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Information Controlled Erosion

This paper documents research of a design process that interrelates a single information model to 5-axis, water-jet cutting technology. With the intention of creating an optimized design, data is streamed through a building information model that controls geometry parametrically by a component/system relationship. At the scale of a 4'x8' panel, material properties and pattern variability act as underlying initiators of design rather than post-rational information. In a manner uncommon to the discipline, the information model is being used as a generative tool, rather than as one for mere documentation.

:abstract

The research assigns a limestone wall type to the panel—a material predominantly used in areas where it is indigenous and typically desirable for its texture, color, and thermal properties. The intention is to develop potentialities through material specificity in the information model's conceptualization. The water-jet process is then used to erode the limestone to achieve varying fields of scalar voids. In addition, the thickness of wall cladding attenuates for figuration and interest. The final stone panels transition from a rain screen system to a solar screen that modulates light, thereby linking environmental intentions to current technological capabilities.

The information model is exported for analysis of daylight and structural dynamic qualities and quantities as part of the workflow. Parameters within the information model database facilitate a dimensionally controlled iterative process. Moreover, fabricating with building materials via the information model expedites a design and makes possible for materiality to move beyond merely conceptual representation.

1 Introduction

Technological innovation in fabrication along with information modeling transcends the physical process of stone 'carving' or 'erosion' to potentially optimize a building envelope. The discipline's current tendency towards reducing the mass and thickness of more valuable materials such as stone has led to an increased flattening of the cladding elements, which, due to their reduced thickness, have substantially lost the 3-dimensionality or functional depth they may have historically had. This thinning process highlights how economic pressures affect material choices and modern building requirements, but conversely means purposeful characteristics, such as thermal climatic properties, have dropped substantially. The trend to thin the external cladding has reduced the standard dimension to one inch thick—a dimension considered an ample margin of safety and strength of material. Concurrent investigation of water-jet technology as applied to natural material differs in its pursuit of translucency potentialities using very thin stone (Bechthold & Ponce de Leon, 2009). In response, the design-applied research of this paper promotes the potential figurative thickening of stone cladding and furthermore adopts an adherence to environmental forces in its void gradient apertures. The proposed cutting technique shows promise for larger scale projects in which a building could achieve a higher degree of 3-dimensionality and performance in its cladding.

2 Workflow

The fluidity between computer model and physical construct has the capacity to innovate complex designs through information-rich modeling. Moreover, the material properties can be parametrically incorporated at the point of design origination—capturing decisive information not only from its geometry, but also from its content and behavior within an environment. The quantifiable domain of material capabilities is addressed during events in the design process (Figure 1). The following research suggests simple guidelines for using a single information model to collaborate, generate, analyze, and produce the design of a limestone panel prototype.

3 Materiality

The design begins by using a conceptual mass family file in Autodesk Revit BIM 2010®. Then, define the wall type or material to be produced in a slab panel family. When selecting cladding material, take into consideration performance or longevity of the elements produced. The energy savings from thermal benefits of a wall cladding thickness could (in the long run) offset the cost of using thicker stone. Comparatively, thermal properties of limestone significantly increase effectiveness as a cladding system, as demonstrated by the R-values of several common cladding materials (Acocella, 2006).

Table 1: R-value chart for typical cladding materials

	Material type	R-value (at 1 inch)
	Limestone	0.153
	Slate	0.100
	Concrete	0.095
	Marble	0.090
	Granite	0.083

The information model can then contain properties of limestone, such as R-value quantification in relation to a given thickness. These are established as a type parameter on the 4'x8' mass. The process highlights adherence to natural properties of elements at the detail scale that act as secondary agents of decision-making. Additional desirable benefits of using limestone are:

- Low maintenance—reduces the need for frequent maintenance chemical use.
- Durable—withstands wear and extends the useful life of the material, eliminates the need for frequent cleaning, painting or sealants.
- Relatively soft by fabrication standards—allows for efficient cutting process.

3.1 Sustainable practice

The decision to use a water-jet process was based on its material efficiency and production benefits. The areas removed are literally sliced out rather than pulverized like the more commonly used process of subtractive CNC milling—a process that Erwin Hauer and Enrique Rosado's deployed for 'Design 306' Indiana limestone wall panels (Iwamoto, 2009). Additionally, the water-

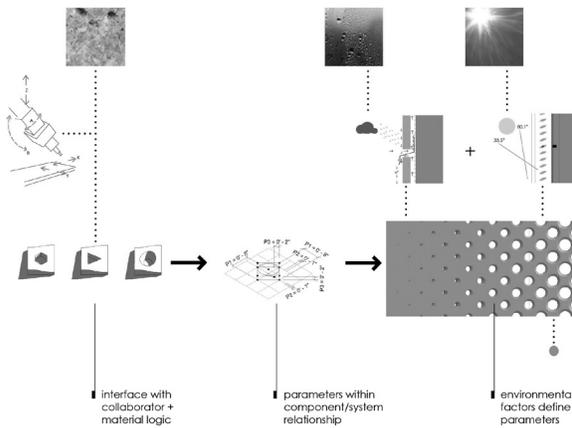


Figure 1: Data flow matrix diagram depicts design origination of material and collaboration with fabrication constraints, component system relationships that adhere to rain and solar requirements.

jet technology is cleaner than milling as it uses plain water to cut profiles, creating little or no dust, by-products, or chemical air pollution. This research testing proved that only 1/16 of an inch of material was disintegrated by the tool path when cutting up to 6 inches of material depth. Beyond 6 inches of cutting, erosion of more stone than was intended began to disfigure the output (Figure 2).

An in-and-out start of the tool path requires that some portion of the material cut be optimized for design, producing off-cuts with visible paths where tool has started and stopped. These off-cuts remain intact for dual usage. For this reason, a design could incorporate both optimized and off-cut pieces as part of the process.

4 Collaboration

Design information can directly generate construction information, enabling a closer investigation of material outcomes from the earliest stages of design. Using material samples, test technological accuracy and capabilities of the water-jet process (Figure 3).

Export the information model file as an earlier version .dxf file to fabricator for file translation and production. The collaborative process also immediately brings up the issues of weight of material with regards to cost and logistics of transportation.

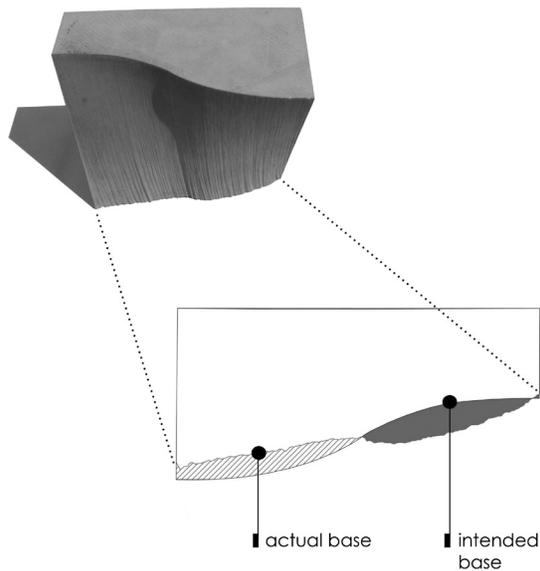


Figure 2: Detail of rippling effect and diagram of discrepancy.

5 Design generation

Three-dimensionality within a flat slab of cladding material can be achieved with selected geometry and 5-axis undercut capability. The research project defines and tests limits of the component variables within a 4'x8' divided surface model by using a curtain panel pattern based.rft file. Although many other shapes of complex geometry are available for design origination, a simple circle void form within a rhomboid divided surface pattern is chosen to initially define the aperture. Values of the parametric information respond dynamically to multiple data sets, such as thickness, condensation, and solar gain in a given location.

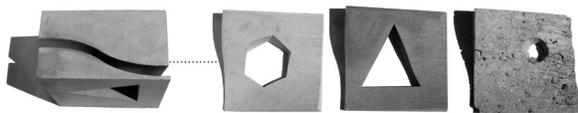


Figure 3: Three 12" x 12" x 6" deep test pieces of varying limestone type inform the 'best-practice' approach for the final panels. In each case, a compound curve was cut in profile and then a unique shape was cut from each limestone type

5.1 Pattern

With advancement in the information model, the varying nature of the digital component redefines the iterative process and also its relationship to ecological domains. Pattern becomes related to causality, even within the workflow. Although pattern classification can be just as limiting as the current reputation of information modeling, the research examines linear versus non-linear pattern making parametrically to derive originating control variables (Delanda, 2009). The particular pattern of this research transitions from closed to open apertures for relieving condensation in the wall cavity at the left end and controlling sun angle conditions at the other. The wall type of the component is registered as stone and informs the design of thermal characteristics as pattern changes occur. The component itself is controlled by the interior and exterior circle instance parameters (P1 and P2). The front and back profiles that create the void geometry in the component have an angle of translation (P3) that is determined by drainage for condensation, solar optimization, or the angle axis of the water-jet technology being a maximum of forty-five degrees. The transitional aperture gradient does not privilege a particular void shape, but can vary according to design input (Figure 4).

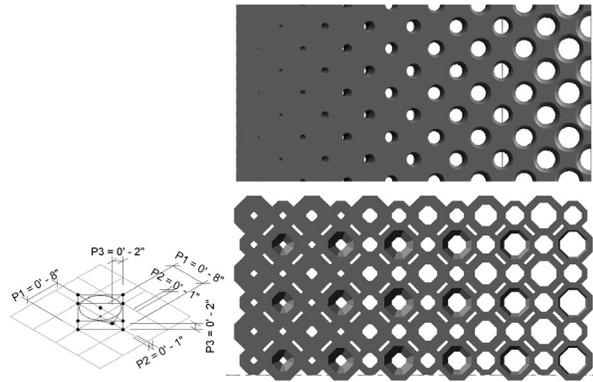


Figure 4: Pattern manipulation based on iteration in component /system variables.

6 Analysis

At the scale of the stone panel, the intention is to analyze a building element within an information model in order to gain time for other events in the workflow—ones that might move the attention away from the formal object.

6.1 Environmental analysis

In order for environmental analysis to take place, the 4'x8' panel had to be placed within a project file for a space to be evaluated within a form. The analysis proved positive, but is not fully available for component or prototypes at this scale, therefore a spatial abstraction of the information model is required to perform analysis in the intended workflow. By exporting the information model as a gbxml file to Autodesk Ecotect®, the generic perforated information model with three inch and six inch thicknesses can be evaluated for daylight and thermal analysis (Figure 5).

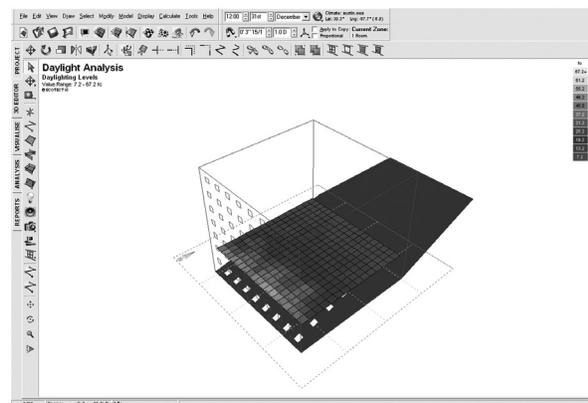
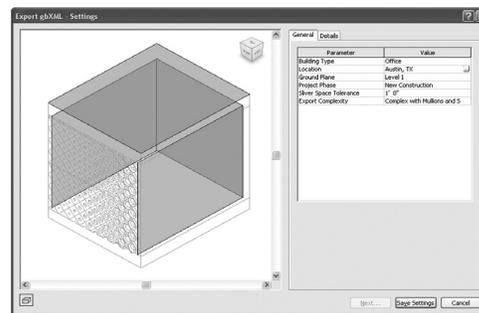


Figure 5: Exportation settings in the information model and daylight analysis on a 3 inch perforated wall.

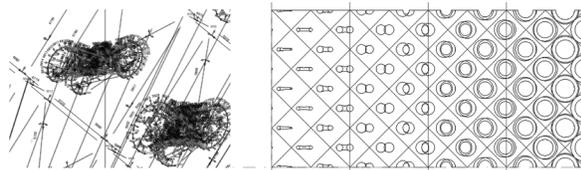


Figure 6: Analysis done at the scale of the aperture inundates profile with information. Materiality is not a factor in this analysis platform for such a small-scaled work.



The difference between the three inch limestone and the six inch limestone seems to lie in the six inch thickness starting off with better initial properties, such as a greater thermal decrement number and a higher thermal lag, making the thicker stone better at resisting heat transfer to the interior.

6.2 Structural Analysis

Like the environmental analysis, structural stability of the perforated cladding requires creating an overall mass or form for the component or building element to expand upon. By simply exporting the massing information model to the Autodesk Robot® plug-in or Conceptual Form Simulation Extension, the design can be pre-rationalized in the decision process. Using the Conceptual Form Simulation extension, you can perform a simulation of static analysis of a 3D solid (*Mangon et al., 2009*). The following information can be imported into the extension: geometry, material parameters, supports, loads, load cases, and load combinations. To perform a simulation using this extension:

- Define a solid mass and meshes on the solid faces
- Launch the Conceptual Form Simulation extension (meshes are exported as finite elements)
- Modify material parameters or thickness values for finite elements
- Define supports at the mesh nodes
- Define loads
- Perform calculations
- View the calculation results (internal forces, displacements, animations of displacements).

The individual apertures prove adequate with virtual testing of loads of itself and a doubling of force. Information feedback however at this scale is not pertinent and becomes overwhelming, as every surface normal is evaluated and every node demarcated (Figure 6). The model could be aggregated onto a conceptual mass and analyzed as described above, but this would then focus on formalism as opposed to the pursuit of the detail.

7 Fabrication

Admittedly, the panel set is essentially a varying flat pattern, not unlike perforated profiles attained by flat sheets in the De Young Museum in San Francisco, designed by Herzog and de Meuron in 2005. The generic circle pattern is envisioned to

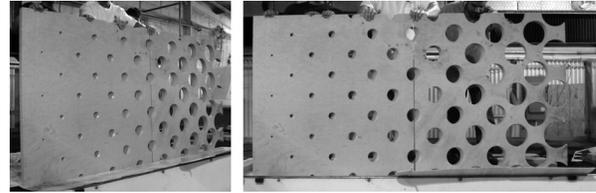


Figure 7: Completed pieces in fabrication warehouse.

be in a larger scaled application than the single panel set, and when expanded at the building scale, fabrication allows for each piece to be a unique figure-cut without losing efficiency.

By taking full advantage of the 5-axis capability to perform undercuts, the apertures have a duality in that the front and back circle geometries are displaced and have two differing radii, making each aperture distinct. Being two sided enables the panel to control solar heat gain to the interior at its fully open apertures. Because each circle is unique in diameter and the displacement of void openings overlap, some three dimensionality and depth is achieved. The circle translation in this project expresses the 2-inch depth of thickened cladding, an attribute that would double the standard thermal properties of a panel (Figure 7).

A 'file-to-factory' approach still holds the possibility of human error and misunderstanding of intention when collaboration is an agent in the process. Some of the voids were remodeled without author consent, which in the end produced a faceted variation in final surface outcome. Also, the water-jet process requires a significant amount of time to level the cutting bed for such a scale of production. Hand adjustments became necessary to align the stone to suit the homing device. One can expect to double cutting time for this procedure. Final handling and transportation of pieces, as well as storage, are all issues that determined thickness and 4'x4' piece size.

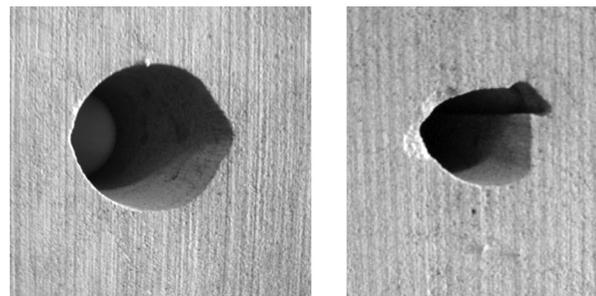


Figure 8: The front and back of one of the smallest apertures demonstrated some fracturing due to organic make-up of material and discrepancy of the fabrication technology.

As stated, limestone is extremely soft compared to steel or even some other stone cladding materials. Serendipitous occurrences can also be expected when fabricating with soft, organic materials such as limestone (Figure 8). The texturing that occurred in the test pieces could be a point of design departure for future projects, along with information data triggering the fabrication process to shift in unexpected ways.

8 Conclusion

Increasing figurative depth to a limestone cladding system achieves and demonstrates the potential of using an information model for design and fabrication. The relationship of environmental control parameters to fabrication produces a specific articulated surface that is beneficial to elevating mundane factors of information (like the R-value of a selected material) to innovate and optimize a single panel within a form. The strategy of nesting a component within a component system of a building element of an information model is innovative research as is the combination of water-jet technology applied to limestone using an information model. The design process demonstrates dynamic feedback from

the full-scale production of material—the modeling of which translates to actual geometry for building and material efficiency through the fabrication technique.

Given the limitations encountered with analysis, one possibility is for the design process to make the use of third party analysis software superfluous when particular parameters register ecological information at the onset. Likewise, the technological process of water-jet cutting is advantageous as it is much cleaner, more efficient, and produces less damage of the material in the act of cutting itself. The 5-axis technology (as oppose to 3-axis) may not be absolutely necessary to optimize form making but is indeed liberating in its ability to create under-cuts, bevels, or complex shapes into any material not possible with CNC. A reciprocal relationship between optimized panels and off-cut pieces can be an element of the process of design, whereby material efficiency and functionality become parameters for creative decisiveness. The cognitive and perceptual ability of the designer and fabricator remain inherently necessary for setting up and producing work that refocuses attention from merely formal constructs to ones that respond and react to embedded information about the environment.

Acknowledgements

This author would like to thank the help of Research Assistant Laura Grenard, Master of Architecture Candidate 2011- University of Texas at Austin, whose tremendous energy and focus aided this project's completion. The research is indebted to the funding support granted by the University of Texas 2010 Research Grant. Also recognized are the knowledge, patience, and understanding for this research process shown by Tony Woodall and Carl Wibbing, Head Fabricator, of AST Waterjet. This author would lastly like to acknowledge work and tutorials demonstrated on the websites of David Fano (www.designreform.com) and Zach Kron (www.buildz.com).

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Appendix

Table 1: The initial investigation determines optimal limestone type, precision of the technology, and settings for the 5-axis, water-jet fabrication.

cut#	Limestone Type	Program Speed	Outcome	Cut Shape
1	cream cordova	50% (slower)	high resolution at top 6", bumpy bottom	hexagon
2	leuders	80%	higher, bumpy at bottom	triangle
3	shell	70%→120%→135%	very low resolution at bottom	circle