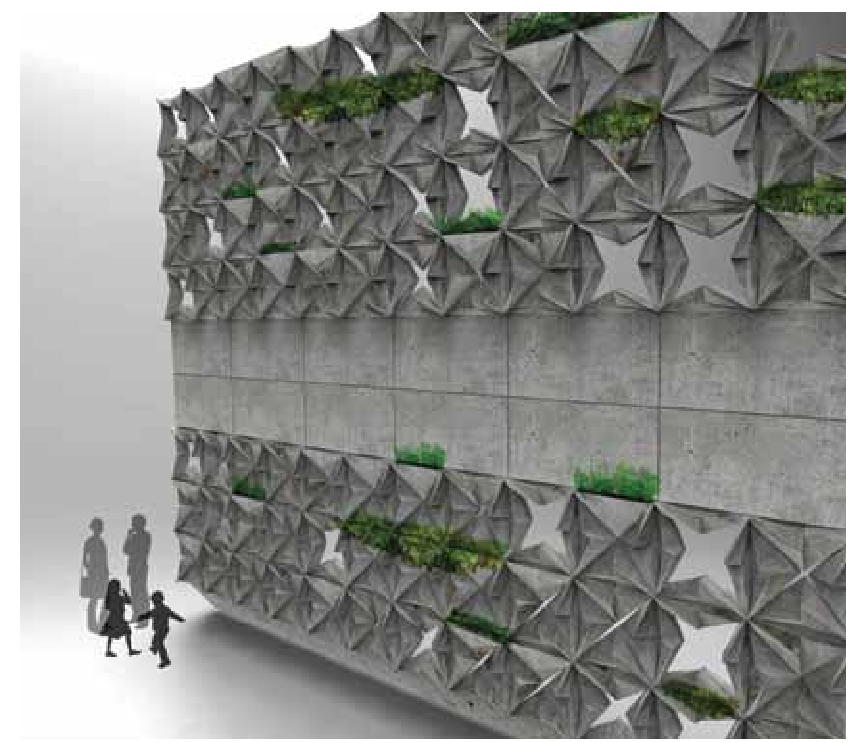


figure 1

figure 1

Aperture facade panel rendering showing variation in openings and integrated planting pockets.

1 INTRODUCTION

"[A] fascinating characteristic of engineering realizations lay in their capacity to adjust to the site in a dynamic way, often by revealing its hidden potential or by reshaping it. This capacity had been theorized in the late eighteenth century through the emergence of the 'technological sublime.' A transposition to engineering works of the aesthetic category of the sublime. Engineering was sublime insofar as it both fought and revealed nature. Nineteenth- and twentieth-century engineering was to retain this capacity to react dynamically and often in a dramatic way, to the geography of the site." (Picon 2006.)

As Antoine Picon suggests, it was at a moment that engineering, specifically civil engineering, split from the precepts of architecture in the mid-eighteenth century that the tension between technology and architecture arose. However, in the past decade there has been a reemergence of the architect taking objective performance criteria as impetus for initiating the design process and abandoning notions of style and theory as progenitor. On one end of this spectrum is the wide embrace of green and sustainable building components; on the other is the exploration of digitally designed geometries capable of responding to a complex range of requirements. To place it in highly reductive terms: designers in a multitude of fields are now using information to navigate terrain that is more defined by the science of intricacy and precision than gesture and style. This move is allowing architects to arrive at more informed, intelligent, and efficient design solutions.

Parametric Precast is an ongoing funded research project attempting to navigate a middle ground of computation architecture and, if not sustainability, then at least a more intelligent building technology application. There is an effort to leverage the computational capacity of parametric software to author highly explicit geometries for the purpose of generating more environmentally responsive architectural components. Specifically, this research attempts to use more expansive performance criteria for the purpose of evolving the precast panel. While there is significant development being made in the composition of concrete as a material and how we might make it more sustainable and efficient, this research is more concentrated on the function of the panel and how its geometry provides an increased performance capacity as a result of the new geometry.

Solar panel, aperture panel, and sound diffusion panel.

Because this initial phase of research attempts to link environmental and formal criteria to the geometric development of precast formwork, there is some benefit to examining dual application opportunities. By doing so, a broader range of usage scenarios is made available. The two primary areas for programmatic exploration are 1) mechanically stabilized earth (MSE) panels, commonly found along major urban transit corridors; and 2) building facade panels. Within these two program types, three panel types are being developed: a) solar panel, b) aperture panel, and c) sound diffusion panel (Figure 2).

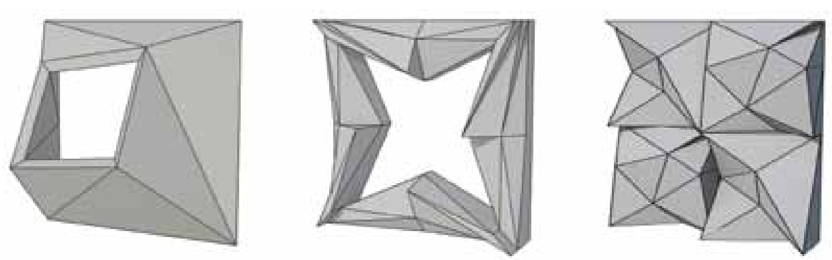


figure 2

figure 2

Solar panel, aperture panel, and sound diffusion panel.

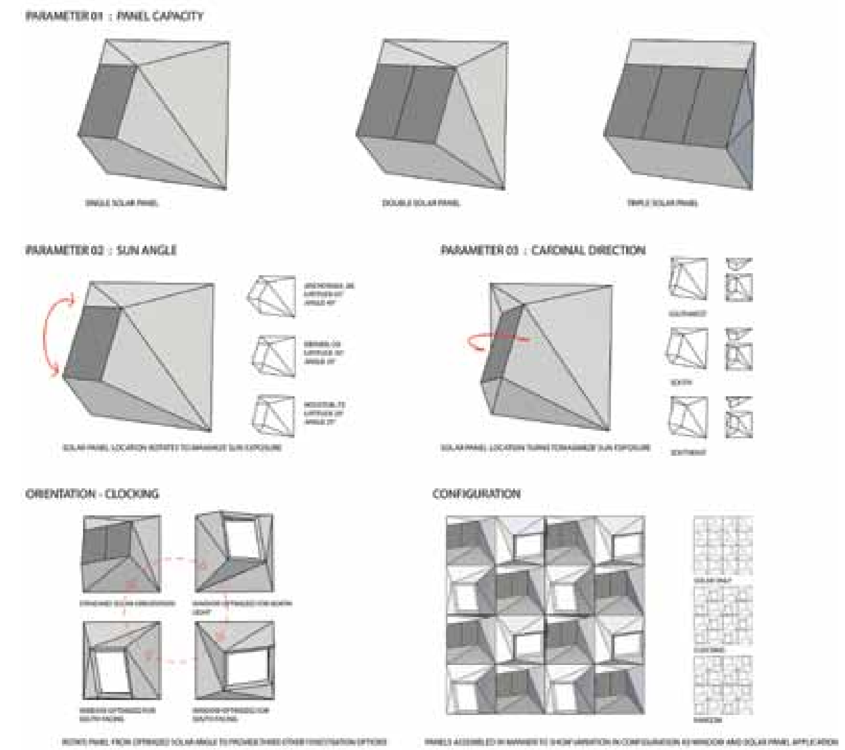


figure 3

figure 3

Geometry variation within the solar panel based on photovoltaic (PV) number, clocking direction, and matrix configuration.

2 SOLAR PANEL

The examination of the solar panel provides an opportunity to coordinate the geometry of the precast panel to very specific data. Optimal performance of the solar panel requires precise alignment with correct sun angles. Extrinsic factors like a building or MSE wall latitude or energy needs might suggest one configuration scenario within the parameters of design. Conversely, intrinsic factors such as project orientation or more subjective considerations in matrix sequence might produce a different configuration scenario. These forces on the design process—external and internal—are not diametrical, but rather are now able to be more seamlessly integrated through the use of parametric software. User interface and calibration based on objective or subjective criteria may now be coordinated through the singular model and resolved, tested, and reworked according to the essential functionality of the parametric functions.

First generation photovoltaic (PV) technology is initially explored for how it might afford other opportunities in creating fenestration within the panel. Specific manufacturers' PV panel sizes can be coordinated as one of the parameters, with the sizes of panels from various manufacturers becoming precise data points in the model to control the geometry. Beyond the use of the PV application, the panel still provides shading benefits when clocked in other directions. In this regard, by exchanging the PV panel with glass and changing the orientation of the precast panel, one can implement the fenestration (Figure 3).

As a mechanically stabilized earth (MSE) panel the introduction of PV provides an interesting opportunity to integrate large quantities of energy corridors along the seemingly endless miles of expanding freeway and infrastructure found in most major urban centers—or, by contrast, those in some remote locations found in the national park system throughout the country. The opportunities

figures 4–6

figures 7

figure 8

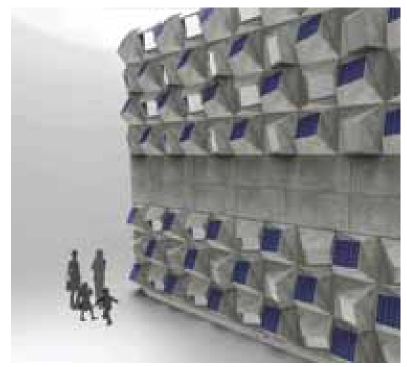


figure 9

figures 4–6

Two-part urethane mold for ¼-scale prototyping; Six panels clocked in various positions to show orientation possibilities; Detail.

figure 7

Side view of prototypes.

figure 8

Sun zenith chart for Denver, CO.

figure 9

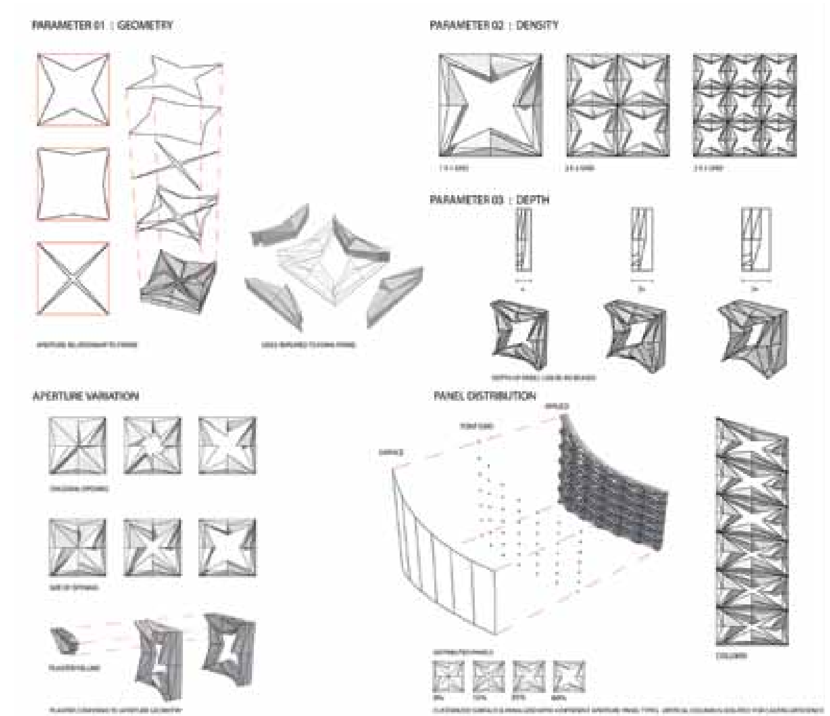
Wall facade matrix showing the mixture of PV and fenestration options.

to utilize these panels as energy sources—to provide urban lighting through vehicular corridors or peripheral event activity spaces, or just primary energy sources for remote sourcing—is a unique merger of infrastructure with renewable resources.

To date, the solar panel cast is a complex two-sided mold requiring a two-part urethane form in order to reduce weight. While prototyping thus far has undertaken the implementation of computer-numerically-controlled (CNC) to the fabrication of the mold, continued scalar increases of the prototyped productions to date would necessitate additional examination of mold-making possibilities beyond urethane. However, it is conceivable that with additional axis capability, direct "mill to mold" formation might be possible. The panel as pictured in Figures 4-9 is calculated for the sun zenith and latitude of Denver, CO.

3 APERTURE PANEL

The examination of the planter aperture panel provides an opportunity to introduce vegetation to a vertical surface while also considering various aperture sizes. In the application of a facade, the aperture becomes the primary controlling factor for the geometry of the panel. Aperture configuration and size can be calibrated according to the amount of light infiltration desired, or the aperture size can be coordinated in accordance with the adjacent program behind the panel. In either instance it is the capacity to find a varied and diversified spectrum of options that initiates control functions of the aperture. An equal number of outputs for the planter box associated with the panel is keyed into the opening and conforms into the top face of the panel. The vegetation inserted into the planter would thus need to be coordinated to the capacity of the planter, access for maintenance, and availability to a gray water source from either the building HVAC or, in the case of the mechanically stabilized earth (MSE) panel application, storm runoff.



figures 10

figure 11

figure 12

It is possible to consider a single plant source in relationship to the planter or climber vine as an option. Each would present subtle variables to the planter but might, more importantly, begin to reconfigure the other peripheral geometry. Properly articulated geometries could be regulated to channel surface moisture or to facilitate directionality for vine growth. The star-shaped aperture allows for gradual and calibrated control over the opening. The surrounding fins provide shading for the opening and are also a variable within the parametric model that can be given greater or lesser degrees of expression depending on cardinal orientation or design preference (Figure 10).

The planter aperture panel is a single-sided mold that utilizes the CNC machine to directly mill the casting surface (Figures 11 and 12). Given how industry and design concentration has leveraged a more singular face approach to precast, this method would seem to provide the easiest transition opportunity. The prospect of a CNC mill working with the gantry and long singular panel system commonly found in most precast plants would suggest the capacity for easy integration. We have demonstrated the panel in an idealized shape but anticipate that in application there may be an opportunity to customize and group multiple panels. In this way, the unique heterogeneous nature of each panel does not change the fabrication methodology. Whereas in traditional precast form construction, the unique nature of the aperture coupled with the overall form would potentially be costly, the direct "file-to-form" approach circumvents this issue and allows customization that is bound and regulated by only the largest issues of precast fabrication such as transportation and panel installation.

4 DIFFUSION PANEL

The examination of the sound diffusion panel provides an opportunity to coordinate the geometry of the precast panel to the manner in which the geometry of the panel might diffuse or deflect sound.

figure 10

Configuration variables for aperture panel including planter and nonstandard unit application.

figure 11

Aperture panel prototype.

figure 12

Single-sided mold.

figure 13

Grasshopper model showing relationship of control points to panel geometry.

figure 14

Configuration variables for sound diffusion panel showing the triangulated surface inflection and nonstandard unit application.

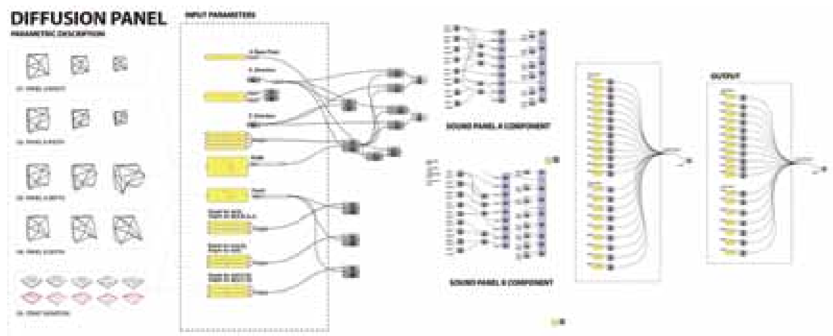


figure 13

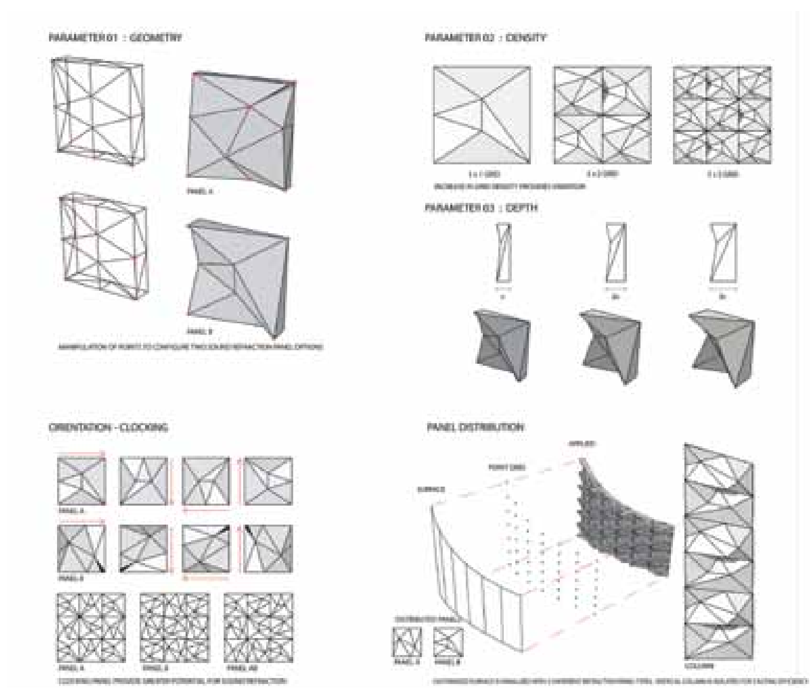


figure 14

Optimized performance for sound abatement is now possible through very precise digital analysis, and consequently it is possible to translate the manner in which a wall or volume might assist in diffusing sound by the depth, angle, or configuration of the panel surface. Urban noise pollution continues to impact real estate value and will only rise as population density increases.

In the application of either facade or mechanically stabilized earth (MSE) panel, it is possible to consider how a more calibrated and integrated precast panel might participate in revitalizing real estate zones or protecting buildings' programs from unwanted noise pollution. As specific performance criteria emerge, it would be possible to connect height, proximity, duration, and frequency to the parametric model to understand more fully the diffusion and atmospheric capabilities of the geometry (Figure 13.) Where necessary, it would also be possible to override pragmatically derived solutions for aesthetic considerations. Specifically, the panel geometry is controlled by subdividing face geometry units between a matrix of 1, 4, or 9 and then adjusting the triangulated face that would provide the diffusion through two forms of manipulation by articulating frequency and depth to attain a spectrum of different angled surfaces within the panel (Figure 14).

figure 15

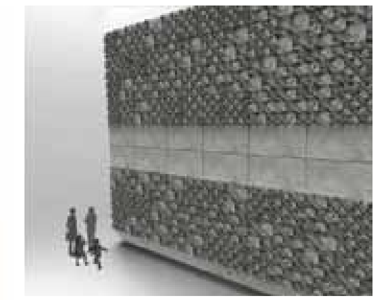


figure 16

figure 17

figure 15

Sound diffusion panels prototype showing nonstandard configuration.

figure 16

Rendering of wall facade.

figure 17

Detail of prototype.

For the purposes of this research the sound diffusion panel is a single-sided mold that utilizes the CNC machine to directly mill the casting surface. In addition to applying a range of modular densities to the panel (1 × 1 column vs. 3 × 3 column), it is also a consideration to apply a range of these multi depths to the surface. As well, similarly to the planter aperture panel, there is an opportunity to customize the modular layout to an overall wall configuration, thus creating unique and varied individual panels. These single panels then might be "ganged" together to make super panels that can be cast in lengths up to 36' long (Figures 15). This would then make it consistent with targeted lengths of precast within current standard precast practices for transportation and installation, etc. While the longer panels might be best suited for building facades, much of what the application might be best suited for is the urban corridor application. Sound barrier walls and MSE panels are the ideal component type for this panel, and in that scenario the panels would be smaller and customized according to more localized conditions of context and infrastructure.

5 FUTURE STEPS

While the preliminary stage of this research has outlined the general intentions and trajectory of the work to be undertaken, it is clear that several subsequent steps need to be taken to refine the current empirical data. A fundamental starting premise for the research is the interrelationship between the matrixes of parameters set between a spectrum of control factors. For instance, the specific influences of a solar panel and the control factors of the precast procedures combine to provide the geometric boundaries of the work found in this work to date. However, there is an opportunity to leverage a range of software to more explicitly and rigorously investigate the integrity of these assumptions. Our next stage of investigation will link the digital software platforms for more robust levels of data output for environmental performance, structural load capacity, and geometric variation enhancement. This will require the use of testing labs working with the engineering labs on our campus and expanding the collaborative nature of this work.

As well, there is a desire to increase the scale of the physical testing. Through our collaborative working partnership with a national leading precast company, we have established an opportunity to work toward mock-ups in their facility that exceed what we have currently been able to produce in our own facility. We feel that the combination of the quantitative and qualitative data will strengthen the research in a very important way. Ultimately it will be the increase in scale and the more precise control factors articulated through the parametric software that will produce enough data for us to assess the viability of our working hypothesis. At the moment our phase one–level investigations have provided proof of concept in linking the working methods at a cursory level to the output possibilities. Phase two will evaluate the testing of larger prototypes with a closer and more rigorous methodology for how the panels perform relative to the issues unique to each panel type.

ACKNOWLEDGMENTS

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WORK IN PROGRESS

FABRICATING SUSTAINABLE CONCRETE ELEMENTS: A PHYSICAL INSTANTIATION OF THE MARCHING CUBES ALGORITHM

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ABSTRACT

This paper explores how an algorithm designed to represent form can be made physical, and how this physical instantiation can be made to respond to a set of design imperatives. Specifically, this paper demonstrates how Marching Cubes (Lorensen and Cline 1987), an algorithm that extracts a polygonal mesh from a scalar field, can be used to initiate the design of a system of modular concrete armature elements that permit a large degree of variability using a small number of discrete parts. The design of these elements was developed in response to a close examination of Frank Lloyd Wright's Usonian Automatic system, an architecturally pertinent historical precedent (Pfeiffer 2002). The fabricated results positively satisfy contemporary design criteria, including maximal formal freedom, optimal environmental performance, and minimal life-cycle costs.