Designed for Performance: Informed Models and Experimental Methods in Architectural Education

Increasing performance with respect to energy and sustainability is an ever-increasing demand on buildings and the design profession; a more explicit approach to prototyping and experimental design in education is required, involving an experimental process framed upon informed models to better understand the links between designed artifacts and performance.

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ARGUMENT: INFORMED MODELS

With ever-increasing efficacy, today's buildings are expected to respond to the multivalent challenge of sustainability. A critical aspect of this sustainability is the integration of performance with the many qualitative imperatives of design. Yet in architectural education, sustainability at times is limited to ancillary technical knowledge from textbooks and building cases – leaving a gap with the broad activities of design upon which architectural education is focused. The field of architecture has learned from the profession that designing high performance buildings involves more than the application of technical knowledge – it is a pursuit where performance must be addressed as integral with design, where an understanding of performance informs decision making throughout design activity. Preparing architecture students to contribute to the design of high performance buildings means education must introduce students to methods of understanding, evaluating, and maximizing performance in the design process, thinking beyond simplistic efficiency towards the integration of broader architectural imperatives related to environment and occupants.

In discussing the introduction of performance in architectural education, this paper presents work from a research studio at Kansas State University that worked closely with the Kansas-City based firm Berkebile Nelson Immenschuh McDowell (BNIM) to dialogue about research methods' emerging role in practice, and to better understand the relevance of research findings against building imperatives. One of the important aspects of this studio was intensive use of experimentation, prototypes, simulations, and design scenarios to study and explain the performance of ventilated building skins in warm climates. While the studio's research topic is summarized, the dialogue in this paper focuses upon how the research process was integrated in studio and the implications of the research process to design and practice.

Two important trends in design – evidence-based design and research-based prototyping (closely associated with Design-Build) – are united in the concept of informed models in the experimental process. Evidence-based design and prototyping by themselves are criticized for their narrow focus: respectively focusing either too narrowly on evidence and data, or focusing too narrowly on the act of fabrication. What will be argued is that in answering the problem of performance, informed models as part of an experimental design approach integrates evidence, simulation, and prototyping in a single mode of research. These informed models can become the organizing framework for research, experimentation, and inquiry, suggesting an alternative view to evidence-based design. While evidence-based design is methodically a bottom up approach (loyal to the scientific method), the informed model allows the process to work both from bottom up and top down, bringing the bottom-up approach of the scientific method together with the solution-driven approach that characterizes the messiness of the traditional design process (Fig 1).

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The arguments made in this paper don't call for the wholesale appropriation of the scientific method by designers. Instead the attitude presented here is one where design remains the centerpiece of the experimental process, providing a framework for scientific methods to inform design. The importance of hewing experimental methods in design is also quite evident when we compare what we can do with technological tools versus their actual impact in the profession. In order to achieve high-performance architecture, it is the approaches and methods incorporating these tools that must be integrated in design, rather than the tools and the data they reveal.

SCIENCE, ARCHITECTURE, AND PERFORMANCE

Designers tend to either fully embrace the scientific method or are skeptical that objective thinking will ruin the creative purity of the design exercise. Brian Lawson (2009) describes the rift between analytical, science-based thinking and creativity as a sort of "schitzophrenia" that faces designers. A 1979 experiment conducted by Lawson presented student designers and student scientists with a simple design-like problem, characterized by interdependent yet also ambiguous rules: the scientists began with organized analysis and solved the problem after it was clearly understood, while the designers began by testing whole solutions to evaluate successes and failures (Lawson 2009). In Lawson's terms, this experiment illuminated the difference between the analytical approach used by science and the solution-based, creativity-biased approached used in design.

In the architectural discipline, we tend to treat design as solution-based, creating buildings (or building components) and declaring their successes and/or failures – not unlike the design students in Lawson's experiment. Yet buildings (and design problems) are wildly complex: the environmental systems, material systems, and

Figure 1: Engineering and science disciplines are known for a bottom up reductionist approach while designers and other creative disciplines work from the top down; working around an informed model allows both bottom up and top down thinking.

assembly systems interacting together in buildings are hardly understood in an absolute sense. In the sciences, the complexity of nature is approached not with solutions, but with inductive reasoning made famous by Francis Bacon's statement that "[w]e cannot command nature except by obeying her." Faced with this complexity, science assumes the answer is unknown and must be revealed analytically. The performance realities of buildings can only be understood through testing, and thus architects have to augment solution-based design thinking with an experimental process that can illuminate a complex interaction of systems.

Consequently, the practice of architecture is shifting towards delivering performance alongside design. At Berkebile Nelson Immenschuh McDowell (BNIM), the importance of performance in practice is ushering in important changes to the way projects are designed and delivered. First, performance-based compliance is now a normal feature of projects that use innovative or non-standard ways of complying with energy code and LEED criteria; this requires a team of experts, but also requires deep knowledge of building performance that must be cultivated within the firm. Secondly, the demand for performance is increasingly 'realistic' where owners are concerned with things such as live cycle assessments and net-zero operations that unlike energy efficiency can't be evaluated by any single tool but must be realized in the process from the beginning. (BNIM interview)

Traditionally, architects and consultants faced building performance challenges only in the design process. In order to better realize sustainability in buildings, building commissioning is now a part of green building certification. Commissioning is the forensic process of verifying the original, designed performance promises of buildings along with its building systems: in other words, performance testing the building against its original predictions. A 2009 report from Lawrence Berkeley National Lab summarizing the commissioning of 643 commissioned buildings tallied over 10,000 documented deficiencies that were resulting in energy use excess of 13 to 16% on average (LBNL Paper). Thus the gap between performance intent and reality is fairly wide. Philip Schneider, director of the National Institute for Building Science predicts that commissioning will "impact practice the same way litigation did in the 1970s" (Schneider 2014) making this an issue of great importance to designers, giving the realization of performance more important than merely the aspiration of performance in the design process. If architects must become serious about performance, we must better understand and predict how buildings work rather than superficially evaluate their efficiency or rely on a separate process of engineering.

Answering the call to reintroduce analytical methods to design was the contemporary movement of 'evidence-based design' which now dominates the dialogue regarding the use of research methods by designers. Evidence-based design, in summary, called on designers to support design decisions with "credible, applicable evidence" that would be gleaned and assembled through rigorous methods (Brandt 2010). The emphasis of 'evidence' as part of evidence-based design, however, is misleading because it suggests that the evidence has a sort of primacy across the process of research and design, overshadowing the initial formation of research assumptions and interpretation of research results. These latter two components are more nuanced than literature reviews and data collection expounded in evidence-based design discourse. Interestingly, the scientific community has cultivated a similar debate over the role of experimentation in science: with one group arguing that experimentation must be purely based on observation (i.e. evidence) while others argue that experiment without theory is impossible, with theory introducing essential "non-local" meaning to research (Radder 2003). Hans Radder uses the example of Newton and Hooke's dueling theories of light in the study of prisms, which uses similar experimentation to reach two very different theoretical positions that were significant for their interpretation and scientific context, rather than their individual observations (Radder 2003). Thus it is necessary to approach analysis and design with an emphasis on interpretation and context; it is important to acknowledge the importance of how research must be interpreted and applied. Integrating analysis and scientific methods with design is more significant than simply guiding design decisions with evidence; the evidence must after all be contextualized within the artifacts of design. Recognizing both the creative and analytical potential of doing so, this approach should be cultivated from an early stage in the experimental process.

FROM EVIDENCE TO INFORMED MODELS

Traditionally, models were used by designers to organize design intent into a holistic statement of what the project should be. Such a model can brutally top-down, however, as the building is contorted to fit the framework of the model. When these models integrated systems (the performing components) these systems were engineered to yield to the authority of the design. Bringing evidence into decision making makes this process more objective and bottom-up, but we are also arguing for an approach that can be both solution-based and analytically based at the same time. When organizing background research, evidence, and observations, scientists create what is referred loosely as a 'model' representing the system that is the subject of research. The model serves important functions, beginning as the initial prediction of outcomes, functioning as a framework for observations and for identifying data patterns, and later as the scaffold for future predicted behavior and scientific theory. In the search to better contextualize evidence, the 'model' from scientific research proves similar to the iterative models used by designers in the design process. Here we arrive at informed models, where the design model is overlaid with information, predicted behaviors, and evidence that are associated with the research process (Fig 2). Robert Brandt writes that with respect to models:

> "[c]ritical…is the willingness of the design to create a hypothesis about an artifact to be tested, either physically or virtually, knowing the perception of the artifact is incomplete or maybe even wrong. The iterative process of testing and evaluation, modeling, or simulating transforms an artifact toward some specific articulated performance outcome, use/activity, light, behavior, etc. This process is not about rationalizing an idea or a vision, but one of transformation of ideas and visions to meet specific performance outcomes. The more rigorous and transparent the performance outcomes, the more transparent the design process will become connecting the artifact to evidence that supports increases in performance." (Brandt 2010)

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Figure 2: Students sketch out a working 'cool skins' model to Professor Larry Weaver of the KSU Department of Physics. Informed models are both solution -based and analytically based at the same time, representing both the assertions of the research and its proposal as a designed artifact.

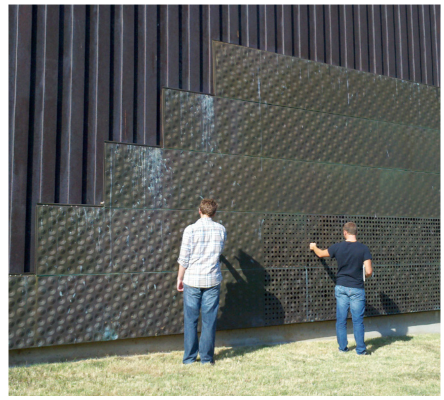
As the key to an experimental process, informed models (rather than data) provide a place to contextualize evidence and knowledge, while also becoming the vehicle for inquiry. It may be argued that an approach centered on informed models presents a clearer picture of how creativity and analysis coexist in the same process. Bill Mitchell of the MIT Media Lab refers to models (via prototyping) as a critical "first action" generating the critical questions required to propel research forward, noting that in design, designers need to "speculate first" in research (Brandt 2010).

Michael Brawne writes in *Architectural Thought: Design and the Expectant Eye* that the artifacts of design (sketches, models, prototypes) are primed with "conjecture and refutation" underscoring the notion that design inherently involves testing unknowns, giving designers the need to probe and iterate to find design solutions

(Brawne 2003). When informed models organize the research process, they not only structure decisions and information; models are critical in the process of evolving assertions and developing critical interpretations (Fig 3). From the beginning, if designers are primed to interrogate models, this offers an improved framework for dealing with the complexities of performance. Activities like energy simulation and commissioning are no longer 'final steps' but an extension of a continuous experimental process.

A CASE IN INFORMED MODELS: THE COOL SKINS STUDIO

The main aim of this paper is to argue for and articulate an experimental approach to architectural problems based around informed models, borrowing from scientific methodologies and augmenting what is already part of the discourse of evidence-based design. In support of this argument, a research studio conducted at Kansas State University and composed of twelve graduate students is introduced along with the studio's research process. For many students, this research studio is the first occasion where prototyping and experimental methods were pursued in systematic, objective inquiry. In the studio, prototyping was not merely passive, but critical exploration where both quantitative and qualitative performance was measured, interpreted, communicated, and applied. In this process design knowledge was not alienated but rather served as an important asset for the students in experimental process.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The impetus of the studio was to study how to maximize the cooling season performance of passively back-ventilated building skins (also known as rainscreens) in warm climates with intense solar heat gain. Preceding the convening of the studio in the Fall of 2013, an earlier research process took place that helped to define and narrow the focus of the studio. Inquiry began in the Fall 2012 (see Gibson 2013) exploring the simple premise that rainscreen walls, normally used for moisture control in envelopes, were capable of mitigate cooling season loads for buildings. The latter was the first 'model' in the research, a series of sketches and images that synthesized among various knowns and unknowns about the thermal behavior of the system. This informed model was an important lens for the literature review and critical evaluation of existing models (mathematical and empirically derived) for calculating heat transfer in ventilated cladding. Experiments were conducted using live testing of full-scale prototypes as well as computer simulation. The results of experiments required deep interpretation but in the end a new model emerged that explained that to perform optimally for cooling, ventilated cladding should have open joints and should use a material like aluminum that combines high thermal diffusivity and low mass. (see Gibson forthcoming)

The Cool Skins research studio conducted during the Fall 2013 began with the aforementioned cool skins model as their starting point: aluminum skin, ventilated, with open joints. Students moved forward with the charge of developing and testing cool skins models that improved upon conventional aluminum rainscreen cladding. During the first half of the semester, students toured the A. Zahner Company of Kansas City to learn about fabrication technology and were able to share early conceptual ideas with Zahner engineers for feedback. The group of twelve students divided into three teams, with teams pursuing increased performance over conventional aluminum panels with three distinct strategies. The first strategy looked for advantages in materials, with students looking at a range of metals, patinas, and surface treatments. A second group took on surface perforation, choosing to work within the unchanged plane of the cladding. The third group explored geometric variations in cladding and cavity depth. Work in the studio moved forward through

Figure 3: Students evaluating the thermal behavior of a Zahner mock up of the De Young Museum -- leading to a "hypothesis about an artifact to be tested." The observations evolved into a model for further inquiry.

first clarifying the parameters of interest in tests. In earlier testing, cladding and backup wall equilibrium temperatures were tested, along with air velocity. When experimental design began, a literature review (see Gibson forthcoming) and new assumptions about the dominant forms of heat transfer in cladding led the group to pursue measurement of cladding equilibrium temperatures in experimental systems rather than generalize a complex system of convection. All of these refinements added layers to the models developed in the research.

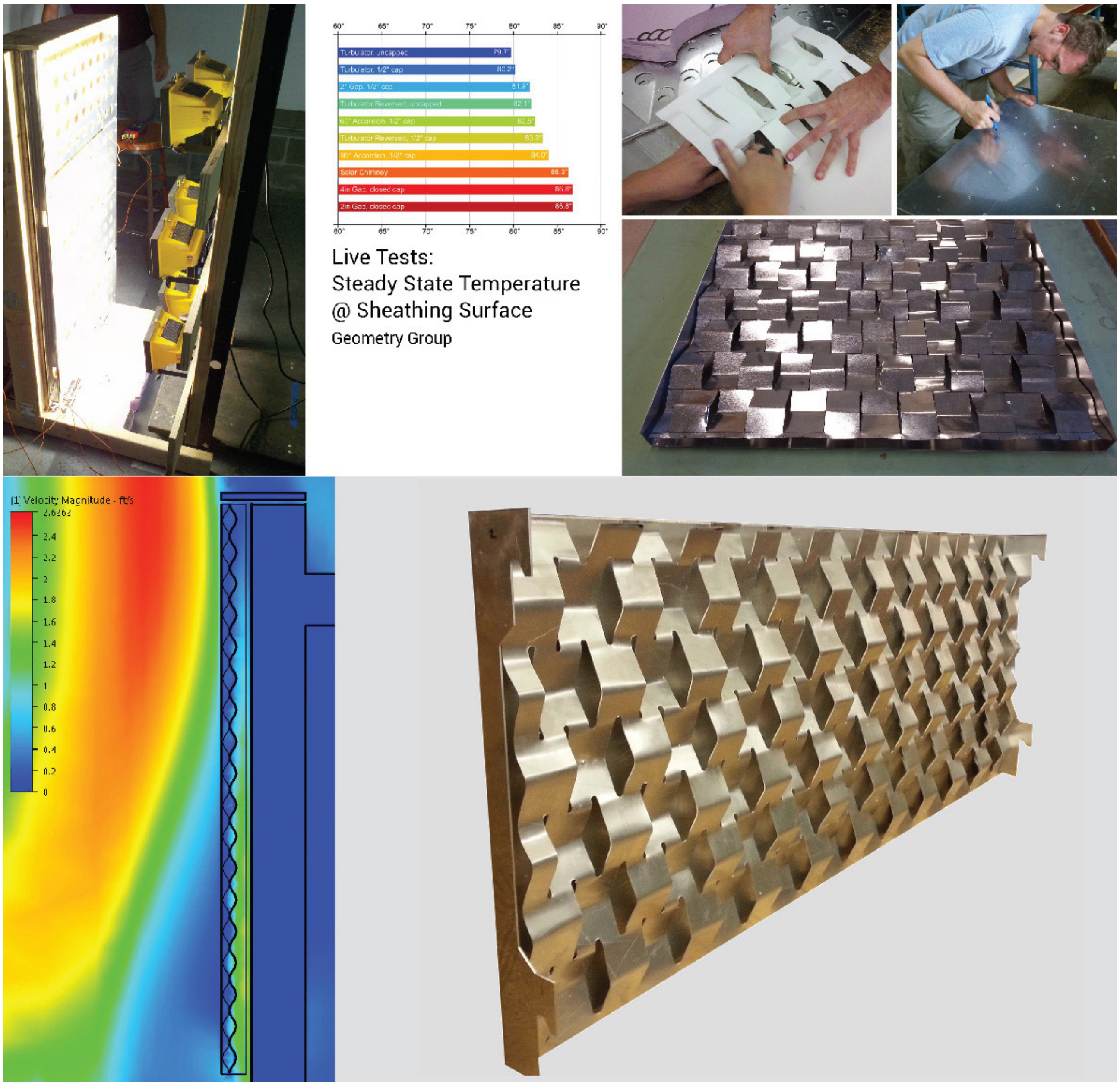

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Figure 4: Progression of models and experiments produced by the Geometry group in the Cool Skins Studio, showing the evolution of the 'turbulator' concept through live testing, prototype redesign, CFD simulation, and full scale prototyping

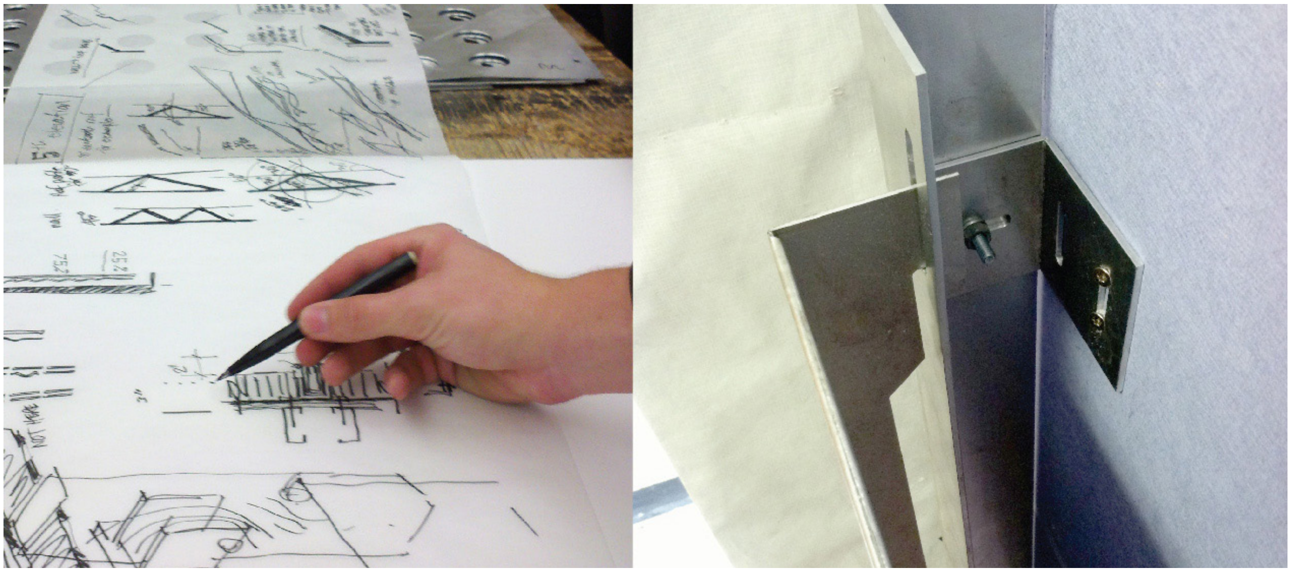

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Figure 5: Students developed their own backup system of girts and connections that was adapted to their models; the desire to maximize ventilation inspired to the students to choose a vertical girt system where stiffened panels could free span without obstructing the ventilation cavity as in typical rainscreens.

Research during the semester moved from the live testing of small 'desktop' models to computational fluid dynamics simulation, finally to a four foot wide by eight foot high mockup of their experimental cladding system mocked up fully in aluminum. Various forms of prototyping and sketching were deployed during the semester –informed models structuring the performance problem and working as a scaffold to integrate results and interpretations back into new models. Reviews with architects from BNIM, Zahner engineers, and other outside consultants from industry helped the students to understand the broader implications of their systems. The iteration of models and experimentation for one of the groups is shown in Fig 4. Conclusive results for each experimental system is still pending while the systems await further testing in an outdoor testing structure, and quantified results will be shared at a later building science venue when testing is completed. In structuring research around models and prototypes, the breadth of inquiry also engaged issues of construction methods and assembly, as the students devised their own backup system and connection details that would maximize ventilation potential behind the cladding (Fig 5). Throughout research, informed models allowed inquiry to uncover new lines of research and consider issues of integration and architectural relevance. Like scientific experiment needs theory, architectural research shouldn't eliminate context but rather should integrate context through the presence of the architectural artifact.

A FRAMEWORK FOR INFORMED MODELS

In order to generate credible knowledge, scientists' efforts must address the entirety of the scientific method and not just the collection of data within experiments. Designers employing experimental methods must address the entire process involving these models, and not just their testing and simulation. What follows in this section is a discussion of how informed models were developed, integrated into experiments and testing, and used as the basis for interpretation. The following proposed framework is a work-in-progress that is intended to inform and be investigated in future research studios.

EXPLANATIONS AND CAUSAL LINKS: MODELS IN THE EARLY STAGES OF EXPERIMENTATION

Research questions are often identified as originators of the research process. For designers, examples that are discussed often take the shape of "Will this particular thing happen if I design this in a particular way?" Students in the cool skins studio began with a conceptual model, rather than a question, that could be sliced and rearranged into conjectural hypotheses to test performance relationships. Students in the sciences sometimes use an "explanatory story" to induce inquiry, based on the concept that "testing explanations" and "causal links" is at the heart of scientific inquiry rather than simple questions (Carey 1998). While a research question begs for the polarity of true and false, the students' conjectural hypothesis – itself a proto-model – sets up experimentation around a 'causal links': links that are not just true or false, but must be evaluated, qualified, and explained by experimentation. Researches must be prepared to predict, identify, and evaluate these links, which will be manifest in a wide range of meaningful performance outcomes.

Consider the work of the Material Group in the Cool Skins Studio, who set out to test the relationship between different metal types and surface treatments and material equilibrium temperature, an issue of interest. This group may have stalled with literally dozens of individual research questions. Instead, this group was able to pursue a conjectural model with a causal link (changing metal type and/or surface treatment would improve thermal performance over raw aluminum). This link in turn predicted a relationship that honed in upon an issue of interest informed by background research in the thermal properties of metals. As a result of a solid foundation of background research and a clear understanding of causal links, the group discovered that stressed-skin sandwiches of two thin metals would allow huge performance gains over heavier single layer panels, even for thermally detrimental metals that were heavy and dark.

DIALOGUE BETWEEN MODELS AND EXPERIMENTS

Donald Schon coined the phrase "conversations with representations," referring to representations as important inputs to the thought process, rather than passive outputs (Schon 1983). We may think of informed models in the same way, as both organizing elements and important sources for discovery in experimentation. Introducing models into the framework of experimentation involves carefully considering that which is being tested (i.e. causal links) but also must anticipate unknown possibilities. In the experimental process, the interchange between experiment and informed models should remain fluid, since experimentation ultimately feeds back into new models, organically introducing opportunities for tweaks, refinement, and lateral lines of thinking. Secondly, the nature between design and performance outcomes is complex and thus it is important to think about models as parametric systems within the process of experimentation that easily iterate, while also balancing the isolation and manipulation of individual variables.

The Surface Group in the Cool Skins Studio presents an example of the fluidity between models and experiments; this group sought to improve the performance of ventilated cladding by manipulating the surface of the building skin, primarily through perforations. First the optimum perforation size was tested, but results were superficially disappointing – none of their perforated models performed better than the unperforated control test. Yet the group's experimental model was robust and they were able to determine that radiation admitted into the ventilation cavity compromised their perforated systems. Eventually the group uncovered through conjecture and experimentation that perforations could be located sparingly but strategically, balancing increased convection while blocking radiation. In sum, the experiments conducted by this group needed to be both solution-reinforcing but also solution-revealing, even when models didn't perform as expected.

CRITICAL REFLECTION: INTERPRETATION, ITERATION

Connecting performance with design variables in informed models makes interpretation an important part of the experimental process. Kees Dorst argues design problems are "inevitably under-determined" or "over-determined" and thus require interpretation by designers in order to pursue a solution (Dorst 2006). Thus in interpretation, designers must understand what matters and be able to recognize causal patterns and other significant observations. Interpretation in this sense is not just about the quality or validity of evidence; instead it is about understanding and articulating relationships that reveal important conclusions, and depends on the informed model as a conceptual framework. Consequently, two researchers with the same evidence may be driven to two difference conclusions by differences in their interpretative framework; thus interpretation is important in thinking critically about conclusions from experiments. Argumentation – positing an assertion about the evidence and supporting it directly – is a key element in this process. Additionally, informed models depend on iteration, as early experiments inform models that become the center of new experiments. Without interpretation as a link from one experimental framework to another, iteration would be a fruitless pursuit.

In the Cool Skins Studio, the group looking at Geometry as a way to improve ventilated cladding performance was perhaps the most entangled by the challenged of interpretation during research. In contrast to the Surface and Materials Groups, this group's experimental systems were immediately more complex than the others. Merely declaring one experimental system better than another wasn't a useful research conclusion unless the mechanisms driving the performance difference were understood. Through creative thinking, the group developed a novel matric undulating aluminum behind the cladding panel to create intentional turbulence in the air cavity, slowing the air volume down and forcing it to make fuller contact with the façade panel, carrying away heat more efficiently. The group's final prototype represented a truly spectacular idea – however it was an idea that was difficult to understand based on the experiments carried out. In order for a model to progress in experimentation, it must be informed by rigorous knowledge of its mechanisms and implications. It can't just be 'better.'

CONCLUSION

Models are more than just for representation, but are important vehicles for inquiry. In many design practices, architects are the only members of project teams that have the knowledge and the tools to understand the push and pull of multifaceted performance issues (i.e. building science, construction means, economics, etc.) and building knowledge around an informed model is the only way forward in responding to the architectural problem. Given the challenge of performance, informed models lend structure to an experimentation process that will become increasingly important in education and in the profession.

In the meantime, a cultural shift is required in the design fields to use experimentation effectively. Such research requires that designers accept unknowns openly and prepare to seek knowledge and explanations even when the process illuminates failure and underperformance. Arguably design is about bringing ideas out of the unknown (Michael Brawne's "Expectant Eye") but design risks creating its own reality – just because a design exists, it is expected to be workable, competent, and stable. There is an attitude that research, experimentation, and technology (i.e. simulation software) exists just to verify designs. When models underperform, designers must be driven to understand the mechanisms of performance – a huge unknown today in the design field that seems to only be combated by specialized consultants. The design profession has to come to terms with the reality that our

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Figure 6: The full scale mockup used by the students to evaluate the performance of their systems at full scale. Architectural education and practice must move models beyond simple design propositions to take on a role in inquiry as informed models.

tools and research processes exist to serve us, and we need them to illuminate the unknown. Yes, evidence is useful in advancing design decision making, but to progress into a new era of high-performance design we need to work with informed models whenever possible and make curiosity, hungering for knowledge, and innovation a part of design culture.

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