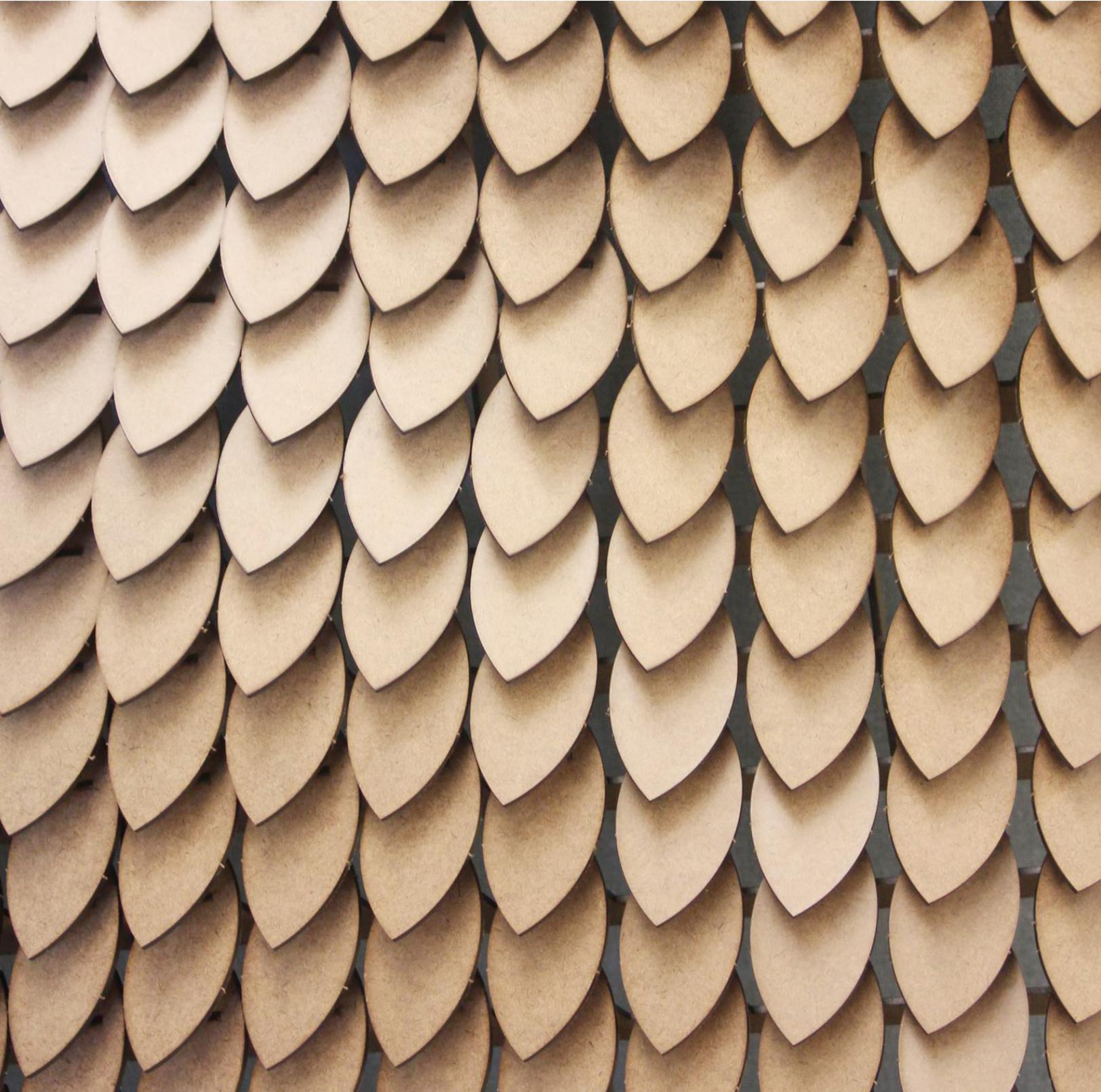


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04.

PERFORMANCE-DRIVEN DESIGN AND PROTOTYPING:

Design Computation and Fabrication

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ABSTRACT

This article discusses performance-driven design and fabrication as one of the emerging approaches in architectural design, where computational tools are used for integrated design exploration, analysis and fabrication. It discusses development of a new course that integrates simulations into the design process with special consideration for parametric design. Simulations and digital modeling are used to investigate design performance while fabrication is used as rapid prototyping method to explore forms, material properties and actual physical characteristics of the design. This course was a collaboration between University of Cincinnati, Perkins and Will and University of North Carolina Greensboro. The objectives were to investigate best practices for performance-driven design and the correlation between digital modeling and physical prototyping through digital fabrication techniques. The article presents several student projects from the course that explore the general process.

KEYWORDS: performance-driven design, analytics, fabrication, computation

1.0 INTRODUCTION

By using computer-aided design (CAD)/computer-aided manufacturing (CAM) and simulation tools, architects and designers are integrating digital computation with analytical design processes and fabrication techniques. These processes are emerging as a new direction in computational design and provide unprecedented methods for the exploration of form, analysis of physical properties and simulation of building performance. To test the use of computational methods for model generation, analysis, decision-making and design communication, a new course, "*Performance-Driven Design and Prototyping*", was developed in the School of Architecture and Interior Design at the University of Cincinnati during spring 2011. Co-taught by Professor Ming Tang, Dr. Ajla Aksamija, Mike Hodge and Professor Jonathon Anderson, this course covered parametric modeling techniques associated with performance-based design and digital fabrication. The course explored the integration of parametric design, building performance evaluation, analysis, visualization and physical representation. Rapid prototyping and digital fabrication methods were

used to study design at varied scales and for reviewing constructability.

We used video conferencing and podcasts for remote collaboration and teaching. This method was also used as a means to critique student projects. As a result, eight projects were designed and fabricated in the Rapid Prototyping Center at the University of Cincinnati. This article reviews the foundations of performance-driven design and digital fabrication, their use in architectural design process and outcomes of the course.

2.0 WHAT IS PERFORMANCE-DRIVEN DESIGN?

The central feature of performance-driven design is a process supported by an analytical evaluation of environmental performance based upon simulating physical conditions. The performance results then become the input for form-finding and basis of geometric modeling through the use of digital tools. Quantifiable predictions through simulations and modeling help in identifying strategies and methods to improve building

performance¹. For example, the objectives for attaining extremely low and zero energy buildings rely on several strategies including the use of passive methods, advanced building technologies and renewable energy sources. There is a need to quantify the benefits of each individual methodology and relate them to a specific design problem, building, climate and context. Quantifiable predictions during the different stages of the design process help establish matrices that can be used to measure improvements by using these different strategies.

A design method that integrates energy, environmental and other types of analysis at early design stages is the basis of performance-based design. The differences between this approach and traditional design methods are¹:

- **Traditional Method:** has certain deficiencies because: (1) it includes simplified assumptions based on rules-of-thumb that can be imprecise (for example, forcing an aesthetic feature); and (2) may not be accurate in relation with performance measurement of design solution.
- **Building Performance-Based Design Method:** has power in assessing the performance of a design solution because it: (1) uses performance measures with actual quantifiable data and not rules-of-thumb; (2) aims to develop a simulation model of a complex physical system; (3) uses the model to analyze and predict behavior of the system; and (4) produces a quantifiable evaluation of the design.

Performance-driven design integrates design objectives and analysis/simulations, such as solar radiation, to reach solutions based on input parameters and design logic to establish results of design process. Figure 1 is an example of an integrated design workflow combining analysis and parametrically responsive surface panels. In this case, solar radiation data is used to determine the degree of shading needed to protect a complex geometric form and reduce solar heat gain. The design of shading elements and their form is parametrically determined based on the solar radiation analysis results².

Oxman describes this approach as a determinant and method for the creation of architectural form. She states, "in such circumstances digital design diverges from a design paradigm in which the formal manipulative skills and preferences of the human designer externally control the process to one in which the design is informed by internal evaluative and simulation processes."³ During the last decade, performance-based design has become the leading digital design methodology in a spectrum of emerging design computation methods. It is transforming practice, research and development and education. This new course explored the generation of spaces and building components by regulating a series of parameters driven by performance-based factors. In this investigation, students furthered their understanding of space by discovering how parameters affect the overall performance quality and character of a spatial artifact. Digital tools such as Maya, Rhino, Grasshopper and Ecotect were introduced to the process for simulation, digital form-finding and fabrication.

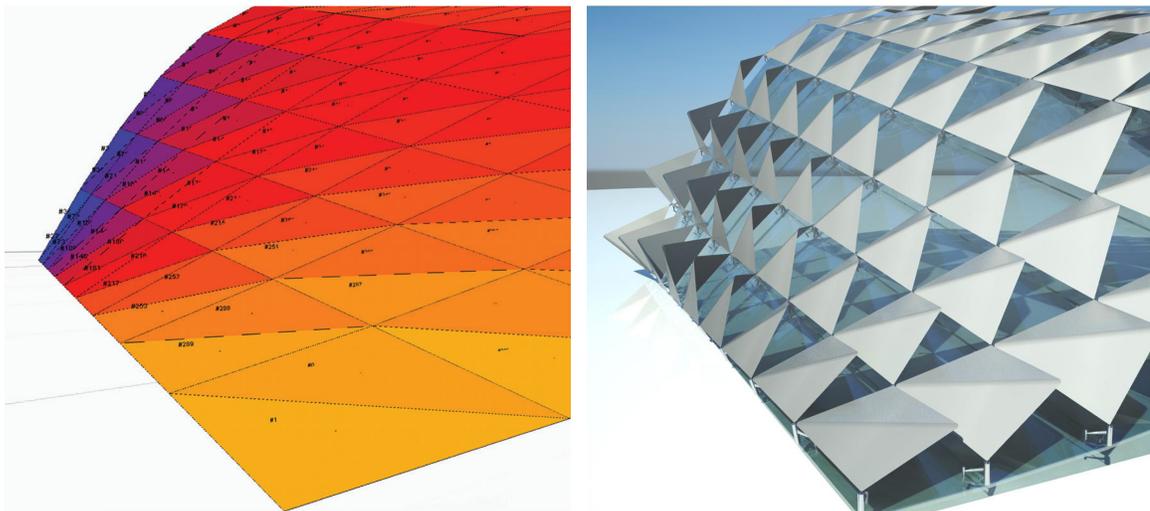


Figure 1: Design of building skin and shading elements in response to solar radiation data.

3.0 WHY IS THE PHYSICAL REALIZATION AN ESSENTIAL PART OF THE DESIGN?

Representations of architectural design have evolved to reflect the changes in building technology, materials, design practices and construction. Advancements in information technology allowed for novel representational methods through primarily CAD systems, three-dimensional modeling and simulations of building performance⁴. Furthermore, parametric thinking and CAM tools have yielded a significant leap for designers, where they are able to explore digital fabrication and material processing techniques. As Castle argues, “the onset of CAD/CAM interfaces that allows designers to design directly for manufacture has placed production potentially back in the hands of the architects.”⁵ By combining parametric design tools with rapid prototyping techniques in the design process, designers and architects have powerful real-time capabilities to generate multiple design options, iterate conceptual approaches and end with scaled artifacts to study, review and critique their design solutions.

Digitally generated solutions lend themselves to fused deposition modeling (FDM or 3D powder print), CNC milling or laser cutting methods. Part of the design challenge, when designing with digital fabrication as a driver, is the ability to realize the conceptual idea within size limitations and allowances of the current fabrication tools. As Iwamoto describes, “as in conventional construction processes, information is translated from one format to another to communicate with the builder – only in this case the builder is a machine.”⁶ For example, one of the challenges is how to break down complex forms, which are automatically generated from a performance-driven design process, as simplified components that can be realized by fabrication and assembling. Through a slicing method, a complex form can be easily divided into a large quantity of 2D contours or patterns. For instance, these components can be labeled and cut with laser cutters or CNC milling machines and then re-assembled to reveal the complex form. The workflow from performance information, such as solar radiation, to the pattern of building skin, to

the G-code of CNC machine stimulated many interesting approaches among projects, which are discussed in the next sections.

4.0 COLLABORATION

In this academic and professional collaboration, topics such as parametric design, fabrication and simulations were introduced with the objective to design and fabricate a building component based on performance-driven design. Ming Tang covered fundamental principles of performance-driven design and essential computer skills with various software and methodologies. Dr. Ajla Aksamija and Mike Hodge covered performance-driven design in practice, application of simulation tools during the design process through several real projects where performance-driven design methods have been used. They also shared results of research projects and internal tools they developed for parametric design.² Jonathon Anderson covered various fabrication techniques such as vacuum modeling, casting and CNC patterning/folding. The course focused on the following key elements:

- **Performance-driven design methodologies:** Key concepts and issues in the application of performance-based design were introduced. Case studies and several group projects were developed to challenge students to design a building skin that responds to environmental input parameters.
- **Rapid prototyping:** Digital fabrication technologies were used as rapid prototyping method to develop different physical models (study, development and final models). Here, the direct capability of digital model-to-fabrication served as a means of producing a tangible “artifact” to study and/or represent milestones through the design process and development.

Digital production processes that were used during the course allowed for distinct design and fabrication phases (Figure 2). The design phase required the use of simulations and parametric modeling techniques for the design of forms and components based on perfor-

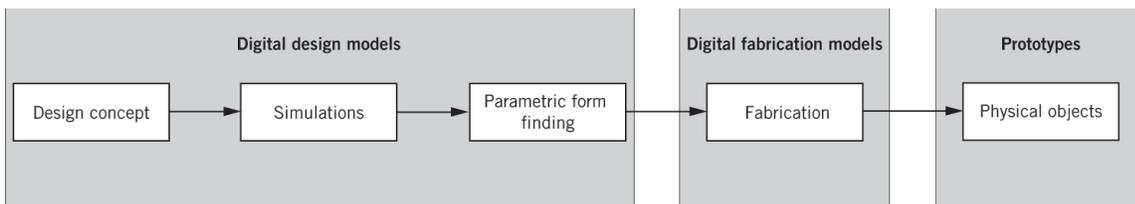


Figure 2: Digital design production process.

mance data. The fabrication phase introduced different techniques such as laser cutting, CNC milling, 3D printing and assembly. The final outcomes were physical prototypes of the designed components.

Each student produced a few conceptual models including a set of diagrams used to understand the relationships between performance and the resulting actions that generated the form. They produced final prototypes of their designs, which demonstrated the transition from design concept, performance-driven solution to fabricated assemblies (Figure 3).

This teaching method received positive feedback from students and colleagues at the University of Cincinnati. Video conferencing, blog postings and data sharing provided efficient ways to communicate among the collaborators located in four different locations. Students greatly appreciated the opportunity to talk to professionals who are using the digital tools in practice. In the course evaluation, students anonymously described that the most important aspect of the course was, “insight into techniques how the parametric design can/may impact architecture in a practical way”.

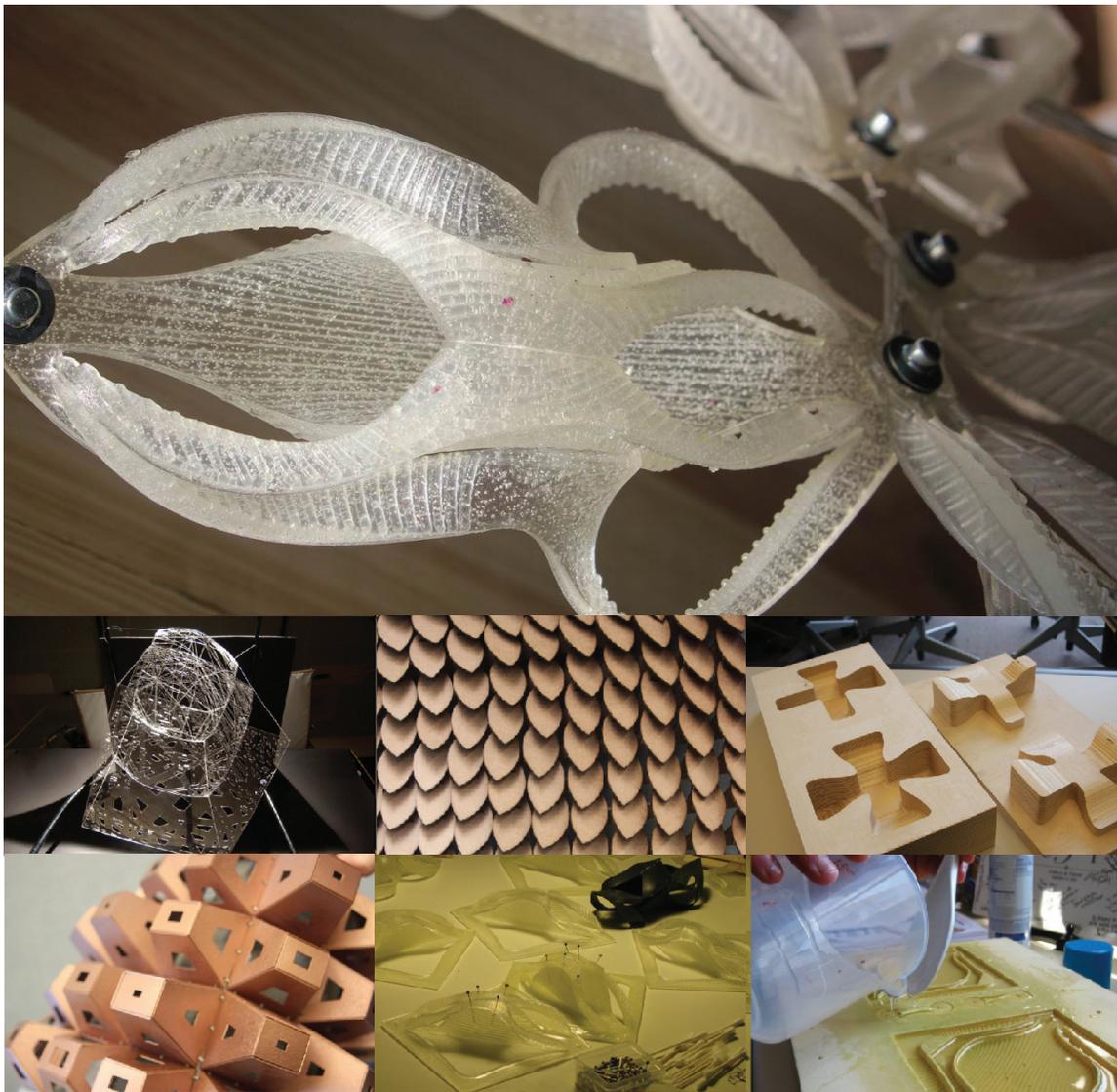


Figure 3: Examples of fabricated components.

5.0 PROJECTS AND COURSE OUTCOMES

At the end of ten teaching weeks, students were exposed to performance-driven design methodologies and fabrication techniques. Students demonstrated advanced modeling skills to explore complex forms with parametric design processes. They also demonstrated various digital fabrication skills with CNC milling, laser cutting and casting as manufacturing methods. The following are a few selected projects.

5.1 Parabolic Elasticity

The purpose of this project was to explore material prop-

erties of casting urethane elastomers and their structural behavior. The form was derived based on tensile stresses and deflections of this material and behavior of a building skin component. The material performance became the design driver where the tensile stresses in the material were tested and adapted to a rigid frame. CNC-milled high density foam mold served as the casting medium for liquid urethane elastomers. Series of lines were cut in the mold to form surface texture on the components. After all individual urethane elastomer components cured, they were assembled using aluminum connectors (Figure 4).

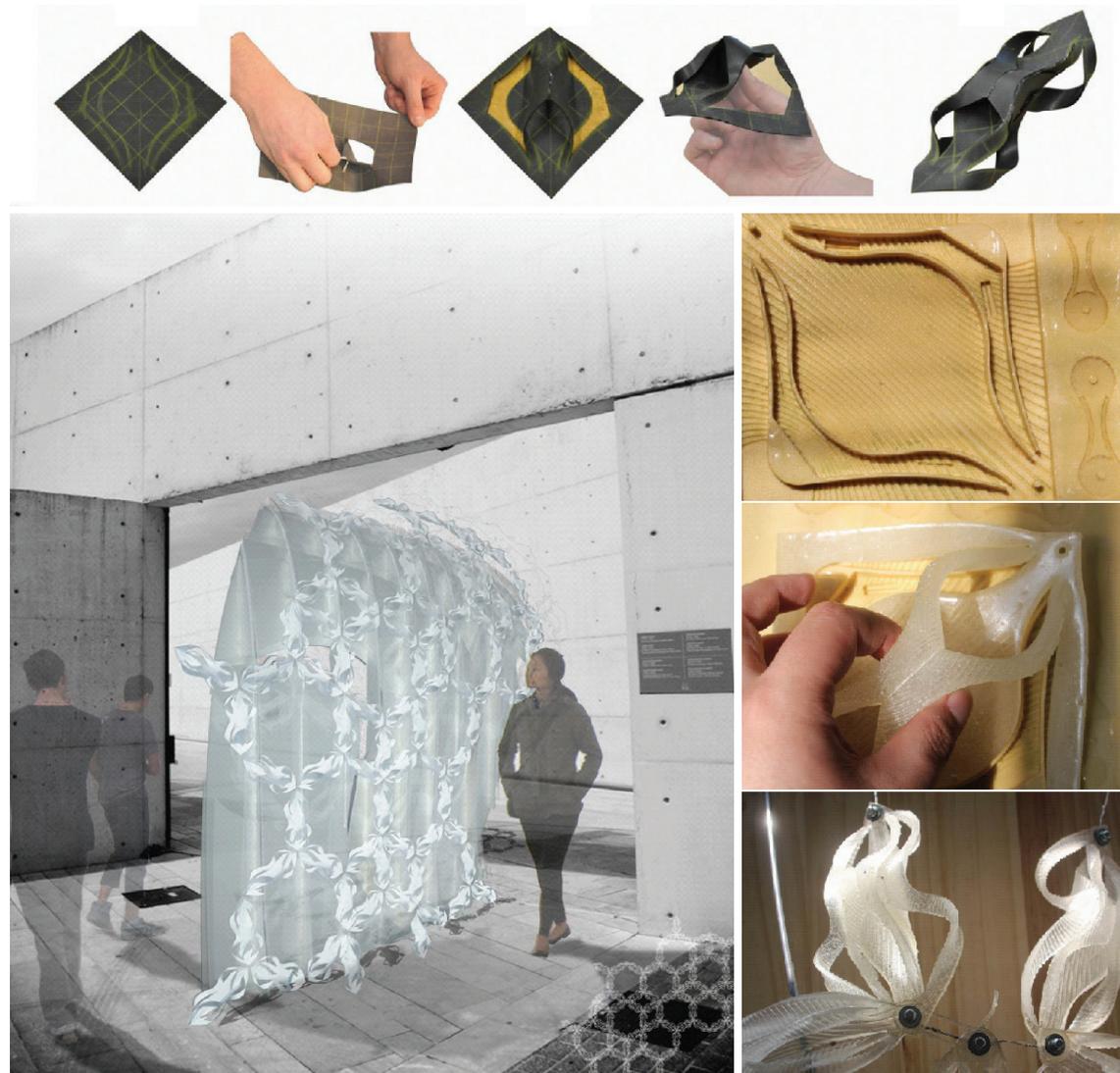


Figure 4: Project example with fabricated cast urethane elastomers.

5.2 Geometric Morph

The purpose of this project was to investigate parametric design as it relates to a component of a building skin with varying percentage of openings and controlled geometry. The module was designed as an extruded octagon, consisting of square openings where the scale of the aperture was controlled parametrically

based on design constraints. The design rule was that openings would be smallest at low points and largest at high points, which resulted in a gradient across the entire surface. This component was fabricated by laser cutting where the negative shapes were cut from mat-board to reveal the fabricated components and complex geometry (Figure 5).

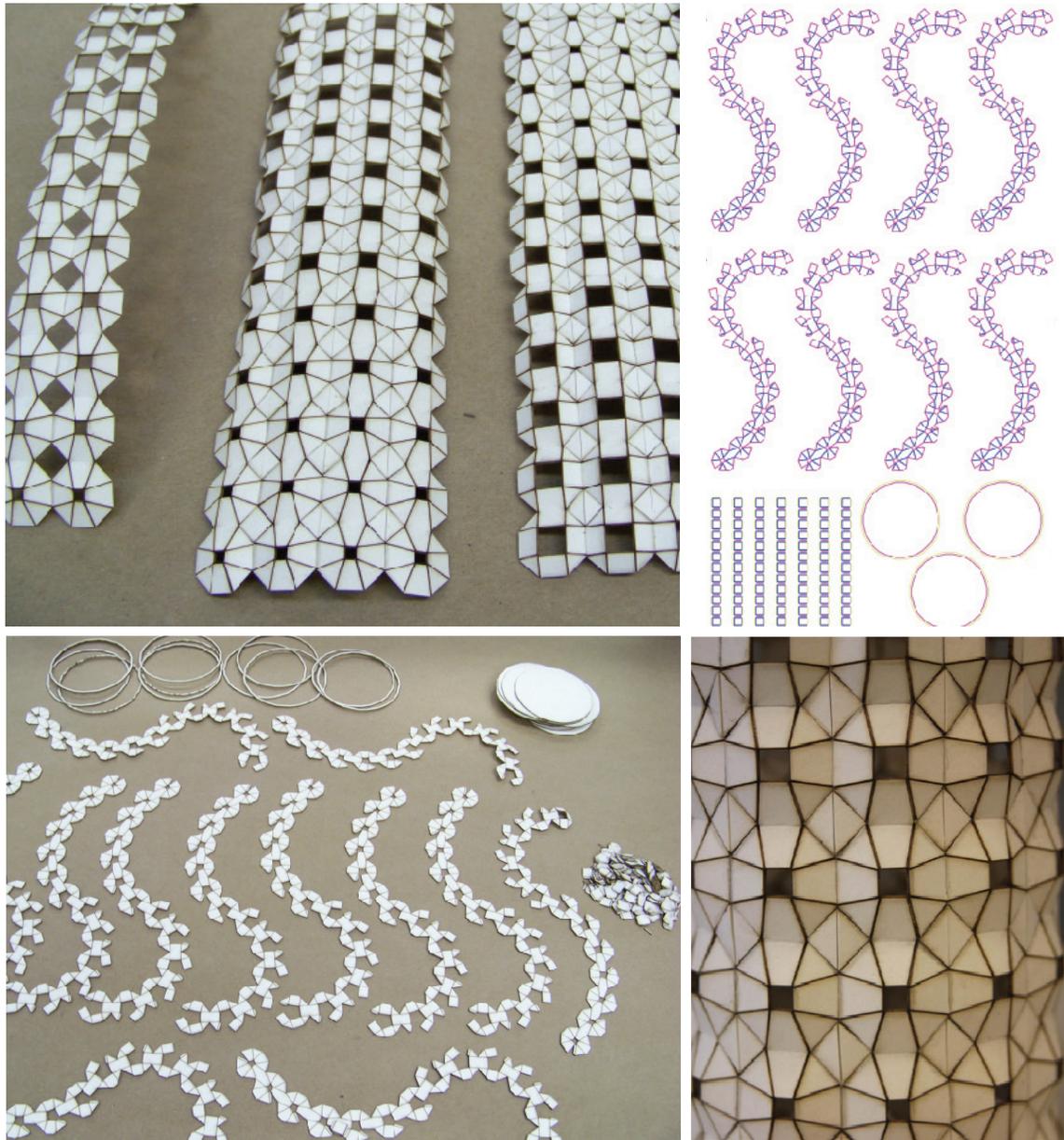


Figure 5: Project example with laser cut parametrically-derived geometry.

5.3 Parabolic Weave

The objective of this project was to create a shading system that responds to varying levels of solar radiation. The system consists of a metal frame and series of threads woven through the frame. The metal frame can be expanded and collapsed, changing the porosity

levels between the strings. The metal frame was fabricated from aluminum panels using CNC milling. Steel joints were manually fabricated and the prototype was assembled by joining individual aluminum frames and weaving string (Figure 6).

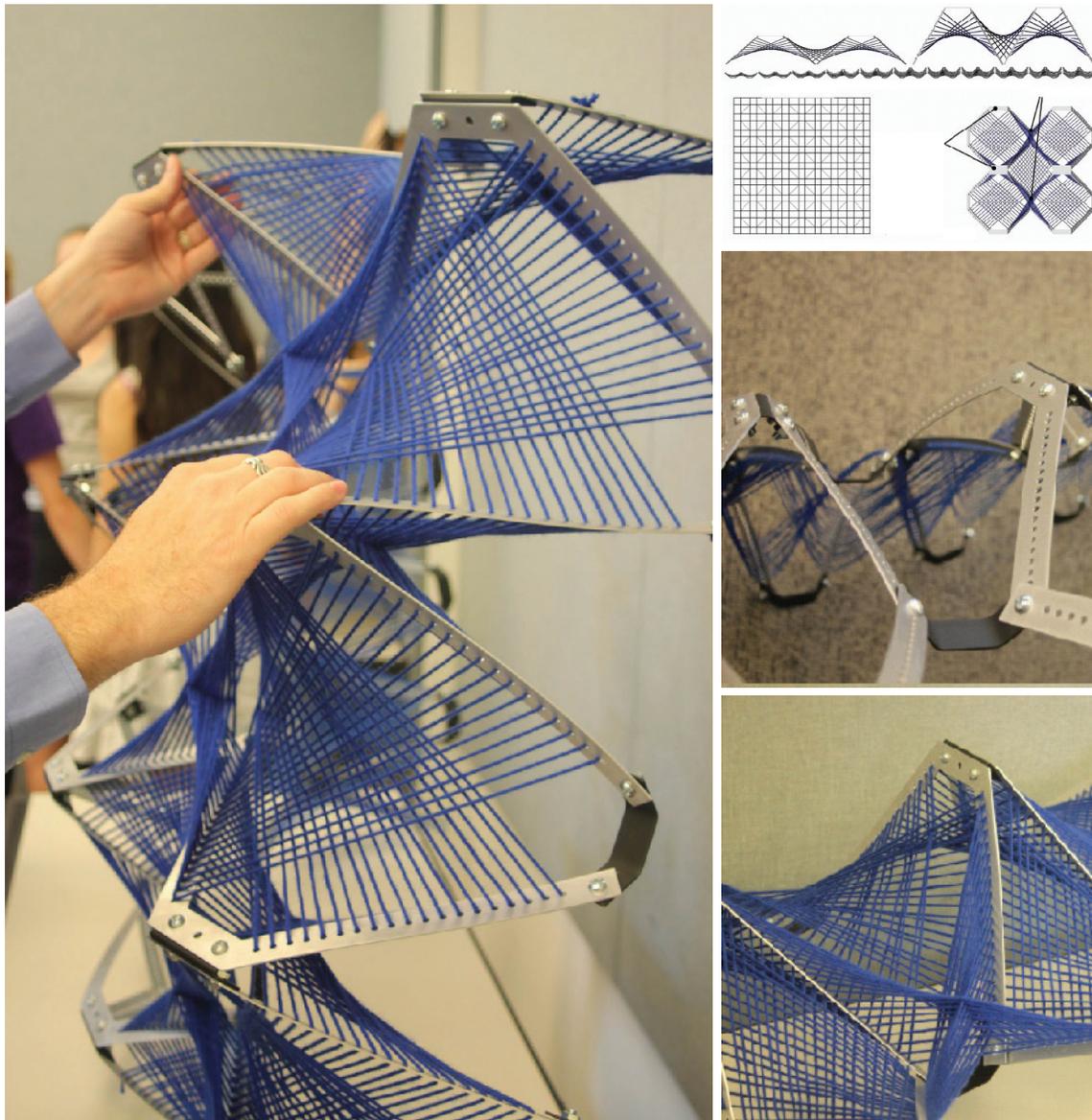


Figure 6: Project example with CNC-milled aluminum frames and movable parts.

6.0 CONCLUSION AND FUTURE COLLABORATION

New developments in advanced computational tools and methods are offering unprecedented ways for design exploration and evaluations. Performance-based design that integrates simulations and analysis in the design process has an advantage over traditional design methods since it allows a certain design iteration to be measured and evaluated against different solutions. Also, digital fabrication techniques allow for creation of physical prototypes, which can be used to evaluate constructability, material behavior and selection as well as aesthetic qualities. In this article, we discussed a collaborative course focusing on performance-driven design and prototyping, which explored integration of simulations, environmental analysis, parametric design and digital fabrication. The projects showed that students learned effectively through emerging technologies that were introduced in the class. By engaging the students in an interactive and collaborative learning process through web conferencing and social media, we have created a rich learning environment crossing the bridge between academic institutions and architectural practice. During the current fall quarter of 2011, a studio course has been launched at the University of Cincinnati to further the collaboration and research.

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REFERENCES

- [1] Aksamija, A., and Mallasi, Z., (2010). "Building Performance Predictions: How Simulations Can Improve Design Decisions", *Perkins and Will Research Journal*, Vol. 2, No. 2, pp. 7-32.
- [2] Aksamija, A., Guttman, M., Rangarajan, H., and Meador, T., (2010). "Parametric Control of BIM Elements for Sustainable Design in Revit: Linking Design and Analytical Software Applications through Customization", *Perkins and Will Research Journal*, Vol. 3, No. 1, pp. 32-45.
- [3] Oxman, R., (2008). "Performance-Based Design: Current Practices and Research Issues", *International Journal of Architectural Computing*, Vol. 6, No. 1, pp. 1-17.
- [4] Aksamija, A., and Iordanova, I., (2010). "Computational Environments with Multimodal Representations of Architectural Design Knowledge", *International Journal of Architectural Computing*, Vol. 8, No. 4, pp. 439-460.
- [5] Castle, H., (2005). "Design through Making", *Architectural Design*, Vol. 75, No. 4, pp. 4.
- [6] Iwamoto, L., (2009). *Digital Fabrications: Architectural and Material Techniques*, New York, NY: Princeton Architectural Press.