RE-VAULT
EXTENDING FORM FINDING WITH COMPUTATION, ECOLOGICAL INPUTS AND ROBOTIC FABRICATION
APPLICATION TO THE RESEARCH THROUGH MAKING GRANT
TAUBMAN COLLEGE OF ARCHITECTURE AND URBAN PLANNING, UNIVERSITY OF MICHIGAN
01 ABSTRACT

As three professors within the school of architecture, we propose a collaborative exploration into the process of form-finding and masonry vaulting. Our research seeks to extend traditional form-finding processes and vaulting tectonics beyond the monoculture of structural performance using contemporary tools of algorithmic modeling and robotic fabrication.

The outcome of this research will be a pavilion constructed of robotically deposited foam as permanent formwork for an unreinforced (compression only) stone vault-system constructed inside the initial layer of foam. The pavilion will incorporate slumped glass fenestration and will be at least partially earth covered.

02 BACKGROUND

As a formalized process, form-finding techniques have a long history, tracing back to the work of Catalan architect Antoni Gaudi. Gaudi, and his twentieth century contemporary, Frei Otto, carefully crafted intricate and interconnected vaults of catenary nets and soap-film surfaces to study and measure the effect of force upon form. Once restrained to the computational capacity made possible through the material properties of such models, form-finding techniques are now enjoyed by a greater accessibility to engineers and designers with the aid of computer calculation. Yet the art and practice of finding form remains largely restrained to the question of structural problem solving.

Form in nature is dramatically more complex, seeking instruction through an interaction of myriad environmental constraints and continual feedback. Formal solutions are sought through adaptive speculation placed within a rich polyculture of influences rather than a singular input.

03 PROPOSAL

Our research seeks to diversify traditional form-finding techniques beyond the monoculture of structure by emulating nature’s iterative model through the addition of design criteria, i.e. constraints. We acknowledge that the forms produced by Gaudi and Otto were indeed instructed by criteria beyond structural performance (programmatic, material, financial) yet seek to diversify the set of formal influences further still. Aided by custom-written software and algorithmic models, we propose to design and build an unreinforced thin-shell compressive vault, and, in so doing, expand the tradition of architectural form-finding.

In addition to structural constraints, the form of the vault is directly contingent upon contextual constraints. Primary to our attempt to extend the tradition of form-finding will be the addition of passive environmental controls to the vault. We will attempt to enclose the vault and imbue it with the same environmental control and comfort expected of all contemporary buildings. Using a specific building site in Ann Arbor, our project will explicitly negotiate the multiple inputs of:

- passive solar performance: selective solar gain
- passive ventilation
- thermal mass regulation

Using such constraints as local sun angles and predominant wind direction, the vault will iteratively grow and adapt accordingly. To do so, we will exploit the capabilities of such environmental analysis software as Ecotect in close collaboration with our own custom-written software.

Our research intends to extend the scope of design criteria associated with form-finding as well as traditional masonry vault construction. The integration the environmental controls listed above into our form-finding algorithmic model of the vault will require a sophisticated understanding of traditional thin-shell vaulting tectonics. We intend to research the design of a tectonic system of material layers, including past examples of Gothic and Catalan vaults, with a focus on vaulting greater environmental control of enclosed space. The evaluation of the effectiveness of such design speculations will include data collected from experiments, such as the thermal capacity of various masonry materials, will be continuously fed back into the form-finding algorithms to instruct the final construction. In keeping with our ecological criteria, every effort will be made to use an environmentally-conscious material palette (locally sourced with low embodied-energy).

Due to the contingent nature of the form-finding process, our vault design is unlikely to follow a strict and repeating structural-bay organization. The vault we propose will be directly derived from the immediate climate and terrain of the site. Consequently, conventional generic components must be replaced with contextualized components – that is, every piece of masonry will be unique. The vault will act as proof of our extended criteria for form-finding. Yet the construction of the vault will be a complex technical challenge.

The complexity of contextually form-found vaulting requires the use of mass-customized fabrication methodologies. The school’s newly acquired seven-axis robotic arm and other computer driven fabrication tools will be fully exploited to make the installation possible. Consequently, our proposal also acts as a catalyst to advance digital fabrication and robotic assembly methodologies. All components of the vault will be fabricated off-site in the school’s fabrication laboratory and then transported to site for final installation.

The research and building outlined above attempts to achieve several goals. Our proposal seeks to create a methodology that engages complexity and self-organization in all aspects of the initial design stage to final fabrication without any transnational leaps. Aside from the explicitly named procedural and technical aspirations of the project, our proposal should be regarded as an attempt to extend the architectural practice beyond the ‘we-can-build-anything psyche while simultaneously reorienting, but not returning, the architect toward the master builder.

04 EVALUATION & ASSESSMENT

Although the combined project team carries its own diversity of skills, independent criticism and consultation will be indispensable to the project. Each stage of the project (research, design, construction, ‘post-occupation’) will require feedback from our attempt to extend the tradition of form-finding will be necessary to hold the vault against the constructive scrutiny of peer review. Design critics will be sought periodically to provide feedback. To assist the quantitative evaluation of the built space, we will also seek out consultation from experts of environmental control, including the school’s own professors of environmental technology.

Once the vault is constructed we will evaluate the performance of the passive environmental controls. The success of the design of the passive systems will require a thorough and quantifiable assessment. Quantitative measures of thermal performance as well as perceived comfort of the space will allow us to compare the as-built with the as-designed and thus evaluate not only the built space, but the proposed algorithmic model as well.
05 PROJECT TEAM

This project team strategically combines leading individuals with diverse skills and proven track-records each operating to extend the boundaries of traditional practice in architecture. This specific combination of people emerges from a series of successful collaborations between members from within the group. Together they bring a depth of creativity, knowledge and technical skill and practical experience in producing high-quality design installation work.

Applicant 01 (A1) Computational Design Expert
A1 co-directs research into robotic fabrication at the University of Michigan where he is the Visiting Professor of Practice. A1 has extensive experience directing large teams including his role as project team leader for the $5.5 billion Euro project to extend Monaco for Studio Daniel Libeskind. A1 is responsible for software development, computational form generation and visualization, and for overall project coordination.

Applicant 02 (A2) Robotic Fabrication and Craft Expert
A2 designed and installed the robotic fabrication facilities for Harvard’s GSD and the University of Michigan. A2 holds final responsibility for fabrication and for the quality of the final installed environment.

Applicant 03 (A3) Ecological Design Expert
A3 has extensive experience in producing high-quality design installation work. He will guide the direction of passive systems into the vault design. A3 will also direct material testing and sourcing and be responsible for prototype production.

06 SCHEDULE (KEY DATES)

2010 APRIL/MAY
Notification of RTM Application Approval
Team Re-Vault Kick-Off Meeting.
Confirm final site for construction.

MAY
Material testing + experimentation.
+ Computational form-finding functionality development. This includes creating an iterative feedback loop with Ecotect using existing ‘middleware’ or developing our own custom plugins.

EARLY JUNE
External Review 01
Presentation of research and techniques

JUNE
Full-scale (1:1) Prototype Design, Development, Fabrication + Testing

EARLY-JULY
External Review 02
Presentation of final sketch design

MID JULY
Confirmation of Final Design

MID-JULY - MID-AUGUST
Construction of final assembly components. (Some overlap with on-site construction)

MID AUGUST
Begin construction on site

MID-SEPTEMBER
Construction Completed
External Review 03
Presentation of completed project

DECEMBER
Exhibition materials compiled

2011 Exhibition of project

07 BUDGET

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PRECEDEnTS
OTHERS WORK AND RESEARCH THAT INSPIRES US AND THAT WE WILL BUILD UPON
FOUNDATIONAL RESEARCH
OUR OWN EXISTING BODY OF RESEARCH TO BE EXTENDED THROUGH THIS GRANT
ALGORITHMIC TRACERY
SYSTEMS WITH STRUCTURAL AND ORNAMENTAL BEHAVIOURS
Iterative catenary and non-catenary (non-uniform load) solving

SuperRelaxation
2006-2010

CUSTOM WRITTEN DYNAMIC RELAXATION STRUCTURAL OPTIMIZATION CODE

DIGITAL FORMFINDING

<< SIMULATION STATISTICS >>
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TIME: 0:00
RMS count 1200
CPU time used: 0.0020

APPENDER: 11
Iain Maxwell
03 ROBOT CONTROL CODE

CUSTOM WRITTEN INVERSE KINEMATIC SOFTWARE

// FOUNDATIONAL RESEARCH

03 Hotwire Cutting simulation sequence exported from custom written robot control software

SuperKUKATools 2009-2010

Applicant 01
Applicant 02
Applicant 03

Applicant 04
FOAM DEPOSITION
ROBOTICALLY CONTROLLED POLYETHYLENE ADDITIVE FABRICATION

Additive Foam Research
Full scale polyethylene foam wall prototype

Applicant ID, Applicant 01 [Instructors]
Kris Walters, Les Key, Jae Ryong Oh, John Puff, Dan Weissman [Grad. Students]

CNC Surface Milling after foam deposition
Additive Foam Research
Full-scale polyethylene foam wall prototype
Kris Walters Jr, Les Key, Jae Hyung Oh, John Puff, Dan Weissman (Grad. Students)

Large Scale additive fabrication sequence
Additive Foam Research
Full scale polyethylene foam wall prototypes
Applicant 02, Applicant 01 (Instructors)
Kris Walters Jr, Les Key, Jae Ryong Ch., John Puff, Dan Weissman (Grad. Students)
05 SURFACING STONE

Installation on the grounds of Harvard GSD, Completed 2009

01 Completed wall, spring
02 Tectonic detail
03 Elevation, NTS

Foundational Research

6-AXIS ROBOTICALLY CONTROLLED WATER-JET CUT STONE
Glass Slumping Research
Initial Prototypes

Applicant ID, Applicant SI (Instructors)
Sang Hoon Lee and Jianyi Zhang
Grad. Students

Credits