Parametricism (SPC) ACADIA Regional 2011 Conference Proceedings

Janghwan Cheon  
*University of Nebraska-Lincoln, jcheon2@unl.edu*

Steve(n) Hardy  
*University of Nebraska-Lincoln, shardy4@unl.edu*

Timothy Hemsath  
*University of Nebraska-Lincoln, themsath3@unl.edu*

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ACADIA Regional 2011
Parametricism (SPC)
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edited by Janghwan Cheon, Steve(n) Hardy, and Tim Hemsath

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Dan Williamson is currently a graduate architecture student at the University of Nebraska-Lincoln where he has studied under Steven Hardy in a studio environment and continues to work with him as his UCARE research partner. Dan’s interest throughout his schooling has been in the experimentation and exploration of grasshopper as an associative and parametric tool for a performatively responsible architecture. Dan currently serves as the Marketing Director for the UNL chapter of AIAS, a member of Tau Sigma Delta, the President and Founder of a UNL Sport Club, a UNL Outstanding Leader nominee and a UCARE research student. Dan also is an Architectural Intern for the St. Paul office of HDR, Inc.

Nay Soe is a graduate student at University of Nebraska-Lincoln, College of Architecture; focusing his thesis on the reformation and contemporary functions of post-war American suburbs. Nay’s interest is in optimizing and evaluating the role of parametric and computational methods in the fabrication of architectural design process. Currently a research assistant for the Killinger professorship in Urban Design and Architecture, working with Steven Hardy to construct a simulation base approach towards the computational generation of cohesive urban forms. Before graduate studies, he has worked as an undergraduate research assistant in creating rapid iteration of three dimensional urban landscape tissues, and won second place in the international competition for the Rome City Vision Competition in 2010.

The UCARE [Undergraduate Creative Activities and Research Experiences] program is funded by the University Pepsi Endowment and Program of Excellence Funds. UCARE provides opportunities for undergraduates to work alongside faculty and directly participate in cam-
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Session Introduction/Forward
Foreword
Nancy Yen-wen Cheng

The organizers framed this conference to systematically examine the breadth of parametric design, to understand what can usefully undergo the process of abstraction into variables and relationships. Juxtaposing a digital approach with U.S. architectural education criteria allows us to question the robustness of both our standards and the parametric concept. While architecture professionals have been using computers in various roles for decades, the Student Performance Criteria in the NAAB 2009 Conditions for Accreditation only mention digital technology once, in the limited context of Visual Communications. The papers in this volume give a glimpse into how schools are leapfrogging accreditation guidelines to embrace the possibilities offered by technological advances.

Designers are diving in deep to create personal tools with coding and visual programming. Getting under the hood, they are re-inventing their creative role. Moving seamlessly from laptop to workshop, they are refining digital representations with performance analysis, material testing, joint prototyping, and kinetic assemblies. With infinite material, form and site interactions, the hybrid digital-physical process keeps opening up possibilities, spawning a visual poetry of components and relationships.

The results raise the question of whether new techniques help us construct new meaning or do we only understand them through biological metaphors, archetypal spaces or what we know. How much can programmed relationships address what humans need in an environment? When is it a matter of being smart enough in defining how crucial variables interact and when do the rules become too deterministic? Within this fluid world of multiple possibilities, what should we hold invariant? Where are the limits to what can be interpreted and translated?

Given the complexity of architecture, individual researchers can only begin to address these questions. We hope this mosaic of their papers has glints of insight to capture your imagination. In this spirit, we offer the proceedings of the first Regional ACADIA conference.
2011 ACADIA Regional Conference Acknowledgments

Timothy L. Hemsath

As co-chair of the ACADIA Regional conference, I would like to extend our gratitude to all those involved in making this conference a success. First and foremost the conference planning team, Steve(n) Hardy and Jang-hwan Cheon for their efforts in organizing the conference schedule, abstracts, papers, proceedings, workshops, posters and keynotes. Teamwork was key in the hard effort and work involved to make the event successful. Speaking for all of us, I would like to acknowledge all those involved in making this conference successful.

The conference would not have happened without the leadership at ACADIA. I must thank them for their trust, feedback, insight into the organization and execution of the conference. Nancy Cheng for her leadership as ACADIA's president and engaging us frequently providing the team with access to resources and insight. Thanks to our entire list of peer reviewers and paper authors whose contributions made for a wonderful two days of exciting discussions and quality presentations.

Our sponsor Autodesk was integral in the success of the dinner and workshops. We thank all our workshop teachers, first Nancy Clark-Brown and Jim Cowen for their workshop teaching contributions. Second, we thank McNeel and Brian James for the Rhinoceros 3d modeling workshop. Thank you to our colleague Dr. Zhenghong Tang for his Geographic Information Systems review. Nathan Howe from Kansas State and his last minute agreement to run a basic Grasshopper workshop. Finally, NBBJ and Nathan Miller for his advanced Grasshopper workshops.

We would like to thank them all for their quality efforts and work, particularly Roland Hudson, Drew MacDonald, and Mark Humphreys who received the Best Paper Award. Their paper was selected from the five finalists by the ACADIA steering committee. The five finalists were identified first during the abstract review by the peer review then selected from the 32 full papers by the conference chairs. Papers were selected for presentation by blind peer reviewed abstracts, 58 total were submitted, with an acceptance rate of 55 percent.

We also thank our keynotes, Tom Verebes, Jeffrey Day and Nathan Miller for their thought provoking work and critical perspectives on our conference theme. We would like to also recognize the faculty, staff and students at College of Architecture at the University of Nebraska-Lincoln. Everyone worked hard to help us make this event successful. Our Dean and Director for their support and recognition of this significant pilot of the first ACADIA Regional Conference. We thank our fellow colleague Chris Ford, the conference exhibition curator who made sure our student work was prominently featured. Student thank you are awared to Sara Ben Lashihar for website assistance, Andrew Portis, Dan Williamson and Nay Soe for design work/paper layouts. Student help was made possible by the Undergraduate Creative Activities and Research Experiences (UCARE) program.

I will end with a challenge to those who are reading these proceedings. Every effort can quickly be forgotten and fade into history. The value the regional conference provides ACADIA was to diversify the audience, focus on local expertise while drawing from national and international academic talent, and brings a specific flavor of discourse to the organization. I challenge those interested to not forget and build on our beginning to develop your specific focus and contribute to the conversation on computer-aided design in Architecture.

We thank everyone involved.
Introduction
Parametricism: Student Performance Criteria (SPC)
Steve(n) Hardy

In today’s computer savvy world it is no longer interesting to discuss digital tools purely as means in themselves. The growth of abstract exponential systems or the generation of modulated patterns for their own sake simply strain justification in light of real-world concerns such as climate change, decaying cities, and economic crises. However, the impact of explicit logic and computational thinking on design and design process remains substantial. So we continue to pursue evolving digital techniques in hope that they prompt innovative design strategies and creative organizational, effectual, or material innovations that align with the evolving technologies which shape contemporary life. But exactly how are these tools to be explored and utilized within the post-technique milieu?

The theme of ACADIA’s first regional conference, Parametricism: (SPC) strategically positions Patrik Schumacher’s Parametricism alongside the NAAB’s Student Performance Criteria (SPC). While Schumacher’s stylistic pursuit of Parametricism is often criticized, it remains the foremost proponent for defining the impacts and potentials of associative modeling. In contrast, the SPC offer a performance-oriented list of achievement criteria not engaged with particular design methodologies or generative techniques. Arguably, however, the SPC contain design implications laden with practical considerations which are capable of derailing generative design approaches. These approaches often require a type of systemic delay1 which temporary suspend pragmatic variables in favor of further design explorations within the iterative processes of computational techniques. Does compliance with the SPC signal the end of generative design for the sake of a more practical agenda, or can the rather odd pairing of the two terms suggest a new focus for digital design tools in the ACADIA community?

For more than a decade we have witnessed the proliferation and refinement of digital techniques to produce evermore complex and elegant designs solutions. The recursive processes of scripting and complex data lists in parametric modeling perhaps too easily enable designers to generate modulated patterns. While this has an affiliation with mass customization and a type of cohesive heterogeneity which might be attributable to contemporary society, the prevailing will to modulate is more likely derived from outside fields such as computation or biology than directly from architecture or the project at hand. There are of course interesting discoveries to be made through these types of disciplinary intersections. But in this situation, we are asking if it is possible to shift the iterative capacity of computation or the associate logic of parametric modeling towards the manipulation of the innate logics of more architectonic elements. The conference’s focus is not meant to be the SPC themselves; instead, the general themes and direct relationships to education serve as a convenient vehicle for simultaneously introducing pedagogy and pragmatics to this particular conversation of computers in design.

In architectural education there’s often a strange polarity created in studios between those whose aim is to explore the potential of generative design strategies and those whose aim is primarily to achieve programmatic competence and comprehensive design resolution. However, as our particular computational generation gets older there is an increased probability, given the changing world and the shifting focus of the design disciplines, that our thoughts will lean more towards building. We may find ourselves in the awkward yet hopefully appealing position of no longer being seen as interesting by the (next) younger generation yet still too abstract to be seen as anything but radical by the older. But one thing is clear, design education will evolve along with the instructors who teach it; one can only speculate on a few of the many possible trajectories:

• We can continue the waning path of technique and further computational specialization, but run the risk of increasing separation from the architectural discipline and ignoring important world contexts.

• We can change the focus of our pedagogy - away from the impacts of explicit computational logic on design and the design process – focusing less on technique and giving more room for pragmatics, new criticalities, experimentation, social engagement, disciplinary expansion, etc.
We can choose to use these techniques as tools that are immersed within the larger contexts of the discipline, practice, and a complex array of pragmatic variables with real-world impacts.

By employing the SPC in relationship to generative computation, the conference hoped to highlight SPC topics and other pragmatic variables, not as obstructions to conceptual design, but as necessary polyvariable parameters that might assist organizational, material and effectual innovations. In doing so, the conference intended to discuss the potential shift of generative computational tools away from means in themselves and abstractions derived from other disciplines, towards the generative possibilities of a type of radical parametric pragmatism.

**Parametric Pragmatism**

What is suggested by a parametric pragmatism is not an alignment with normative practice but rather a “virtualization” of the “radicalization of pragmatics and technique”2. In his “Scientific Autobiography”, Zaera-Polo describes a complex continuum in which both theory and practice effectively transform reality.

“To say that practical knowledge is devoid of significant theoretical content is as false as to say that theoretical knowledge lacks pragmatic purpose. I would prefer to describe their assemblage as two epistemological tendencies within a particular discipline and a particular domain of reality, one toward virtualization (i.e. theory), the other toward actualization (i.e. practice).”

Given the gravity of the situation regarding climate change, decaying/shrinking cities, and economic crises, it’s no wonder there have been parallel attempts to re-orient design education, research, theory and consequentially future practice in a different direction. In the post-technique milieu, instrumentation as a means in itself without resulting in a perceivable, practical impact is simply no longer an acceptable avenue. While still in London at the AA, I became a central part of this initial shift - away from pure technique - towards the exploration of generative and systemic design to more projectively engage social, environmental, and generally more comprehensive project briefs. In diploma 16, Jonas Lundberg and I, established the ‘Extreme Environments’ agenda to explore a range of climate change scenarios and extreme natural phenomena. Surrounding the well-developed urban fabrics of the UK and Europe, it was relatively easy to instead focus on performance-oriented infrastructural projects which engaged large environmental concerns in various parts of the globe. These projects were celebrated as being naturally poised at the intersection between science and design, but also increasingly criticized by ourselves for having diffuse architectural content.

My return to the US, and more specifically, the Midwest/High Plains region, brought new realizations and opportunities. While issues of climate change and global conditions remained important, I was surrounded by what seemed like a general design malaise that permeated society and the comprehensive built environment. Rather than lay blame solely on clientele, I began to contemplate the effects that the established educational structures had on shaping the discipline, practice, and consequentially our environments. Schools of architecture in the region were operating under two basic types; while those that tended towards actualization were prevalent, schools with program areas less liable to NAAB, i.e. thesis, beginning design, and the MArch were more oriented toward virtualization. Neither was fully engaged with the potential design issues surrounding them. Not only were actualization studios stuck in a rut of mediocre design strategies but they were working on projects removed from typological concern to the modern urban fabric. At the same time the few virtualization studios I found were focused on expanded disciplinary intersections, abstract and often poorly executed generative techniques, or antiquated theoretical approaches – all at the fringe of having any real impact on the desperate built environment around them. It’s quite possible that students (especially the lower-performing students) were emerging from these schools, unable to bridge the gap between education and practice, unable to grapple with real-world polyvariable parameters, or the clashes of the and conceptual design, and simply caving to whatever normative practice they found themselves operating in.

Another formative teaching experience for me in the UK was LondonMet’s (LMU) Department of Architecture, which nurtured a growing design reputation and became associated with a group of instructors and small
practices commonly referred to as the English Pragmatists. At the time this meant little more to me than increasing the difficulty of launching a new digital design curriculum and associated vertical strand within the school. Recently returning to give a lecture at the school, I noticed the same uneasy relationship between the pragmatically-oriented and parametrically-oriented instructors. But it was quite evident that the two extremes should stop quarrelling and cooperate. While in the past I had been one of the parametricists, this time I sided with the pragmatists. Rather than try justifying the impact of technique, almost as a discourse and an end in itself, why not see these things for the tools they are. They are tools that can engage any type of project, even projects similar to those being worked on by the pragmatists. I concluded my lecture by discussing the prevailing situation within the school and suggested a new operational hybrid: Parametric Pragmatism.

Pragmatism implies a movement towards actualization and evaluative design criteria favorable of real-world and experiential impacts. Parametric (modeling) is a type of instrumental technique which engages associative thinking, explicit logic, polyvariability, and iterative processes. The clearly defined, yet malleable relationships in a parametric model make it a highly suitable tool for design-thinking. However, early attempts of combining ‘pragmatics and technique’ quickly devolved into the radicalization and virtualization of technique as an end in itself. The pragmatic was typically reduced to the pseudo-science of the performative and comprehensive design approaches became impossible given the complex learning curves and computational limitations at the time. So students became masters of technique but were unable to engage in the full-complexities of design.

A parametric pragmatism implies an associative thinking and explicit manipulation of the innate logics of more architectonic elements linked together as interrelated subsystems. On first consideration, BIM platforms might seem to readily address such a description. Current BIM modelers receive many accolades; however, they are also highly criticized for their limitations. By focusing on production more than design, these modelers are perhaps too easily suggestive of a type of agenda geared towards a practical documentation that many view as greatly limiting to design. Looking briefly at a rough categorization of modelers, one can readily see the distinct design impacts of solid, NURBS, and mesh/sub-division surface modelers. Each tool introduces new operations that open up a range of actualization techniques and enable a new set of virtualization concepts. While BIM modelers can be associated with any type of modeler, the more established platforms are typically solid-based modelers. However, BIM environments have several unique properties including the automatic change management system (ACMS), information tags, and element-based modeling which help distinguish it from the other solid modelers.

The ACMS engines instantly update information and drawings throughout the modeling environment. This allows elements to be modeled once and represented in multiple ways. This creates two fundamental problems; it creates drawings before they are observed by the designer and it consequentially erases all traces of design activity. Information tags are automatically and manually attached to modeling elements and can provide relatively easy and quick quantifications. However, this information is often not understood by fledgling designers and overwhelming for seasoned designers in the early design phases. The most profound impact of BIM is that they are typically situated as an element-based environment - arguably creating a new category of modeler. Elements are not just mathematical entities like surfaces or solids, but simulations of real entities which contain their own innate rules or internal parameters that are also understood as sub-systems of a larger building. However, the parametric interface for these elements and inter-associations are still relatively cumbersome and non-generative.

The exhibition at the ACADIA Regional conference hosted a collection of work from the UNL’s CoA. We received many comments complimenting our use of generative and parametric modeling across a range of comprehensive design projects. While we have implemented a strong digital curriculum which now starts in the first year and finishes at the graduate level, we have been interested in pursuing this in relation to comprehensive design. This shift towards a new radicalization of pragmatics has been intentional, and though we are still in its infancy, we are responding to rapidly changing situations and have taken up the charge of shaping this new direction.
In 2002 Michael Speaks wrote the article Theory was interesting . . . but now we have work. However, following the economic crises of 2008, this work has become scarce and schools are more susceptible to moving towards esoteric virtualizations. In contrast, we have become increasingly interested in more fully engaging the implementation and virtualization of a radical parametric pragmatism. We are interested in building but we are foremost interested in mastering the design of buildings and finding design and experiential value in the deep syntax of their interrelated systems.

A radical parametric pragmatism explores design possibilities inherent in the parametric interarticulation of subsystems as they relate to their own internal logic and the pragmatic variables that surround them. Rather than work with element-based BIM platforms we have been creating definitions and scripts that work with the concepts of element-based environments while providing the inherent flexibility and real-time feedback of more generative parametric models. An example of this type of work is an egress modeler. Our current development of such a modeler focuses on INPUTS (occupancy type, sprinkler type and floor dimension), COMPLIANCE CALCULATIONS (automatically sets stair: numbers, widths, distribution and optimal rise/run), PARAMETRIC VARIABILITY (allows for real time changes in rise/run, width, numbers, distribution locations, floor geometry/dimensions and floor to floor heights), and most importantly, a generative DESIGN FEEDBACK.

This feedback not only implies an update of all the geometric components but the design feedback system (DFS) provides an instant visualization of the traces of less tangible entities. The maximum egress distances are shown with dashed circles. These circles are placed at the center of each stair. A Boolean logic is then used to take away the difference of the circles from the geometry of the floor plates and highlight the intersecting overlap between circles. The complex overlay of pragmatic traces provides information lost in most ACMS engines from which more formative design decisions can be made. However, the paradigm for these traces, shift from the process of modeling towards pragmatic variables as a generator. Design experiments within this particular modeler, for example, have focused on optimizing the genotypic condition of egress versus the phenotypic condition of site constraints. The logic resulted in a non-typical but highly efficient floor plan with formative consequences for the overall building. Interpreting the potentials of a deep syntax across the entire assembly of subsystems, the Boolean residuals resulted in a vertical air shaft for stack ventilation to the south and an irregular facade to the north. Other ideas being experimented with include: FAR visualization modelers, structure visualization modelers, maximum occupancy modelers, parking modelers, accessibility modelers, etc.

With these ideas, actions, and initial experiments in place, we proposed the first ACADIA regional conference, Parametricism: (SPC). Our intent was to begin a discussion which brings together issues of comprehensive design and computationally-driven generative design strategies. There were many great ideas discussed at the conference and a lot of positive post-conference feedback. We hope everyone enjoyed themselves and look forward to continuing the conversations and experiments started.

1. Rahim, Ali (Editor) AD Contemporary Techniques in Architecture, Academy Press, April 17, 2002
4. Speaks, Michael “Theory was interesting . . . but now we have work,” arg 6/2, “perspective” June 26, 2002.
Digital fabrication has stimulated the return of the architect as builder over the past fifteen years or so and projects are showing up all over which implement these tools as a major design factor. More recently, parametrics has become a buzzword as its being used to design structures that respond to their environment and other site conditions. While parametrics can be a powerful tool, we rarely see it leave the realm of the design process and venture into the physical world.

Through a project entitled theBENCHES, completed by a digital craft studio at Louisiana Tech University, students applied parametric modeling techniques with a primary focus directed towards the fabrication process. This was executed through three different areas; 1) ‘Back-end Design’ where details were developed and manipulated through a Grasshopper® definition, 2) ‘Statistic Calculations’ where a Microsoft Excel® was dynamically linked to the design model to give live updates on part counts, costs, and feedback information, 3) ‘Fabrication Organization’ which created, labeled, and nested all fabrication drawings.

The result was an extended design phase, lower project cost, and higher productivity. The traditionally linear work-flow model of design, back-end design, production and fabrication was rearranged allowing for several phases to overlap creating a more efficient design process.
Introduction

Like many trends, it seems as if parametrics have taken over discussions within current trajectories of architectural education. It is a rarity for one to make it through an afternoon of reviews and not hear the words “scripted”, “associative”, “programming”, “algorithmic”, or “gerative” used to describe potential design strategies. That is, however, all the further these suggestions tend to emply themselves; delegated to the abstract space that is the design process. But the potentials of such parametric design techniques have tremendous possibilities when it comes to fabrication processes and realization.

Throughout this paper I will use the BENCHES project as a vehicle by which to make an argument for the usage of parametric design techniques within the process of making, as it relates to more efficient workflows. More specifically, parametrics can be used in a manner that will extend the design phase, reduce fabrication preparation time, and lessen project costs. I am also going to discuss the advantages of applying these techniques through three areas in particular; ‘Back-end Design’, ‘Statistic Calculations’, and ‘Fabrication Organization’. It is important to understand that these areas are by no means sequential, but rather interdependent, and modifications to one area impart the other two.

In the fall of 2009, I lead a digital craft studio at Louisiana Tech University that focused on a design-build problem through the use of digital fabrication and rapid prototyping methods. While other similar studios design and realize their projects using off-the-shelf parts, the focus on this studio was to design in a way that implemented the digital fabrication equipment in one of two manners; either directly, as a way to produce the parts that become the project, or indirectly, by using the equipment to produce some type of fabricated system which would then create the parts (e.g. jigs or molds).

The program that was used for the studio focused on creating additional seating elements within a courtyard space located in George T. Madison (GTM) Hall. The GTM Hall currently houses the several departments within the College of Liberal Arts, including English, and the courtyard space within GTM Hall is referred to as the Shakespeare Garden (Figure 1). This vacant space has taken on several renovations over the past several years, which include the covering of an antiquated fountain into a stage for the annual sonnet readings that take place on Shakespeare’s birthday. These types of events often draw far more people than the space can seat comfortably and therein lies the design issue of the studio. It should also be noted that at the beginning of the studio, neither the students nor the instructor had any background in parametric modeling software, but simply the knowledge of its potential applications. It is this initial limitation which became the seed for this paper. We were all still learning the software functionality while the initial design process was underway.

Back-end Design

The first task in within this endeavor is to pinpoint the areas in which parametric modeling can assist in the fabrication process of a project as it attempts to transfer from proposal into constructed object. Branko Kolarevic recognizes this potential within his book Architecture in the Digital Age: Design and Manufacturing where he states the following;

This new found ability to generate construction information directly from design information, and not the complex curving forms, is what defines the most profound aspect of much of the contemporary architecture.¹

By integrating the concepts of parametrics into the phase I’m referring to as ‘back-end design’, we will begin the process of producing the necessary construction documents as mentioned above. So what exactly is ‘back-end design’? I equate this term to what my college, Michael Willams, refers to as “design with a lowercase d”², that which supports primary design. While all design decisions at this point are important, the major gestures of the project have been made. Back-end design is about figuring out the details as they manifest themselves in both physical form (how does steel meet...
wood?) as well as material properties (how does steel accommodate wood expanding?). Furthermore, back-end design lies the foundation for process as this is where initial ideas of fabrication have their roots.

For the BENCHES, back-end design begun around week six, as the project direction had been chosen and groups united. It was at this point when students took ownership over an aspect of the project and broke into teams that focused on these tasks. While one group continued to work on the formal gesture, which the seating elements would eventually take, another tackled the details of realization and fabrication. Students quickly agreed upon a ‘cat scan’ technique in which sections would be cut along the longitudinal axis of each bench (Figure 2). These sections would be made of laser-cut steel and ‘capped’ with Computer Numerical Controled (CNC) routed cedar, much like the handle of a knife around its blade.

This is where the parametric model began to prove its worth as we made adjustments to these design decisions. The model allowed us to adjust the number of ‘cat scan’ sections as necessary; more sections meant a more accurate form and more comfortable seating, however at the cost of more steel required, more time to cut it, and more weight. A 2” on-center spacing was determined to have the optimal perfomance criteria to balance comfort, form, cost, time, and weight, as well as allowing for the fabrication process of getting an allen wrench between the sections required to tighten the hardware. The wooden caps had the most depeancy upon parametric modeling as it controlled variables such as cap width (cw), cap depth (cd), wrap percentage (wp), break points (bp), bolt locations (bl), bolt size (bs), and bolt-hole shape (circle in wood, oval in steel)(Figure 3). All of these variables were considered as they weighed the advantages of stronger parts against overall design intent, and material properties. It goes without saying that all these variables also impact project costs in one form or another, but we’ll save this discussion for a little later.

![Figure 1. Shakespeare Garden – George T. Madison Hall – Louisiana Tech University, 2009](image1)

![Figure 2. Initial bench form used as prototype for parametric model.](image2)
It’s important to note that at this point, formal studies were still being investigated by another group while back-end design decisions were being made. A work-in-progress model was used as a placeholder for generating the parametric Grasshopper® definition. The traditional linear work-flow diagram of front-end design > design > back-end design had been stacked, allowing us to extend the design phase as long as possible, and still complete the project in the allotted 10-week timeframe. Students were able to work on a range of project tasks (throughout various phases) simultaneously due to the parametric model. This increased our efficiency, as students greatly reduced downtime waiting on a phase to complete prior to starting the next task (Figure 4). In practice this translates into saved labor costs.

As I previously discussed, all three of these sections should not be seen as a linear progression, but rather as an interconnected system. In the back-end design phase the ‘cat scan’ technique was chosen with the primary variable being the number of sections necessary. It was also mentioned in the project introduction that theBENCHES were to be situated within the courtyard space of GTM Hall. The only means of access was through a series of doors with an opening no wider than 36”. Because of this, no machinery could be used for the installation process. Weight became an issue as all fabricated parts would need to be carried into place. Using the parametric model, students were able to calculate each benches’ total surface area of steel and, in turn, verify the approximate weight of each bench. This information was fed back to the back-end design phase and used to limit the number of allowable sections, while at the same time the surface area calculation was sent out to a powder coater for a quote. These same calculations were used for both internal and external analysis.

Just as the parametric model was able to locate all necessary bolt-holes, both in the steel and wood, it also tallied these openings for a bolt count. Upon multiplying this count by the price per unit and realizing the total hardware cost, it was determined that the initial bolt and nut combination was not going to be financially feasible at the quantities the current design required. A less expensive equivalent part was found; however, this new part had slightly difference dimensions than the original one. These modified dimensions were relayed through the back-end design phase which, as a result, updated all bolt-hole openings.

As the part count grew, it became apparent that Grasshopper® was not going to be the best way to both calculate and manage part statistics and budget information. Microsoft Excel® is a software traditionally left to that of accountants, scientists, and statisticians, however, paired with the right parametric design counterpart, we were able to implement Excel® as a
design tool as well. Both Grasshopper® and Excel® work off the same principle, beginning with a component/equation, one adjusts the input, and the resulting output alters. When used in series though, the benefits of each are multiplied.

Using the ‘Stream Contents’ option within Grasshopper®, the totaled part statistics were able to be streamed live as a text document which was imported into Excel®. From there unit costs were input and multiplied by parts needed. We were able to track costs on all aspects of the project from the number of nuts and bolts needed, to calculating the surface area of cedar and, in turn, gallons of sealant needed. As the design changed, so too did the parametric model as well as the dynamic budget spreadsheet.

Unlike so many projects that exist within the abstract world that is studio, this one had a budget to keep which, in itself, became a design factor. Many ideas the students wanted to implement were discarded for this very reason. This process also allowed the students to target areas that resulted in the greatest financial impact, and allowing them to more quickly obtain a design under budget. By connecting these two programs, Grasshopper® and Microsoft Excel®, design decisions were able to be made with cost implication becoming immediately apparent. It also facilitated a dialog between statistic calculations, back-end design, and eventually fabrication organization.

**Fabrication Organization**

To make this next comparison, I would like to introduce you to another project completed by myself, Joe Baker, Matt Plecnic, and Beau Seyerle as graduate students at The Ohio State University in 2006, under the direction of Prof. Steven Turk. The project began when The Ohio State University’s Experimental Media and Movement Arts (EMMA) Lab approached the Knowlton School of Architecture for an installation piece within their performance space. At the time, EMMA Lab was unable to describe what they envisioned as a physical object, but could clearly express the performative features the final design would achieve. Ideas of interaction, display, seating, screening, and movement all became focus topics as the design took form. The end product was theWALLS, a series of laminated plywood screens that were self-supportive, mobile, and versatile enough to be used as props with or backdrop for the performance (Figure 5).

![Figure 5. theWALLS – Troy M. Malmstrom, Joe Baker, Matt Plecnic, and Beau Seyerle, The Ohio State University, 2006](image)

While the designs of these two projects, theWALLS and theBENCHES, by no means are identical. They do however have similar attributes within their respective processes. Both projects had a similar timeframe of approximately 10-weeks, from initial discussions to completion, both projects were of a similar scale and had a similar number of students, both projects had similar course construct of small groups generating multiple ideas, and both projects had fabrication methods. The difference in these ventures becomes evident in the final output. The objective of each studio was to produce a process, or set of instructions that could live beyond the life of the studio. This was physically manifested for theBENCHES as three completed seating elements whereas theWALLS were only presented as a partial series of what was to be a larger collection. The reason for the incomplete set of screens was simple, time.
In any project there is a turning point at which design must be severally reduced (as I do not feel design ever truly ceases) and give way to production and fabrication. For both of these projects, this took place with about two weeks remaining in the quarter – one by choice and the other due to circumstances. From the onset of the BENCHES, a schedule was drawn up that consisted of a 7-week design phase, 1-week prototyping phase, and 2-week fabrication phase that was followed fairly tightly. As for the WALLS what was scheduled and followed were two difference entities altogether. What was originally planned to be a four-week fabrication phase, was reduced to just two weeks as discussions with the client extended beyond the allotted design phase. In addition to this, we spent nearly four days producing the fabrication drawings which included section cutting the solid computer model, laying out and labeling all parts, and manually nesting them within our stock. After the set of drawings for each screen were created, we could generate toolpaths and estimate run times to determine the final number of screens we had time to produce. The compromise to the extended design phase and production technique was a reduced number of complete screens within the series.

For the BENCHES we approached the task of fabrication drawings from the onset. Built into the parametric model was the ability to take each section (steel as well as cedar caps), lay them out on a base plane, and sequentially number them according to their bench and location (Figure 6). This alone saved hours. However by implementing RhinoNest, which “…can optimize part position and orientation for a material…”, efficiencies of material were calculated and applied back into the back-end design phase to save time and costs yet again. Due to the shape of the wooden caps, as well as our choice of cedar boards, it became very inefficient to maintain the wooden caps as one continuous element. Break points were added to optimize nesting capabilities and minimize material use. Ultimately we found that more is not necessarily better. While more pieces allowed for tighter nesting, this graph eventually planes off as more space is needed for part-to-part spacing, eventually creating more void than solid out of the material. In addition, more pieces required additional tracking of parts and increased the potential of human error. The conclusion of two break points (creating 3 parts) per section was determined to be optimal.

Figure 6. Grasshopper® definition with sections laid-out and prepared for fabrication

My last argument for the application of parametrics within the production phases of this project relates to calculating runtimes of the CNC equipment. For us, analysis of runtimes was an important factor in determining if we had the man- and machine-power to complete this project in the allotted timeframe. Were there enough hours in the day to cut all the steel sections and CNC route the wooden caps? By this point in the design process, we has generated profiles for all the section in need of being cut. After totaling their perimeter lengths, multiplying this by a machine feedrate, and allotting an estimated overage to accommodate for jog times, we were able to get a rough calculation of runtime necessary for each piece of equipment. In our scenario, this amount of time called for outsourcing the laser-cutting of the steel sections to a local factory. This same federate calculation helped determine laser-cutting costs which were then streamed into our Excel® budget for final analysis.

Summary

As you can see, the fabrication process was fully dependent upon the parametric model and techniques. Students were challenged with the task of thinking through the fabrication process in conjunction with, not
subsequent to, the boarder design decisions. This application allowed student to extend design time by implementing a parametric model that eliminated busy-work of production drawings, as well as highlighted opportunities for design optimization. ‘Back-end design’ allowed for students to manipulate design details while also producing parts for future fabrication. In ‘Statistical Calculations’ students received dynamic updates on project costs as design modifications were made. ‘Fabrication Organization’ eliminated the chore of file preparations as the combination of the parametric model and RhinoNest accomplished this task. By implementing a parametric model, designers would be able to overlap various phases of the creative process and extend their design time while reducing project costs; and optimize their efficiency.

References


2 Michael Williams, Louisiana Tech University, 2010

3 www.RhinoNest.com

Figure 7.a. Matching existing Shakespeare bust
Figure 7.b. theBENCHES in GTM courtyard space
Figure 7.c. Break points of wooden sections
Digital Origami: Modeling planar folding structures

Dave Lee, Brian Leounis
Clemson University (CU)

This paper presents a surface manipulation tool that can transform any arrangement of folding planar surfaces without the need to custom program for each instance. Origami offers a finite set of paper-folding techniques that can be cataloged and tested with parametric modeling software. For this work, Rhinoceros and Grasshopper have been chosen as a software platform to generate a parametric folding tool focusing on single surface folding, particularly where surfaces can transform from one configuration to another while retaining their planarity.

Folding surfaces, particularly complex crease configurations can be modeled digitally and tested in variation using this algorithm. This makes it possible to design and test any folding pattern configuration by simply creating a flat tessellation pattern. Because this algorithm is inherently without scale, it has the potential to be implemented on a wide range of applications including retractable walls, roof structures, temporary structures, tents, furniture, and robotics.
1 Introduction

To fold something is to lay one part back onto itself. In this sense folding is neither subtractive nor additive, but instead is self-referential. The most intriguing moment of the fold is the cross from one dimension into another. If you crumple a piece of paper it will take the properties of a three-dimensional shape, though the paper is still a two dimensional surface. With a combination of simple folds one piece of paper may address some fundamental aspects of architecture by acting as both structure and skin simultaneously (figure 1).

As an analog parametric technique, paper folding has its limitations. Working with folding planar surfaces in digital modeling applications is equally problematic because one is normally only able to reposition components locally, one at a time. When modeling transformable surfaces it is helpful to be able to visualize surface movement, but there is currently no way to globally affect rigorous surface transformations without custom programming for each individual case. This research proposes a parametric surface manipulation tool using that can transform any arrangement of folding planar surfaces without the need to custom program for each instance.

2 Paper-folding Procedures

Origami, the Japanese art of folding paper into intricate designs and objects, provides precedence for mathematics, science, art, and architecture. Certain geometrical problems, such as trisecting an angle and doubling a cube are impossible to solve with a compass and straight edge, yet possible with paper folding. Origami works through its own geometrical rules based on the relationship of lines, points, and planes. The mathematician Humiaki Huzita formulated six axioms that map points and lines to help construct and explain folding schemes. These axioms are based on the fact that folding is an accurate and precise quantifiable operation. The sequence and shape, or the relationship between surface and points of an origami object, can be defined by rules and these can be viewed as a type of manual algorithm (Demaine, 2007).

Paper-folding is inherently an algorithmic process involving sequences of creases and folds that are designated with a positive, mountain, direction or a negative, valley, direction. Origami corrugation is a technique of alternating mountain and valley folds in an arrangement that allows movement in a folded model. These patterns have certain properties. A corrugated model that can fold flat will have an even number of vectors entering one vertex (figure 2). A corrugated model that can fold up in one direction contains one pleat or one set of alternating mountain valley folds (figure 3). A model that can fold in two directions possesses a primary and secondary pleating.

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**Figure 1.** Origami Classifications and architectural speculation.

**Figure 2.** Flat foldability. The number of creases meeting at a vertex must be even and the sum of every other angle must equal 180 degrees.
There are five essential folding techniques including the reverse fold, miura ori, yoshimura, waterbomb, and diagonal (figure 4). Each possesses unique formal qualities and a unique range of motion. (Figure x represents a matrix of folding techniques and possible applications.

The flexibility of the folding technique allows for an almost infinite number of variations to be created by manipulating the crease pattern (Demaine, 2007).

3 Digital Origami

The tool that was developed uses the surface crease pattern to define the possible movement of the digital model. If the surface’s form is manipulated, the base crease pattern will automatically adjust to the deformation, yielding a new pattern with the same surface topology. Several folding (kinetic) analog models were created leading to the development of the algorithm, each using variations of origami folds.

In constructing a catalog of folds, constraints and an embedded range of solutions the Grasshopper graphical algorithm editor was used in concert with Rhinoceros. The algorithm works by defining a sequence of operations linked to the various folding properties of the five folding types investigated. There is a root folding sequence that may be repeated as many times as desired, essentially a kinetic pattern (figure 5). Each subsequent surface is defined off the original geometry through a series of commands: move, mirror, and rotate. The simulation of the digital folding of the model is decidedly more complex to define since the kinetic movement of repeated folds must have their own axis and center of gravity as well as be linked to those of the entire surface.

Figure 3. Mountain and Valley folds.

Figure 4. Variations of folding types.
4 Scalability: Joints + Connections

The digital simulation provides precise data on the size of the model when it’s expanded and when it’s collapsed. This is the first step in being able to use this model on a large scale. One consideration that must be accounted for when scaling this work for architectural production is the thickness of material. Tomohiro Tachi (Tachi, 2010) has presented research that explores this problem with consideration of the fold, to account for the theoretical complete collapse of two faces upon one another.

Figure 5. Waterbomb folding morphology.

4.1 Return to Analog

Another important factor, and one explored in greater detail with this project, is the potential for the kinetic movement of a paper-folding sequence to be actuated at human scale. While some of the folding types move along only one axis, the Waterbomb fold moves simultaneously in four axes. A mechanical folding of the Waterbomb was explored that acts along the surface of the material so as not to interrupt the topology of the
An analysis of the movement of each face in the system led to the discovery that it is possible to maintain the kinetic movement of the system by rotating along a single edge of each face. This allowed us to trace uninterrupted paths of movement from one end to another, through the surface of the system. Mechanically, this was executed by connecting certain axes with a universal joint (Figure 6). This joint allows torque to transfer from one structural member to another through torque conversion. The torque then provides the energy to fold the model. Origami possesses similar traits to textiles and fabrics. The pleats allow for creating structure with a thin material.

5 Limitations

One challenge that emerged during the testing of this program was that of intersecting surfaces. To correct for surface intersections, it was necessary to check endpoint coordinates and connectivity of each face such that they did not intersect.

In order to rigorously preserve the geometry of the system it was necessary to be certain that each face was completely flat at every stage of the folding process. To ensure this, a planarity test was embedded into the program. Currently, the algorithm allows for quadrangles and, to account for elasticity, triangulation of the tessellated surface. However, the algorithm does not yet have the ability to predetermine strict planarity of quads when using custom folding patterns.

6 Conclusion

Because origami is bound by physical the physical limitations of paper size, paper thickness, and number of folds it is useful to explore variations using digital tools that may otherwise be unrealized. Folding surfaces, particularly complex crease configurations, can be modeled digitally and tested in variation using these algorithms. This makes it possible to design and test any folding pattern configuration by simply creating a flat tessellation pattern.

References


Algorithmic Modeling: 
Teaching Architecture in Digital Age

Nathan Howe
Kansas State University (K-State)

Can a working knowledge of algorithmic modeling augment student understanding of building architecture? This question is fundamental when addressing student design education today. This paper demonstrates that when students apply a reductive process more in line with Newell, Shaw and Simon (Newell, Shaw and Simon 1957), they can break down a complex problem into simpler and simpler terms until the problem can be resolved. This type of reduction can be applied systematically to the parametric-driven form through reverse engineering. In the process of reverse engineering, students begin to connect descriptive geometry with complex form, breaking down the complex form into its simplest parts. This design process of reduction and reverse engineering leads designers to take a more systematic approach to theoretical ideas, at once creating complex constructs while pragmatically attacking the issues of buildable form. This paper will delve into teaching analytical tools so students not only comprehend the input of form-making, but the necessary output to test building and material concepts. Fostering a clear methodology for testing built form within the design process also furthers the student’s development as a problem solver and design innovator.
Introduction

First of all, we must explain that the person standing in front of them is not someone who asks questions whose answers he already knows. Practicing architecture is asking oneself questions, finding one’s own answers with the help of the teacher, whittling down, finding solutions. Over and over again.

--Peter Zumthor, on how students should be introduced to architecture school (Müller 1998).

While it may seem rather perverse to use a quote by Zumthor to begin a paper about teaching algorithmic modeling, his notion of “whittling down” is a poetic description of reductive thinking, where each problem is resolved by simplifying the complexities. Using the mindset of Zumthor, scripting gives young designers the potential to use the computational realm found in algorithmic modeling to apply systematic rigor to their design, while continuing to pursue the poetic reality of architecture.

Scripting offers new potentials of exploring complexities of form before rendered impractical. Teaching students methods of algorithmic modeling at once furthers their tools as a designer and develops previously untapped design processes to deduce technical as well conceptual ideas. In learning the process of reducing the complex to its simplest form, the students gain valuable insight in how to work through design issues. This paper will use a series of seminar projects that use script logic to facilitate student thinking in terms of complexity, tectonics and other realms of architecture.

The Basics

With scripting, students learn to navigate a world that explicitly describes every move through clear logic of geometric translations. The student must consider point, vector, curve and surface. While some of these moves are clearly similar to CAD manipulations, scripting adds discipline. Scripting, because of its associative relationship to other components, requires the designer to create an associative framework for desired absolute and relative connections. This type of connectivity allows students to objectify their work to more clearly construct intelligence into their design. The intelligence will be further elaborated upon in the material analysis portion of the paper.

When initiating discussion of the fundamentals of scripting language, it is important for students to begin with their hands. Introducing simple plane manipulations through the folding of material, such as card stock paper, is a clear way to understand how simple physical moves create geometry. Using scripting, students then use simple transformations of points and curves to input the geometries of these translations into the computer (Figure 1.). As students engage in this project, it is important to create a loop of information input and the output of making. This process creates immediacy to how the scripting language translates real world coordinates and manipulations into physical outcomes. This closes the loop from physical to virtual back to physical.

The process quickly accelerates from one component being driven by simple variable input to a large, complex surface that is populated by variations of the component (Figure 2.). The final connection of the loop is to make the component aggregation a physical reality, which is where the reductive process and reverse engineering are applied (Figure 3.).

Figure 1. Component Aggregation, part 1. This assignment forms student understanding of input and output feedback loops. The student begins with a simple component created by hand and then designs a script to place the geometry into the computer.
Reductive Process

So the question becomes how to take the complexities of a design and reduce it down to a physical prototype? This is where a shift in thinking is necessary. In computer science, reductive thinking is often used to break down complexities. This reductive process defines the complex problem and reduces it to its simpler parts until each part can be dealt with given the knowledge at hand (Newell, Shaw and Simon 1957). When applied to architecture, algorithmic modeling challenges students to logically confront what they do not know about the complexity of a design problem.

Figure 2. Component Aggregation, part 2. The component, when aggregated, then has sample data control variable(s), making each unique within the system. This new system of unique components must then be reverse engineered for final output. In this example, the component also has a field data control, in the form of an open and closed variable, to create a low resolution porosity study.

In this case, once students have aggregated their component across a complex surface, they are asked to reverse engineer their components for fabrication. This is a watershed moment for the students because most are completely overwhelmed at taking hundreds of unique pieces and developing part files. However, if this complexity is reduced, as demonstrated in the example project that follows, the student finds the information is at hand. They just need to clearly formulate it.

In Figure 1., the student’s aggregation is a component that radiates around a point. Three components make a complete hexagonal pattern. The component has a variable $d$ that is modified to simulate open and closed conditions. When placed together, these layers of complexity are daunting. However, by using the basic geometry the student used to create the component in the first place, the student can then break down the larger system into the necessary information. In this case, the important factors were each hexagonal curve’s side size, $l_{w}$, along with the factor of $d$ already discussed (Figure 3.). These two variables could be gathered from the information already at hand. The student then transfers this variable information to a horizontal plane given the variable’s relationship to the original flattened geometry, as shown in Figure 2.

Figure 3. Component Aggregation, part 3. The final process is to reverse engineer the aggregation for fabrication.

With the major construct of the assignment laid out, it is necessary to analyze the process for its import in regards to algorithmic modeling and architectural design. If one believes the precept that physical models are necessary to design good architecture, then it is important to dwell...
on analogous modeling and fabrication in design processes. As parametric design becomes more prevalent, there is a propensity to create complexity. It is important to shift the student’s attention to the execution of the design. Students can quickly design themselves into a corner, as the complex geometries drawn in the computer can quickly seem too complicated to physically construct, and students create buildings that can only be tested in the computer.

Unfortunately, this condition often creates underdeveloped designs. The student may resort to sectioning or 3-d printing. However, the former often becomes a literal skeleton of the idea and not the true analog of the concept. The use of 3-d printing may show physical results, yet nothing in this realization delves into the process of building the idea. The tradition of model building has become a tool to show analogous process of the design idea becoming a physical reality. Therefore, the ideal is to continue to develop thought processes, such as reductive logic, that allow students to procedurally breakdown complex geometries to analogous fabrication techniques.

Material Analysis

One project developed to demonstrate the dialogue of trial and error and scientific reduction is a simple “material analysis” assignment. Students were asked to take a material, such as chipboard, and develop patterning within the material that would change its properties of form making.

Base test data was collected by testing the point of failure for chipboard when bent to tighter and tighter radii in both directions. The first outcome of this procedure was students discovered that what they thought was a monodirectional material actually had a difference in property, depending on which direction it was rolled.

Figure 4. Material Analysis, part 1. This material intelligence project created analog data collected through a series of material testing of perforated and scored patterns. Each pattern was then tested for increases in material flexibility given these modifications.

As seen in Figure 4., students tested various patterns of scoring and perforating the chipboard. Each iteration was tested for failure, increasing the data set. Students then took this data and created topographical studies with complex form. While still holding to the given minimum radii, students extrapolated whether the material would naturally conform to prescribed constraints under conditions of valley and ridge (Figure 5.). The students measured the amount of curvature to further augment the radii data. From these tests, students took the most successful patterns and applied this information to complex surfaces that were predetermined by the data. Interestingly enough, the chipboard reacted best as a conforming material only under scored pattern conditions. Initially, the perforations seemed to have as much success in changing the properties of the material (Figure 4.) as scoring did. However, students found the perforations weakened the material to the point of failure when attempting to form complex curvatures.
Figure 5. Material Analysis, part 2. The surface used for testing the patterning was analyzed for minimum radii curvature. This surface was iterated until the desired minimum curvature was achieved. Then various patterns were tested for natural deformation.

One might ask, why was chipboard used? Why not some other substrate that is more of an architecturally applicable material, along the lines of the wood studies by Achim Menges (Menges, 2009)? While a more architectural material is not out of the question, the most important outcome of this study was to teach methodologies for formulating base measures, collecting data, and then interpreting the data and formulating further hypotheses for testing. This type of scientific methodology creates a more rigorous process for students to evaluate not only their design work, but from which to crystallize a more clear process for experimenting with formal complexities.

These assignments desire to teach a more rigorous methodology through answerable problem solving. This type of thinking is quite foreign to architecture students, who are used to more subjective architectural measurements. Yet, this type of processing offers designers a whole new horizon of possibilities. The following section will outline a final independent seminar project that applied reductive processes and algorithmic rigor to the design. This project exemplified development of a methodology that harnessed the power of scripting associative logic to not only render an architectural idea, but more accurately and objectively evaluate the design.

Figure 6. Material Analysis, part 3. With a multiplier controlling the various lengths of scores, and the maximum curvature vector providing direction, a rather convincing natural deformation resulted.
Elaboration

The project brief called for a design for a new school of architecture on the Kansas State University campus, and was driven by an extensive façade study of the main architecture studio bar. Graduate student Tim Meyers investigated two contradictory design motivations: a desire to create a glass façade, and a need to conform to the campus façade policy that requires the majority of material to be native limestone.

As seen in Figure 7., the façade was conceived as an intricate network of layers of limestone blocks. These layers both activated the façade and created diffused light within the studios, no matter which direction the studios faced. In the middle of the façade were horizontal shelves of steel structure. The spacing of the shelves was based on the altitude angle of winter solstice. On the southwestern façade, a vertical pattern of limestone veneer was developed. This layer was designed to continue creating diffuse light during the afternoon, when the studios would be in full operation. The interior layer was a more traditional limestone veneer that also functioned to attenuate sunlight to the ideal indirect lighting.

Meyers further experimented with various levels of porosity using Galapagos (an evolutionary component within Grasshopper). The major variables of position and location as per sun angles could be modified and allow this script to be applied to any region on any building. Meyers successfully developed a script that not only created specificity to its site with exacting sun angles, but also provided formal complexity around a rather rigid geometry. The outcome was at once delightful and pragmatic.

Conclusion

The profession must nurture the poetic and artistic character of the student, but must also foster analytical thinking of materiality and structural principles. In addition to the subjective design processes architecture students learn, development of a systematic problem solving methodology such as the reductive process is an important part of design education. As this last project demonstrates, the use of algorithmic processes delivers a more analytical type of thinking invaluable to architects. These thought processes enhance the education of the architecture student by allowing them to better understand how to decipher complex structures and ideas.

Figure 7. The various layers each received specific attributes based on sun angles and porosity to create a rich pattern with performative qualities.
References


Thinking in Parametric Phenomenology

Paola Sanguinetti¹, Chad Kraus¹

¹University of Kansas (KU)

This project explores the relationship between phenomenology and parametric design. Architects have made compelling arguments for a phenomenological understanding of architecture, rooted in the subject and in direct experience, for which the notion of intentionality plays a central role. However, the inherent subjectivity of phenomenology has remained a barrier to its use as an explicit method of design thinking. On the other hand, the widespread use of parametric modeling, as a tool to capture design intent, has led to theorizing parameterization in architecture.

We propose that parametric design be reconsidered to think methodologically and concretize the experience of architecture. The research focuses on the use of parametric modeling to support the representation of experiential parameters. A case study is carried out as a graduate design project involving phenomenological description, parametric modeling, and fabrication. Results are presented to identify recurring parametric structures used by novice designers. We discuss the significance of diagramming to incorporate a qualitative schema. It is expected that the results will enhance the current approach to the parametric design process.
Parametric Design and the Phenomenology of Architecture

At its most basic level, the term phenomenology involves the study of structures of consciousness, necessarily rooted in the subject and in direct experience, for which the notion of intentionality plays a central role (Husserl, 1970). In addition to the sophism that phenomenology is anti-positivistic, the inherent subjectivity of phenomenology has remained a barrier to its use as an explicit method of design thinking. Yet several architects have made compelling arguments for a phenomenological understanding of architecture, focused primarily on exploring “questions of perception” (Holl et al 1994). The work presented in this paper explores the use parametric modeling to capture design intent and support the representation and description of architectural phenomena.

Parametric modelers are embedded in Building Information Modeling (BIM) tools or added as a plug-in to other CAD tools (Eastman et al, 2008). The widespread use of parametric modeling has led to much research and theorizing about its use in architecture. In the AEC field, studies have concentrated on modeling building information and capturing design intent to improve fabrication and construction (Sacks et al, 2003; Zeid, 2005). A recent case study in façade design and fabrication shows that parameterization of design intent requires explicit representation and categorization of qualitative aspects before production of a parametric model (Sanguinetti, 2008). Studies in the field of design computing have shown that parametric modeling increases the cognitive load at the conceptual design phase (Sanguinetti et al, 2007). Woodbury (2010) proposes the use of design patterns - “a generic solution for a well-described problem” - to facilitate the production of a parametric structure. This computational approach to structuring algorithms is influenced by the view of architecture as problem-solving (Alexander, 1977; Simon, 1973). Results from previous research point to the fact that architectural designers must alter their mode of thinking to engage in parametric design.

The question arises whether reducing the richness, complexity, and inherent subjectivity of phenomena to a toolset based on an objective set of parameters presents an irreconcilable contradiction. According to architects such as Tadao Ando, the true task of architecture involves coaxing out the latent character of place through a transparent logic - open to reason and perception - and a transformative process dissolving the complexities and contradictions of the ‘concrete’ world through abstraction (Ando, 1991). This careful abstraction succeeds in intensifying and concretizing the pre-reflective or ‘given’ lifeworld (Husserl, 1970). At one level, parametric thinking is analogous to conventional design processes in that a set of conditions - or parameters - are identified and analyzed, then preliminarily synthesized, tested and reiterated, and ultimately implemented. In any design process, if the set of conditions are misdiagnosed or misunderstood, the resulting design solution has limited potential to flourish and design integrity suffers. Beyond a front-loaded conceptual design phase, the striking difference with parametric thinking lies in its explicit structure that further emphasizes initial assumptions. In this respect, parametric thinking asks the designer to make explicit what the designer has always dealt with in a tacit manner.

Eastman (2006) identifies four types of information to be embedded and structured to express levels of design knowledge in parametric models. Qualitative information, being subjective, can be considered the most difficult to embed, because it is unstructured. Beyond similarities between parametric thinking and design thinking, we recognize that current and future architecture students need to understand the potential of parametric modeling as designers. We explore the capabilities of a parametric modeling tool to support the activities of novice designers, faced with the complexity of layering a semantic dimension, in the form of qualitative subjective information, over a parametric structure in the concept design stage.
Parametric Interface: A Methodology

In this research, we propose two types of parameters that reflect the designer’s intention: experiential parameters that drive the variability of a parametric structure and model parameters used to create and constrain geometrical relationships. By establishing overarching experiential parameters, we speculate on the possibility of reflecting sensory experience - including auditory, haptic, olfactory, visual, skeletal/muscular, kinesthetic, and temporal parameters.

To test these ideas, a case study is carried out as a five-week graduate design project involving three tasks: phenomenological description, parametric modeling, and material fabrication. Students work in four-member teams to design and build an installation, referred to as parametric interface, that responds to the human body to intensify an experiential person-to-environment and/or person-to-person relationship (Figure 1). A set of experiential parameters is established as part of the design process using a parametric modeling tool, in this case the Grasshopper plug-in for Rhinoceros.

Phenomenological Description: The first task aims at identifying sensory aspects of architecture. Students are asked to carefully observe and reflect upon a particular place in order to concretize an experience. Attention is directed toward transferable experiential phenomena beyond mere visual description. This is done through a combination of written, photographic, and recorded impressions (Figure 2). The exercise is intended to aid in identifying experiential parameters for further exploration. Students begin the design process by sharing their phenomenological descriptions and, based on these, they identify intended experiences for a Parametric Interface.

Figure 1. Parametric Interface process diagram

Figure 2. Samples from a phenomenological description

...the musty wood and metal in the enclosed tower seemed so dark; it required interior lighting even on a sunny...The dizzying effect was worse on the way down, because it was unbroken...There was the fear of falling as well as the fear that the groups behind you may catch up to you. Vision was dominant, but now I realize that it was also the kinesthetic aspect too. The repetition of rounding the same center point, the body understands as well as the eye, that the repetition of this motion is unnatural and contributed to the imbalanced feeling. The stairs were worn and each one was irregular...Footpaths left the stone stairs smooth and rounded after so many had passed through the stairwell. I could feel the footpaths of the past as I descended....I kept my hand on the wall the whole time to maintain some form of balance...
**Parametric Modeling:** The second task focuses on distilling the phenomenological descriptions into conceptual sketches and models, which are subsequently translated into parametric models (Figure 3). Students are asked to produce diagrams showing the relationships between input parameters, a script, and the intended experience. Next, they are given a series of Grasshopper tutorials. The concept of a wire-frame structure is introduced to concentrate on modeling parametric relationships rather than a complete representation of three-dimensional elements (Figure 4).

![Figure 3. Translating sketches into a parametric model](image)

**Material Fabrication:** In the final task, teams build an operational and responsive installation - the Parametric Interface - constructed at full scale and intended to respond to the dimensions of the whole body. The interface acts as a ‘prop’ of sorts in a carefully choreographed performance (Figure 5).

![Figure 4. Fabrication process](image)

**Results**

This project explores explicit structures that capture design intent using parameters, constraints, rules, etc. to combine qualitative and quantitative design methods. Findings show that the use of parametric design patterns is useful for novice designers in that it increases the designer’s awareness of a variable causal relationship between external forces and project outcomes.

In the process of moving from the concrete to the abstract, students seek commonalities between their phenomenological descriptions; some based on everyday experience, others drawn from childhood memories. We find that the students, who draw from memory, are able to bypass the need to filter their observations. Before engaging in parametric modeling, students rely on physical study models. We observe that the students postpone the use of the computational tool, partly due to lack of experience with it. Yet the main difficulty is in the abstraction and translation of design intent. In general, it is difficult for the students to strategize how to represent their ideas as parametric structures. In this case study we find the teams eventually gravitate towards one of two overarching experiences of place – threshold or enclosure. These experiences become archetypes to capture the experiential parameters being explored (Table 1 and Table 2). A subset of parametric design patterns is nested within this first level of hierarchy. We find that the “controller” pattern is most commonly used (Woodbury, 2010).
Table 1. Compiled results

<table>
<thead>
<tr>
<th>Team</th>
<th>Physical Description</th>
<th>Archetype</th>
<th>Parametric Wireframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a series of interconnected balanced platforms which activate a series of collapsible frames and fabric panels</td>
<td>threshold</td>
<td><img src="image1" alt="Parametric Wireframe 1" /></td>
</tr>
<tr>
<td>2</td>
<td>a series of pivoting outer frames positioned along a curving path with inner frames rotated incrementally</td>
<td>threshold</td>
<td><img src="image2" alt="Parametric Wireframe 2" /></td>
</tr>
<tr>
<td>3</td>
<td>a series of folded surfaces sited in response to the movements of the sun and wind to aid in isolating auditory and visual stimuli</td>
<td>threshold</td>
<td><img src="image3" alt="Parametric Wireframe 3" /></td>
</tr>
<tr>
<td>4</td>
<td>a series of concentric slatted panels rotating around a stationary observer</td>
<td>enclosure</td>
<td><img src="image4" alt="Parametric Wireframe 4" /></td>
</tr>
<tr>
<td>5</td>
<td>a series of supports from which a horizontal surface deforms in reaction to changes in temperature and sunlight</td>
<td>enclosure</td>
<td><img src="image5" alt="Parametric Wireframe 5" /></td>
</tr>
<tr>
<td>6</td>
<td>a web structure within an already existing space that reacts to pressure differentials and the movement of the body</td>
<td>enclosure</td>
<td><img src="image6" alt="Parametric Wireframe 6" /></td>
</tr>
</tbody>
</table>
Table 2. Parameterization

<table>
<thead>
<tr>
<th>Parameterization</th>
<th>Model Parameters</th>
<th>Parametric design pattern</th>
<th>Grasshopper definition (code sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kinesthetic: shifting weight to</td>
<td>Platform coordinate system:</td>
<td>controller/reactor</td>
<td></td>
</tr>
<tr>
<td>balance on tilting platform</td>
<td>change in z-axis corresponding to each move in x-y axes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual: having a false sense of</td>
<td>Frame structure shifts to</td>
<td>organized collection of points/goal seeker</td>
<td></td>
</tr>
<tr>
<td>stability</td>
<td>respond to platform: cross</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haptic: proximity of collapsible</td>
<td>product component</td>
<td></td>
<td></td>
</tr>
<tr>
<td>frames, and twisting fabric panels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Parallax: continuously shifting</td>
<td>Rotating frame: x-axis</td>
<td>controller/reactor</td>
<td></td>
</tr>
<tr>
<td>vertical and horizontal sight lines</td>
<td>rotation, z-axis shift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial depth</td>
<td>Panel spacing: y-axis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haptic: passing through a series of</td>
<td>rotation</td>
<td></td>
<td></td>
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<tr>
<td>translucent frames</td>
<td>Steel cable web: perpframe</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>box dimension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Visual: transitioning from light</td>
<td>Sun angle: t-parameter on</td>
<td>controller</td>
<td></td>
</tr>
<tr>
<td>to dark</td>
<td>curve Panel location: (x, y)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>point coordinates &amp; rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual/Auditory: transitioning into a</td>
<td>Panel aperture: angle of</td>
<td>controller/jig</td>
<td></td>
</tr>
<tr>
<td>heightened auditory sensation</td>
<td>rotation Panel location: (x, y) point coordinates &amp; rotation</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Pivoting arms around central</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>pole: t-parameter on curve</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Morphing surface: t-parameter on curve to assign changing z-coordinate on surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Kinesthetic: sitting within</td>
<td>Door angle: t-parameter on</td>
<td>controller</td>
<td></td>
</tr>
<tr>
<td>concentric sliding screens</td>
<td>curve</td>
<td></td>
<td></td>
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<tr>
<td>Visual: altering occupants with varied screen densities</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Haptic: experiencing contrast in temperature associated to materiality</td>
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<td>5 Visual: experiencing the change in</td>
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<tr>
<td>light and surface form</td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Auditory: hearing the melting ice</td>
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<td></td>
<td></td>
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<tr>
<td>received by a collector</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kinesthetic: moving under the</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>horizontal surface</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>6 Kinesthetic: grabbing the handle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and opening the door</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Visual: capturing and redirecting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sunlight</td>
<td></td>
<td></td>
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</tbody>
</table>
Discussion

In discussing the results of this project, we examine the process of Team 1. This team selects two descriptions for further exploration in the Parametric Interface. One member of the team captures, through video and text, her experience of reading at the library. The rhythm of daylight changing on the reading surface evokes a feeling of “balance”. Another team member provides a written narrative with two diagrams conveying her experience in the skating rink (Figure 5). She describes the physical act of starting to “balance” her body on the metal blades of the skates.

![Figure 5. Internal and external balance](image)

The team produces a sequence of preliminary models and sketches (Figure 6). They attempt to bring together two ideas of balance; external balance, where the body reacts to achieve equilibrium, and internal balance, where the fluctuation of daylight brings a sense of inner quiet and peace. The first iteration is a sequence of frames and spring-loaded stepping elements. The team combines these discrete elements in the second iteration. This system evolves into a series of collapsible frames that respond to the movements of the body on spring-supported surfaces.

![Figure 6. Concept sketches](image)

The team begins the parametric modeling process by abstracting sketches and diagrams concerned with the lack of balance into experiential parameters; kinesthetic, visual, and haptic (Table 2). The experience of shifting the body on a system of tilting platforms is complimented by a series of frames supporting fabric panels. When the frames collapse, responding to the weight of the body, they reveal an inherent instability heightened by proximity to a precariously balanced participant.

This experience of balance (or lack of balance) is represented in a parametric model as the angle of rotation from an axis perpendicular to the x-y plane. The center of each platform becomes the origin of a local coordinate system. This local coordinate system serves as a plane of reference for the steel frames, modeled as vectors, and the fabric panels, modeled as surfaces.

The platform tilt is based on the weight and location of the body in relation to the local origin. Weight is modeled as a shift in the z coordinate proportionally-related to a shift in the x-y coordinates. All platforms in the system are interconnected, based on shared corner points, to respond to a tilt in any platform. In turn, all vectors and surfaces are recalculated (Figure 7).
The team produces mock-ups and detailed assemblies in preparation for the fabrication process. The students address issues such as platform size in relation to spring strength and the effects of gravity. Other considerations such as site and materiality are also resolved during this process but not addressed in the scope of this paper. The resulting installation, in turn, serves as a prop for a choreographed performance in which their abstracted ideas of balance are re-concretized.

**Reflection**

**Parametric sketching and diagramming:** In parametric modeling, design intent is captured as a set of geometrical relationships, scripted by the designer. These relationships are represented as graph and visualized as wireframe. Grasshopper’s graphical representation of the script and the options to group, color code, and annotate, support the representation of qualitative information,
and put it in the realm of diagramming. Because of this functionality, we find that students are able to add a semantic layer to the computer script. We propose that a relationship between the diagram, or annotated script, and the resulting wireframe representation constitute a step toward a new form of sketching. Furthermore, the annotated diagram has the potential to reveal new parametric design patterns representing geometrical responses to sets of experiential phenomena.

**Design intent and intentionality:** During the project, students found it difficult to use parametric modeling for conceptualization. Although the use of Grasshopper supports the representation of quantitative and qualitative information, the visualization of environmental aspects such as wind pressure and changes in temperature had to be approximated. We find that there is always an inherently reductive aspect to externalizing design intent and representing it in a computational model. Even though in some sense design intent can be tested and “captured” with a parametric model, the notion of intentionality – denoting a subject’s purely mental phenomena directed towards an object – remains completely outside of the scope of parametric thinking. Recognizing this significant limitation, we speculate that with increased proficiency in parametric modeling, the relationship between concept and computation will correspondingly become more proximate.

**Performance in architectural thinking:** In attempting to integrate parametric and phenomenological thinking, the concept of performance has two meanings. Within the logic of parametric thinking, the term performance refers to the pragmatic need to embed analysis and measure the efficacy with which the design, responding to selected inputs, meets specific goals or targets. Performance in a phenomenological context connotes an action or set of actions that possess intentionality and in this case are focused on an individual’s execution or demonstration of a concrete experience. Design thinking is inherently synthetic and must simultaneously reconcile these two meanings of performance in architecture.

We conclude that the use of parametric modeling as a tool for architectural design requires a deeper understanding of how it can support our intentions as architects. The results of this case study point to the importance of embedding semantics in computational models to actualize this deeper understanding. We find that more research is needed in the architectural use of computational tools - originally rooted in engineering - to support the representation of architectural knowledge and intent.

**Phenomenological-Parametric Translation:** In science a phenomena is an observable occurrence that requires instrumentation. In phenomenology, the human body serves as the instrument through which we receive impressions of the lifeworld. This research attempts to mediate between these two approaches which both contribute to architectural thinking. In this project, our students are asked to translate subjective experiences into architectural ones. This requires a process of abstraction where tacit knowledge becomes explicit knowledge.

**References**


This paper describes a building envelope that has been formed from recycled political campaign boards. It explores its formation as a deviation from one cycle of production and consumption (manufacture, implementation, removal and disposal of the campaign board) to another i.e. a re-purposed shade canopy. This reformation is explored through the board's physical properties that are adapted to form individual cellular units by using lamination techniques (cross grain and mechanical fixings at stress points) and developable surface manipulation.

The paper then describes various stages wherein digital design and fabrication provided methods to achieve the reformation. It demonstrates how initial discussions about the cellular geodesic structure were re-interpreted through the constraints of the material as parametric limits (structural performance, elastic limits, load points etc.) along with a reduction in waste during cutting (estimated at 30%).

The project is then described through elements that foster dynamic interaction between the user and the surface i.e. evaporative cooling and heat stress sanctuaries in outdoor spaces. Furthermore the method of repurposing is then applied to other elements that provide the evaporative cooling system, timber glulam legs and sand bag feet. Together these elements help create a microclimate within which gathering may occur to mitigate heat stress in hot arid climates.
Repurposed Political Ply

Jason Griffiths\textsuperscript{1}

\textsuperscript{1}Arizona State University

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“It (David Greene’s intention) argues that if we really understood the implication of a networked world, saturated with millions of useful gadgets, we might find that we are surrounded by countless possible architectural propositions.”

The seasonal nature of American politics provides an episodic abundance of these 5/32” corrugated polypropylene 8‘x4’ sheets. Street corners and intersections play host to the periodic blooming of heraldic photographs, primary colors, slogans and all the paraphernalia of a campaign season. When the season is over they are removed, chipped and sent to landfill sites. What follows is a description of how this material can be re-purposed for architectural uses as a performative skin.

![Figure 01 Underbelly of The “Political Ply” shade structure.](image)

This project will be described from two perspectives

- In the physical sense of its material and fabrication.

- New consideration about the design life of materials.

The first may be described as “formative” and the second “embedded”.

These twin concerns offer a zone of negotiation that lies at the center of discussions on digital design in architecture and which often represents quite different poles. In this case of the formative fabrication and RP represents a new version of ideas about flexibility in that the end of functionalist spatial flexibility and mobile architecture has given rise to a design stage flexibility of pre-production permutations. In effect flexibility has been moved up the design chain and is now embodied in terms like mass-customization and “delayed differentiation”. This might be countered on the other hand by Paskian notions of the role of cybernetic structures of architecture wherein the most contemporary technology plays an ongoing role in activating the user. In this case the embedded computer implies a long-term relationship between the digital and architecture. Here both architecture and the computer form a symbiotic relationship while the formative interpretation suggests a high front-end engagement after which the computer is largely discarded once the building is complete. By contrast the embedded computer might suggest a different kind of modernist flexibility within architecture albeit under the term “adaptive” or “responsive”.

**Transitionary design processes.**

The nature of this dichotomy was central to the preliminary design discussions on the fabrication of an Earth Day festival shade canopy for ASU Polytechnic campus and subsequent exhibit at Nelson Fine Arts Gallery “Art and Sustainability” exhibition. The project was designed and constructed in collaboration with ASU’s SALA undergraduate senior students and GIOS environmental engineers. Our digital concerns where projected upon a program, which required an active solution to temporary shade in a hot and arid climate. Central to these concerns are:
• How collaging and re-purposing changed notions of architectural language.
• How active participation in the change in state of water and evaporative cooling affected notions of the user.

While both the first and second points turned out to apply more to the notion of formative digital processes the third featured more heavily under the notion of embeddedness.

Formative design process

The role of this building was a relatively straightforward requirement to provide shade in the form of an easily assembled temporary structure (an alternative to the “easy up”). However the design discussions where suffused with a persistent environmental slant in that not only was the event to be a celebration of Earth Day but its focus was upon locally grown organic food. In the design process both issues of design life and architectural language were at the forefront of the design process. For a long time the project concentrated on a purely geodesic solution in the traditional sense that it provided an achievable temporary structure based on existing precedents. However ideas about how the project improved a typical geodesic structure were not resolved until we arrived at a material that prompted a design life discussion. Pressing issues of material cost eventually produced the ideal material of reusable plastic political campaign boards. Prolonging the design life of these boards moved the project into its final form and into production. (While there was some discussion about the legacy of “Drop City” it was felt that the contemporary nature of the material and its fabrication process would provide enough development). The appropriateness of this material was partially due to a kind of coincidental temporariness i.e. political billboards have a similarly temporary/episodic existence in the same way that they are lightweight, weatherproof and cheap. Additionally we liked the way that the boards heraldic graphics could be aesthetically re-phased. In revamping this material both the language and workings of material lifespan issues came right to the fore.

Figure 02 Repurposing of political campaign boards.

It this stage the digital design and fabrication processes provided methods by which the material could be reformed into a shade structure. Initial discussions about the cellular geodesic structure where re-interpreted through this material. Cellular components designed in 3D as a hexagonal cellular dome where the applied to the twin walled plastic sheet. Each cell was formed into a continuous strip as an unrolled developable surface via a Rhino model. Each strip could be folded into a rigid cell and braced with an infill panel with an open center to reduce weigh and improve structural rigidity. Further rigidity was generated by laminating two layers of sheet with each fluted section running at right angles to one another in a similar way to the grain orientation of timber ply. Each unfolded strip would be Rhinonested within the 8x4 plastic board to reduce waste as far as possible (estimated at 30%).

Figure 03 Unfolded permutations of cellular units.

This quality of the tessellations also informed the stacking of the individual cells and was key to solving the stacking and storage issues of the project. Both issues were resolved digitally. However the additional and perhaps
most important part of the digital design process lay in the analysis of the hexagonal grid of cells that formed the geodesic dome which were initially assumed to be repetitive. Our Rhino analysis of the dome form undid this assumption (the closest repetitive variant being the Bucky Ball where the cells were too large) and led to a dome geometry formed from four different cell types each with their own particular geometry. These could be easily formed from mass customized pieces under the provision that their difference was not so great that they would exceed the tolerances of the stacking tessellations.

This digital formation process also contributed to the design of the glulam legs again under the condition that we focused on material expediency i.e. we attempted to avoid profligate CNC cutting patterns. Here we restricted ourselves to 2x1/4 “ unit timber strip based on a study of its bend tolerances and nature of its developable surface as individual layers in a glulam structure. In both this and the cell unit the “unrolldevsurf” Rhino command played an important roll in the physical transformation from flat stock to formed final element. In the case of the cellular dome however the digital transformation process also added to the sense of transformation of a material from one use to another that lay outside its original purpose.

While these functional benefits can be reasoned empirically it could not explain the way in which the project was aesthetically transformative. In a sense this became the most significant motivation. When one team member suggested that we turn the images of Fulton Brock and his family inwards so the structure would be the predominantly white rear faces of the board the suggestion was roundly rejected by all. In this sense what the team responded to was the quality of collage as transformation of meaning by juxtaposition. A subtext of the fabrication process became a quasi Photoshop-like Exquisite Corpse viii game wherein the image of the political campaign language was used to undermine its authority. Stacking the cells also became some kind of Bretonian game as well where in the vertical permutations could reveal a composition of disconnected body parts similar to a Hans Belmer composition.

This notion of re-purposing of the conventional object offers a segue into digital fabrication’s corollary of the embedded computer/responsive environment. In this case the re-purposed object is the plastic Voss bottle. In considering the environmental aspects of the project the team felt that it should respond directly to the use and interaction with existing environmental context (in this case hot and arid). Our aim was to provide an active cooling mechanism that in turn could activate users in a haptic dialogue with the project. In this respect we turned our attention to the prognosis of the fluid dynamic qualities of the space by adopting heat stress analysis ix as a means to provide a heat stress sanctuary below the canopy. The Voss bottle was now re-purposed into a
A personalized mister that could be pressurized via bicycle pump with reused tire valves and misting heads. This bottle is then manually pumped by visitors and hooked into the hexagonal cell. Each Voss bottle mister then soaks the inner surface of the cells shade canvass to produce a wicking effect that provides a radiant and evaporative source of thermal comfort to the visitors below (direct misters are considered to be potentially unhealthy as particlized water carries pathogens that can gather in misting heads). This effect was used to counter the high values of heat stress that are a common experience in environment we are working in. (Heat stress is described as “Temperature Index (WBGT): a weighted average of three temperatures -Dry bulb (DB)—shielded from direct sun light- Natural wet bulb temperature (NWB)—exposed wet bulb sensor-Globe temperature (G)—temperature inside a hollow metal sphere where $WBGT = 0.7NW + 0.2G + 0.1DB^\text{xi}$. The cooling effect is maximized whenever there is a prevailing wind current by channeling air downwards via a strut that opens the upper surface of the shade structure. In this manner the CFD simulations of the engineering team could be realized in a cooled zone beneath the canopy.

However while these simulations represent one use of the computer within architecture it does not engage it in the sense of the responsive environment. With this in mind we turned our attention to the manner in which the projects research component could become an ongoing information loop within the design. This aspect of the project offers a means of incorporating the heat stress sensor within the structure in a way that would convey the changing contours of heat stress index on the fly. Here the information relay is intended to work via a wireless connection to a webpage from which heat stress information can be accessed. Here we also envision making this information available to Haque Research Pachube i.e. “A web service that enables people to tag and share real time sensor data from objects, devices and spaces around the world, facilitating interaction between remote environments, both physical and virtual”. This information relay system can only be partially described as responsive in that the user is not digitally engaged in the activation process i.e. the activation process is a manual interaction whereby the bottle is pumped up and clipped on. The users participation is probably more digitally passive in that he/she receives information digitally and can respond by seeking out thermal comfort zones.

Figure 06 Heat Index Checker 8758 - the device provides real time analysis of cooling efficiencies to a local laptop. It can be set up through a wireless connection to a laptop close by.

The motivation for such ambitions (as Haque describes it) is to make the physical actualities of the built environment analogous to the adaptive nature of the free libre open source software (FLOSS) wherein users can adapt, improve and pass on components of the built environment. Here the analogy is crucial to the translation of ideas about software into physical form while both sharing the aim of overcoming the immutable structures of current architectural production. Both the Voss bottle and the re-used plastic campaign board are both “usable artifact” wherein their “repurposing” partially achieves this aim. The relay of environmental information on the other hand returns the project to the realm of software in a more traditional mode of gathering and presenting information. Further permutations of this project would seek to make this process a two-way relationship where users might use environmental information to adjust the cooling performance.

Conclusion

In this text I have offered a demonstration of a two-pronged approach to the deployment of digital procedure
within architecture. I have suggested that this can be characterized by considering the digital as either a formative design process or a manifestation of embeddedness. The project that was used to convey these concerns incorporates both in incomplete forms in a way that suggest that they are coupled and co-exist.

Together these aspects of the Political Ply structure create a new, temporary space for gathering. In this way the material has produced a low cost solution to a persistent problem of shade in the American Southwest. It demonstrates how contemporary forming processes can be adopted to make a demountable solution to temporary shade. This formation considers both the structural issues of the material and its stacking arrangement between uses and locations. It also explores how this formation process results in an aesthetic that helps to promote the importance of repurposing materials to its users. The project considers how other materials can be similarly repurposed to provide further structure and to provide a manually operated cooling system.

As a consequence this structure has been deployed at several different events since it was built in the spring of 2009. These events have included student end of year gatherings, art events, the EPA 2009 Expo in Washington and its current role as a shaded outdoor space on the ASU Tempe Campus in Arizona (it was also select for two design awardsxvi). Its formal and aesthetic qualities draw people together and help prolong gathering via the cooled underbelly and misting system.

References


iii See both Situated Technologies and Hague Research.

Situated Technologies, a project by Omar Khan, Trebor Scholz, and Mark Shepard, is a co-production of the Center for Virtual Architecture, The Institute for Distributed Creativity (IDC), and the Architectural League of New York.
http://www.situatedtechnologies.net/

Haque Design + Research specialises in the design and research of interactive architecture systems. Architecture is no longer considered something static and immutable; instead it is seen as dynamic, responsive and conversant. Our projects explore some of this territory. http://www.haque.co.uk

iv See http://students.asu.edu/discovery/feastival


vii Bill Massie describes use of PVC piping as American bamboo then we describe this as Political Ply.


ix Work done in collaboration with Joby Carlton Asst Research Technolgst (FSC), Institute Of Sustainability and GIOS environmental engineering students.

x See “Application of “cool canopy” for outdoor thermal comfort”. Harvey Bryan, Ph.D. Shivani Shah, Rashmi Sonal
xi AMS_Joby Carlson_Permeable Parking Lot Heat Stress Monitoring. GIOS ASU

xii Heat Stress index- Joby Carlson

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xv Ibid

xvi First Place in 2009 AA Fabrication Awards and S. EPA and AIA Lifecycle Building Challenge 2009 Award of Honorable Mention EPA
Weaving Methods in Architectural Design

Qing Xing¹, Gabriel Esquivel², Ryan Collier³, Michael Tomaso⁴, Ergun Akleman⁵

¹Department of Visualization-Texas A&M University, ²Department of Architecture-Texas A&M University, ³Corgan Associates-Dallas, ⁴Corgan Associates-Dallas, ⁵Department of Architecture-Texas A&M University,

Abstract

In an effort to investigate surface logics consisting of highly porous, irregularly defined weaving systems a series of investigative strategies were employed. This paper discusses certain modes of research and their derivatives through a case study, Spülenkorb, as an entry into a digital fabrication competition by Texfab, in which the project received honorable mention. The initial form is conceived as a Möbius band, a geometrical variant of the pure mathematical “strip”. The base mesh of the initial form is developed using the software TopMod3D and Maya. This base mesh is then processed into a woven object using internally developed weaving software.

Knots and links are interesting structures that are widely used for tying objects together and for creating interesting shapes such as woven baskets. To topologists, a knot is a 3D embedding of a circle and a link is a 3D embedding of more than one circle. We prefer to use the general term link, since each component of a link is also a knot. Mathematical links can be used to represent weaving structures such as a fabric, a cloth, or a basket. While there are a wide variety of weaving methods, the most popular is plain-weaving, which consists of threads that are interlaced so that a traversal of each thread alternately goes over and under the other threads (or itself) as it crosses them.
Introduction

Beyond its use in fabric design, weaving provides a wide variety of ways to create surface patterns that can be embodied in sculpture and in innovative architectural design. It has recently been shown [2] how any given polygonal mesh can be transformed into objects woven from ribbons of varying width, such that the ribbons cover the underlying surface almost completely, except for small holes, as is typical in woven surfaces. The ribbons can be manufactured inexpensively using laser cutters or water jets on a variety of planer materials. The corresponding plain-woven sculptures are constructed physically by weaving the resulting ribbons. For example, the sculptor James Mallos has recently constructed a large triaxial woven sculpture of a fingertip [9], using a Mercat type algorithm on a manifold mesh surface with a boundary. In addition to sculpture, there is a strong interest among architects to explore weaving as an alternative construction method [8, 6] based on traditional bamboo-woven housing [7, 10]. However, our research suggests weaving can also be economically viable even with more complicated shapes.

The case study to be discussed is with Spülenkorb (see Figure 1), a plain woven digital fabrication project. The initial form was an umbilic torus – an orientable figure influenced by non-orientable Möbius strip geometry. Figure 2 shows the basic geometry developed in Maya. The mesh then underwent a series of iterative tessellated studies in TopMod3D to study vortex apertures and variable, ornamental perforations, which was also a testament to the robustness of the weaving algorithm as shown in Figure 3. Software is currently being developed to streamline this process and manage construction of woven objects such as Spülenkorb.

Sensibility

In looking at traditional weaving techniques, our team looked at “coiled” and “plaited” basketry. Baskets are categorized by technique. While diagonally plaited baskets producing a more contemporary effect, it was found that coiled baskets provide more stability in that they employ a technique of bundling strands or rods stitched into a spiraling oval or round form with a thin, flexible element to create a coil. Ultimately, numerous variations of stitch types and embellishments (such as imbrications) can afford a wide range of possibilities. Spülenkorb, then, is a combination of both techniques.

The word spülenkorb literally means a coiled or spiral-form basket. The interest in a coil-spiral-weaving technique is the idea of movement (a propelling force that makes things operate - often found in patterns and certain geometries referential to physics and chemistry as well as in popular culture, music, and film) while
maintaining sound architectural logic of elegance in structure and form as defined by the competition brief. It was through this iterative investigation and sensibility that the project yielded honorable mention in the “REPEAT” competition organized by TexFab in November 2010[11].

Surface Design

![Image](61x366 to 272x520)

Figure 2: Initial surface in Maya

Maya was employed to design the initial base object of Spülenkorb (See Figure 2). Maya is an application used to generate 3D assets for use in film, television, game development, and architecture. Users define a virtual workspace (scene) to implement and edit media of a particular project. Scenes can be saved in a variety of formats, the default being .mb (Maya Binary). Maya exposes a node graph architecture. Scene elements are node-based, each node having its own attributes and customization. As a result, the visual representation of a scene is based entirely on a network of interconnecting nodes, depending on each other’s information. For the convenience of viewing these networks, there is a dependency and a directed acyclic graph. More information can be found from the product web page [5].

For further changes in the design of Spülenkorb, we extensively used TopMod3D, which is a topologically robust polygonal modeler that has been developed and implemented by the research group led by Ergun Akleman [1]. The initial version of software, TopMod3D 1.0, has been available as free software since 2003. Since conception, several artist and sculptors have employed the software to create interesting geometries. In August 2007, a new version, TopMod3D 2.0, with an improved user interface and scripting editor was released. This version also runs on Mac, Linux and Windows platforms.

The main achievement with this modeling system is the development of new ways and tools to design polygonal meshes with huge number of handles, holes and columns, i.e., very high genus 2-manifold meshes. It is a very dynamic and growing system. Its underlying data structure and minimal set of operations help to develop simple algorithms and guarantees to have 2-manifold property of meshes. The current version of the system already includes a wide variety of tools that provide a large number of ways to manipulate 2-manifold polygonal meshes. The system is compatible with commercial modeling systems i.e. the models created in this system are portable, and can be manipulated in other systems like Maya. It is also easy to construct very complicated watertight shapes that can directly be built using rapid prototyping machines. Figure 3 shows the design of Spülenkorb in TopMod3D.

![Image](287x148 to 498x301)

Figure 3: The resultant mesh after application of the pentagonal subdivision routine to the initial coil mesh in the software program TopMod3D.
One of the reasons behind the popularity of TopMod3D is that it has a very easy learning curve. The designers in our team used less than one day to learn the interface and operations. Though the most important differentiating feature of the system is the robust and easy modeling of very high genus manifold meshes, the system has many additional features which complement the high genus modeling tools. For instance, it provides a wide variety of remeshing tools which can be applied to polygonal manifolds. Using these tools, all semi-regular mesh structures can be created both from imported geometry or geometry native to the program. This provides us a rich pool of base meshes that can be used to generate different weaving patterns in our project. While several routines were investigated, the pentagonal subdivision [3] was particularly useful for our project because of the treatment of aperture as seen in Figure 1. A pentagonal subdivision scheme was applied to a base surface (see Figure 3) to create the final form of Spülenkorb, as shown in Figure 1.

Plain Woven Object Conversion

As mentioned previously, a system based on a theoretical approach by Akleman et al. [2] (See Figure 7) was employed to covert a base surface to a plain woven object. This theoretical approach is used to create plain-
weaving structures based on graph rotation systems.

With graph rotation system structures, it has been formally demonstrated that by twisting a subset of edges of an orientable manifold mesh, one can obtain an alternating link, which is the mathematical model for a plain-weaving. Based on this result it is possible to convert a link projection on a polygonal surface to a plain-woven object. Figure 4 shows “sparse” and “dense” weaving conditions that can be obtained with this method [2]. It can be seen that the “sparse” weaving strongly resembles familiar woven-basket structures, which are created using bendable but straight yarns. These structures can leave large gaps in some weaving patterns. By adjusting parameters in the weaving program, the user can control the size of the gaps, so that one can obtain “dense” weaving. With “dense” weaving, the original manifold surface can be covered almost without gaps using ribbons whose unfolded versions are wavy as shown in Figure 4(c). While parametrically controlled, Spülkorb uniformly employs a relatively “dense” weaving pattern.

The system employed can convert any manifold mesh to a plain-woven object. The shapes of the threads can be interactively controlled with a set of parameters. The system provides two types of flavors for 3D thread structures, ribbon and tube. Figure 5 shows all eight cycles of the Bunny model in the tube form. In the case of Spülkorb, the structure of underlying mesh defines the overall look of final woven objects as shown in Figures 3 and 4. In Figure 6, the notation (m0;m1;...;mn) refers semi-regular structures where most faces have n sides and vertex valences are m0;m1;...;mn in a cyclical order.

As it can be seen in Figure 6, weaving from (3;3;3;3;3;3) meshes can look significantly different from weaving from, say, (6;3;6;3) meshes. Since Spülkorb’s initial model used pentagonal subdivision over a quad mesh, our polygonal mesh consists of mostly (3;3;4;3;4) (see [2] for detailed discussion.). An example of such pattern is shown in Figure 6(d).

Figure 6: Examples of weaving patterns obtained from mostly regular and semi-regular meshes. The Figures 6(a) and 6(b) show two semi-regular weaving patterns. The rest of the patterns are not semi-regular.
Once the basic geometry was developed, we experimented with a series of subdivision routines to help determine which might provide the type of weaving that we ultimately desired. Figure 3 shows an example of the initial plain woven objects. Our team finally selected the pentagonal subdivision [3] because of the flower-like aperture treatment and the relationship between the various ribbons. Figure 7 shows the weaving ribbon pattern. Here various ribbon cycles are differentiated via color.

There was also strong consideration for the necessity of the final algorithm: weaving the mesh required inclusion of mesh based knots and links. These links can be represented in various ways, and can be passed through a subdivision-extrusion-reevaluation procedure to produce the desired woven effect. The weaving program exports the weaving geometry in an .obj format which can be further processed by Maya.

Spülenkorb consists of a series of six continuous ribbons of various lengths. Additionally, none of the ribbons are straight, nor do they uniformly maintain their width. These variables are determined by the geometry, the algorithm, and the further parametric variables provided in the weaving algorithm. Each ribbon includes several hundred developable surfaces, all with a unique four-sided condition as shown in Figure 8. It is because of these specificities, largely the algorithm and the inclusion of developable surfaces, a project can be conceived, digitally or otherwise.

**Conclusion & Future Work**

Up to this point much of the study in digital fabrication research has been based on tessellated surfaces typically derived from some abbreviation of the Catmull-Clark subdivision routine, which is preference in several popular modeling softwares. Our research presents alternatives through the parametric solutions found in emerging tools (such as TopMod3D) and algorithms (such as cubic pentagonalization and weaving theory and technique), providing an opportunity to experiment in new directions. Therefore, Spülenkorb reveals a distinct relationship between form and system, not only as structure, but also in terms of aperture, geometry, and effectual space, all provided through geometric application and the parametric algorithm.

While the geometry of weaving is an extremely interesting topic, the transportation of weaving into the realm of architectural tectonics and materiality is even more intriguing. Our next endeavor is to study the application of weaving on a larger architectural scale. Figure 9 shows the size of Spülenkorb related to a human. Figure 10 gives us a feeling of standing inside the woven enclosure.

There are many practical issues to consider. First, it is difficult to take fabrication techniques that work at one
scale and apply them at another scale, as there are numerous problems with the scale shift (as with many architectural techniques). Second, the unrolled flat strip is difficult to execute in regards to almost every flat-sheet fabrication method: it is inefficient and might potentially create a huge amount of waste material. Third, the strips would be so long and cumbersome at that scale that the actual weaving might prove difficult in construction. Therefore, we propose the strips could be cut into logically directed yet shortened, manageable lengths – providing the opportunity for the design of a connection condition. Not only would it would make a more interesting surface condition, but would continue to evolve our understanding of weaving in Architecture.

Additionally, we are currently researching materiality concerns and construction techniques of irregular weaving on an architectural scale. We plan to start with small scale objects by using different materials. Once the properties of each material are deduced, our focus will shift to solving various technical challenges of fabricating the object full scale.

References


In contemporary architecture, there are clever crooks engaging in organized crime. New architectural identities arise from the clever doubling of the performative and aesthetic/affective roles that architectural surfaces must, and can now feasibly assume. In 1908, Adolf Loos, in his celebrated piece, Ornament and Crime, called for "the elimination of ornament from useful objects." Rather than demanding elimination and removal, it can be understood that what Adolf Loos was really calling for was reinterpretation. Through the clever re-interpretation and generation of ornament in contemporary architecture with the aid of parametric design software the term "ornament" has assumed a new definition and identity.

Two design projects supported by parametric digital design processes and completed at the University of Kentucky showcase the potential to re-imagine how ornament can actively operate within architectural design. In both projects, primary building components simultaneously fulfill the technical requirements and aesthetic considerations that make the overall visual appeal of the project unique, potent, and affective.


Figure 10: Woven enclosure
Organized Crime: The Role of Ornament in Contemporary Architecture

Kyle Miller

1University of Kentucky - College of Design, eightyeight-west, architecture + design

In contemporary architecture, there are clever crooks engaging in organized crime. New architectural identities arise from the clever doubling of the performative and aesthetic/affective roles that architectural surfaces must, and can now feasibly assume. In 1908, Adolf Loos, in his celebrated piece, Ornament and Crime, called for “the elimination of ornament from useful objects.” Rather than demanding elimination and removal, it can be understood that what Adolf Loos was really calling for was reinterpretation. Through the clever reinterpretation and generation of ornament in contemporary architecture with the aid of parametric design software the term “ornament” has assumed a new definition and identity.

Two design projects supported by parametric digital design processes and completed at the University of Kentucky showcase the potential to re-imagine how ornament can actively operate within architectural design. In both projects, primary building components simultaneously fulfill the technical requirements and aesthetic considerations that make the overall visual appeal of the project unique, potent, and affective.
Organized Crime

In contemporary architecture, there are clever crooks engaging in organized crime. New architectural identities and images arise from the clever doubling of the performative (technical) and aesthetic/affective (conceptual) roles that architectural surfaces must, and can now feasibly assume. The terms ‘ornamentation’ and ‘surface’ in architecture are being redefined and repurposed as each strive to become multi-dimensional (literally and figuratively) and performative, shedding the superficiality that they were associated with in previous architectural discourses.

The use of ornament in architecture has long provided fuel for debate about architectural aesthetics. Ornament is typically defined as the elaboration of functionally complete objects for the sake of visual pleasure or cultural significance. Historically, ornament in architecture has been conceptualized as something that is an additive, unnecessary, building component applied to a host surface or object. In 1908, Adolf Loos writes, “The evolution of culture is synonymous with the removal of ornament from utilitarian objects.” It is largely accepted that Modern architecture (1900-1968) abided by the call to eliminate ornament from architecture in lieu of augmenting the true spatial experience produced by architectural surface, form and space. It is also often agreed upon that Post-Modern architecture (1968-1994) took an opposing position to the use of ornamentation, utilizing it to support its desire to communicate, to reference something other than itself. Post-Modern architecture seeks exuberance and celebrates the use of ornament. In contemporary architecture (1994-Present), many practitioners are seeking to redefine the term, “ornament”. Rather than being viewed as additive or an appliqué, ornament can now be understood as an integrated, performative, functional building component, one that bears technical responsibilities such as enclosure, aperture, daylight modulation, and temperature control, as well as the aesthetic and affective considerations that augment the visual potency and overall emotive qualities of a contemporary structure, and more specifically, a contemporary building facade. Contemporary ornamentation rejects the superficial applications of previous architectural genres and simultaneously seeks the authenticity that was sought after in Modernism. In Organized Crime, there are no lies and nothing is fake.

Rather than demanding elimination and removal, it can be understood that what Adolf Loos was really calling for was reinterpretation. Through the clever reinterpretation and generation of ornament in contemporary architecture (specifically in contemporary, complex building facades), the term “ornament” has been redefined and has assumed a new identity. One can understand how ornamentation can be reinterpreted in a project such as Tomato (Fig. 1), a design completed in the 2010 University of Kentucky College of Design seminar led by Kyle Miller. In this project, the generation of ornament occurs naturally through the strategic assembly and active manipulation of the façade’s wooden slat system. A proposal is made to redefine how a tobacco barn in Kentucky, a vernacular symbol of the state’s agricultural heritage, is visually received and to reinterpret its image in contemporary design culture. The agenda is to create an operable, performative façade system (Fig. 2), one that fulfills the changing environmental requirements from season to season and yields a complex visual resultant that is tied directly to its performative aspects. The operable facade permits the tobacco farmer to conceptually slice the façade incrementally, allowing for optimal environmental conditions with respect to the cultivation process. Both temperature and humidity inside the barn can be precisely controlled.
A tobacco barn façade is inherently thin; but in calling

Figure 1. Tobacco Barn Façade Design

Figure 2: Tobacco Barn Façade Slats
upon this surface to perform (actually and virtually), the façade gains thickness and becomes volumetric. It is within this volume that there is an opportunity for complex design. By repositioning the surfaces of the wooden slats in the barn’s façades, a complex visual construct is generated while maintaining nominal environmental parameters. It is this concept of employing multiple intrinsic qualities that embodies the performative nature of this design. Ornamentation ceases to be symbolic of something else and becomes valid in its own right as an integrated design element.

The reinterpretation and generation of ornamentation can also occur through more complex combinatorial processes and clever prototyping of new composite materials. This means of reinterpretation can be best expressed in Fresh Gills (Fig. 3), another design completed in the College of Design seminar led by Miller. The primary goal for this urban infill project was to design a complex façade system capable of performing basic functions of interior environmental controls. Simultaneously, there exists a desire to explore the generative capacity of unsynchronized local, physical building component manipulations at the scale of the individual dwelling unit to produce coherent, complex visual field effects at the scale of the building facade. The four superior floors are equipped with an array of colored vertical fins, creased and hinged along their length, capable of transforming between lying flat, parallel to the façade, and folding in half, orienting themselves perpendicularly to the facade. Fin deformations are controlled in two manners that produce or exploit macro patterns emerging from the field: control by a coordinated master system that deploys the hinge motion according to prearranged patterns; control by each individual apartment user.

Preset macro patterns deployed across the field can be organized seasonally and according to time of day, allowing for temperature and lighting control at the scale of the facade. Macro patterns can also be exploited to create a range of interactions between the building and the public. Periods of time when automotive traffic is dominant indicates that the dominant viewer group is moving at high speeds, whereas primarily pedestrian times involve people moving at significantly lower speeds. The façade system can employ patterns best suited to be visually consumed by each user, evolving large, unarticulated patterns as well as more articulated patterns with localized, subtler deformations. Such a pattern also emerges when the individual inhabitants directly deform the façade. Not only could this produce a ‘hyper articulated,’ unique pattern, but the façade also functions organically as an index for internal functions and desired environmental conditions. The fins are also colored along a separate, invariable, radial gradation, free of the kinetic system (Fig. 4). Thus, a disassociation between the chromatic field and the deformed three-dimensional field evolves naturally. Combined with the constant transformation of the field (Fig. 5), the chromatic gradation contributes to creating a strong break with expectations regarding pattern associations, inducing a potent, affectively driven visual construct.

Critical to the repurposing of the terms ‘ornamentation’ and ‘surface’ is the desire to create an “affective” architectural construct. Affect can be best described as temporary, cognitive pattern-recognition disruption that produces non-cognitive bodily sensations. Simply stated, affect is visceral engagement with the built environment. Affect relies on and requires the absence of reference.
The pursuit of affect as a discourse in architecture follows a clear path of architectural movements and architectural intentionality throughout the past century. In Modern architecture, built work seeks to stimulate the human consciousness through the inhabitants of a building engaging in a subject/object relationship with the building itself in order to siphon the essence of the architecture. Phenomenology, backed by the writings of Martin Heidegger, is born as an architectural discourse and considerable attention is paid to the experience of building materials and their inherent sensory properties. In contrast, Post-Modern architecture seeks to stimulate the human consciousness through semiotics and simulated building references. The individual is the reader and the building (or any architectural construct) is a text to be read. What is viewed, intentionally points to or refers to something other than the viewed object itself. In contemporary architecture a new agenda of affect replaces the previous discourses of phenomenology and semiotics. Architecture now seeks to appeal viscerally to
the senses rather than cognitively to the mind. Affect, similar to phenomenology, is most concerned with the non-cognitive visceral experience. Phenomenology is more concerned with tangible, authentic spatial extents, whereas, the discourse of affect is more focused on an unlimited, sensual experience.

In On Intelligence, a book written by computer engineer and entrepreneur Jeff Hawkins, the basis of human intelligence is explored. Hawkins identifies the brain as a memory system that stores experiences and remembers sequences of events. The brain makes predications based on those memories and nested relationships that exist among them. With this in mind, one can understand how affect in architecture will always be temporary as an individual experience. Affect, as a discourse of interest, was first activated through digital formalism. Unexpected, unprecedented, immaterial architectural forms were capable of being produced, and induced unfamiliar visual sensations. As the newness of formal experimentation wore off, material experimentation took its place. Many contemporary practitioners currently seek to both prototype and produce new building materials, and to use conventional building materials in an unconventional way. In both instances (formal and material experimentation), unexpected visual experiences cannot connect with a cognitive reference (memory). This produces visceral, non-cognitive sensations void of signs and void of mental representations or culturally predefined meanings aimed at sentimentality or nostalgia.

In Organized Crime, reinterpreted ornamentation, thickened architectural surfaces, and a growing interest in the discourse of affect are strategically combined to create technically and aesthetically sophisticated, honest architectural constructs. The impostors subsumed by the creation of their counterfeit architectures will be arrested and the clever crooks will prevail.

Notes

Supported by new publications and recently built complex contemporary building facades, the seminar surveyed how ornamentation has become performative and functional (both actually and virtually). Participants of the seminar sought to understand the difference between ornamentation and decoration; furthered the distinction between scientific (technical) performance and aesthetic (virtual) performance; and learned to objectively evaluate contemporary ornament based on the seemingly ambiguous parameters of affect and sensation. The seminar specifically analyzed contemporary how new parametric software increases the potential for complex façade systems to develop through highly controlled, efficient, iterative processes. The end product of the seminar was the design of a rain-screen façade system. Students were prompted to fulfill the requirement to create an inclusive, ornamental (performative) façade system and to consider how construction techniques (twisting, tessellating, folding, puncturing, peeling, etc.) not only generate ornamental effects (material and process based), but also are tuned to meet the design criteria for each situation.

Fresh Gills
Raleigh Arrowood
Matt Knowles
Jonathan Laurel

Tomacco
Josh Duddey
Ross Graham
Jason Milstead
Kellin Vellenoweth
The design objectives of this seminar were the following: To further develop an understanding of how contemporary building facades reconceptualize and reconsider the use of ornamentation as a functional, performative, and integrated building component; to understand how building elements are integrated into the façade as functional components and control tangible parameters such as natural light transmittance and inhabitable or structural depth of the façade; to master parametric design techniques that allow rapid production and manipulation of a façade design and its potential variations, to present a thoughtful analysis of the façade’s visual and spatial effects through varying the individual or collective elements that create these effects and a specified overall surface affect; and to indicate how specific variations of components, locally (at the scale of the panel of module) or universally (at the scale of the field), create significantly or subtly different overall aesthetics of the building facade.

References


Human health and energy problems associated with the lack of control of natural light in contemporary buildings have necessitated research into dynamic windows for energy efficient buildings. Existing dynamic glazing technologies have made limited progress towards greater energy performance for curtain wall systems because they are still unable to respond to dynamic solar conditions, fluctuating building demands, and a range of user preferences for visual comfort and individual control. Recent breakthroughs in the field of information display provide opportunities to transfer electropolymeric technology to building envelopes that can achieve geometric and spectral selectivity in concert with pattern variation within the façade. Integrating electroactive polymers within the surfaces of an insulated glazing unit (IGU) could dramatically improve the energy performance of windows while enabling user empowerment through the control of the visual quality of this micro-material assembly, in addition to allowing for the switchable patterning of information display. Using parametric modeling as a generative design and analysis tool, this
paper examines the technical intricacies linking system variables with visual comfort, daylight quality, and pattern design of the proposed electropolymeric dynamic facade technology.

Introduction

In the last several decades, there has been increasing interest in improving the energy and daylighting performance of windows for building facades. This is due to two main concerns: human health and energy conservation. Standardized mechanical and artificial lighting systems have created homogeneous indoor environments, shifting the dependence on natural daylight and fresh air to that of mechanical means. While the thermal and visual homogeneity of these indoor environments was initially considered to constitute ideal working conditions, instead it created severe energy concerns and problems for human health. The energy crisis during the 1970s was evidence that artificial means of heating, cooling, and lighting indoor environments had to be reconsidered (Carmody et al., 2004). The persistent desire for transparency in modern buildings warranted a thrust in research towards windows that could mitigate solar heat gains (Lee et al., 2006). Studies revealing the vital relationship of daylight to human circadian systems (Figueiro et al., 2002) suggested the need for windows that provided views and access to modulated daylight. Concurrently, extensive research has been undertaken into glazing technologies that can modulate energy flows while addressing needs for human comfort.

Comparable technologies

Numerous glazing technologies have been developed to address these demands, including glass coatings and tints, spectrally selective glazing, low-emittance (low-E) glass, and most recently, electrochromic glazing (Carmody et al., 2004). Electrochromic glazing is a switchable chromogenic film device that can provide seasonal and diurnal control over solar gains by switching on and off the number two surface of an IGU in order to mitigate solar gains. While electrochromic windows may be capable of providing significant savings on energy bills (DOE, 2006), the technology does not perform well in terms of visual comfort. Electrochromic windows have difficulty mitigating discomfort glare, providing usable daylight, and permitting clear views to the exterior. Because the ‘on’ position constitutes a flat blue tinted coating, it cannot selectively intercept direct solar rays. Often having to face away from the window during periods of low solar angles in order to avoid glare, people are typically dissatisfied with the ‘unnatural’ color of daylight and the inability to control the system to a greater variable range (Clear et al., 2006). This variability is essential for both visual comfort and for diurnal and seasonal modulation of solar energy. Although comparative daylighting systems are making moderate progress towards greater energy performance for buildings (DOE, 2006, Lee et al, 2006), they remain limited in their response to bioclimatic conditions, programmatic requirements, and individual preferences. These technologies do not critically examine the integration of human desires for visual comfort and individual choice for control. Furthermore, with their limited material conditions, existing technologies offer few opportunities for design variation in the architecture. These aesthetic, technical and methodological drawbacks prevent the successful implementation of existing dynamic technologies into building systems.

Display technology for dynamic windows

Recent breakthroughs in the field of information display technology have provided opportunities to transfer emerging materials to glazing systems that can offer increased variability, solar modulation, and user control over visual effects. Electroactive polymers (EAPs) are one such technology for façades that could productively link environmental performance with improved visual
comfort and design variability (Figure 1). Integrating pixilized electopolymeric films within the surfaces of an IGU produces a dynamic glazing technology that could respond to variations of sunlight while allowing for view and varying degrees of user control. The proposed concept for the EAP system is anticipated to outperform comparable technologies due to its effectiveness in modulating solar energy while addressing human desires for daylight, visual comfort and variable optical effects.

**Figure 1.** Integrating display technology within windows creates environmental modulation and visual diversity along the façade.

**Applications potential for building envelopes**

Electropolymeric window technology is a proprietary technology with many innovative properties. One of its main advantages is the ability to electrically control the physical position of very thin metalized polymers (Schlam et al., 2010). In transferring this technology to building applications, a gridded array of electopolymeric metalized films is adhered to the interior surfaces of an IGU (Figures 1 and 3). These films can be rolled up into miniature ‘window shutters’ with diameters small enough to fit within the air space of an IGU (Figures 2 and 3). Upon receipt of a small voltage along a transparent conductive coating (ITO), individual shutters can rapidly roll up or down for the passage of light and views.

**Figure 2.** Single shutter movement of electopolymeric technology.

The electropolymeric shutters tackle an elemental problem for existing shading systems such as vertical or horizontal interior blinds that typically move in one axis only. This restricted physical movement results in a tracking system with more shading material than is required for blocking solar rays, thus blocking potential views and diffuse daylight. If electropolymeric shutters are applied as two layers of a pixilized array within an IGU, then selective solar tracking throughout the day and year is possible. This double layered pixilation creates a geometric and spectrally selective two-axis tracking system (Figure 3). When programmed to intercept all incident solar rays, the mechanical polymeric shutters can immediately roll up or down to potentially block glare while permitting view and ambient daylight to pass through the ‘open’ shutters.

Another significant benefit that electropolymeric glazing could provide is the modulation of heat gain through the building envelope in order to mitigate heating, cooling, and lighting loads. In a double-paned system, EAP glazing

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could eliminate unwanted heat gain during cooling degree days by rolling its shutters down on the number two surface of an IGU in order to block infrared rays before entering the window cavity. During heating degree days, the shutters could roll down on the number three surface to allow the infrared rays to enter the window cavity and re-radiate into the interior, blocking the low direct solar rays to decrease unwanted glare. Through the switching of these surfaces and interception of direct solar rays, EAP glazing is anticipated to have substantial energy savings over the course of the year in comparison to existing fixed layer systems.

If the pixels are distributed over two or three panes of glass within the IGU, the shutter densities will be dispersed depending on the solar angles. This distribution of shading material would provide significantly increased ambient daylighting and views at certain times of the day and year (Figure 1).

In addition to its advantages in modulating environmental flows both seasonally and diurnally (Figure 4), the EAP system offers the benefits of individual control to its building occupants for the manipulation of visual effects along the IGU surface. The flexibility, immediate responsiveness, and remote switchability of the EAP system make individual choice over one’s shading density, privacy, views, and dynamic visual effects entirely achievable (Figure 4).

Figure 3. An IGU containing two layers of EAP shutters could continuously intercept direct solar rays while permitting the passage of usable daylight and views.

Figure 4. Section details of a triple pane electropolymeric glazing design over the course of a September day. Electropolymeric shutters modulate light for diurnal and seasonal variation; at night the façade system can preserve heat, or become an active interface for views.
Modeling dynamic system variables

Because of the flexibility in the fabrication method of the electropolymeric shutters (Schlam et al., 2010), there are several technical variables to consider that could dramatically affect the visual quality and energy performance of the EAP system. For example, electropolymeric rollouts may have a transmittance from 6% to 94% based on the thickness of metallization and by a thin layer of printed ink. They can also range in scale, from 1/10” squares to a 5’ x 10’ single shade (Schlam et al., 2010). Rollouts can be printed with color, maintain a reflective outer coating, or be fabricated to a desired transluency or transparency (6-94%), depending on the architectural and energy requirements.

Scale, opacity and color of the polymeric shutters will create different visual effects in relationship to interior illuminance levels, glare, brightness and clarity of view. These variables are fixed conditions of the polymeric layer and thus must be designed specifically according to site, climate, solar, energy-use and programmatic conditions prior to fabrication. With such a range in possibilities between shutter scale, opacity and color, establishing a parametric relationship between variables will facilitate the appropriate design solutions for this dynamic multi-variate system according to specific design criteria.

In order to test the possible variations of the EAP glazing for visual quality, a parametric model was constructed for quick and varied explorations. Using the three-dimensional CAD modeler Rhinoceros in accordance with the Grasshopper plug-in, a 3’ x 4’ model of an IGU with EAP shutters applied to the number two surface was used to study various shutter sizes (Figure 5). These configurations were examined for shading capabilities and clarity of view to the exterior for three times of day and year for a south-facing window in New York City. The scalar studies used the Grasshopper slider tool to populate the glazing surface with a gridded array of electropolymeric shutters ranging in scale from 1” – 8” squares in a checkerboard formation. Selected scalar configurations were then analyzed as single-variant conditions using the Rhinoceros V-Ray plug-in to generate schematic interior renderings (Figure 6).

Figure 5. Parametric model for designs in shutter scale.

These initial visualizations indicate that an increase in shutter scale could potentially provide more clarity in views outward. However, a decrease in shutter scale could provide more effective shading as well as usable light (diffusion of brightness and glare), but less clarity in views outward. Further daylighting analysis that incorporates precise material properties is necessary for measuring fluctuating daylight quality and potential for glare. However, for interception of all direct solar rays, an increase in shutter size has to correspond with an increase in the spacing between the two panes of glass, thereby necessitating a ‘box-window’ type or non-standard deep mullion curtain wall unit for the larger pixels that would add considerably to the cost of the system, as compared with a standard IGU.
Because of the EAP system’s dynamic characteristics, a principle challenge with simulating its performance relative to daylight is modeling its dynamic states against varying environmental boundary conditions. Prior to dynamic glazing, fixed glazing systems such as low-E glass could be modeled as a static condition. Its geometry could be imported into a daylighting simulation tool, such as Radiance, for performance analysis throughout the course of a day and year. However, the EAP glazing presents a moveable system being modeled against a dynamic boundary condition: rolling shutters and fluctuating sunlight. Simulating the movement of the EAP system with visualizations that illustrate the consequent changing light quality requires a large number of design iterations for comparison. Collapsing data and visualizations into an animated simulation is essential for the design workflow.

Parametric daylighting simulations

Until recently, many daylighting design analysis workflows involved several manual steps for obtaining simulation data, much like what was used to generate the visualizations in Figure 6. These steps included exporting and importing a geometry file to a daylighting analysis program, setting and running simulation parameters, and importing results back into a CAD program for visualizations (Lagios et al., 2010). This series of manual steps is time-consuming for testing a large number of design variants for environmental conditions over the course of a day and year. This is especially challenging for validating the possible multi-variate conditions for dynamic glazing such as the EAP system, which could be capable of continuously changing its thermal and optical properties in response to solar fluctuations.

A new tool linking Rhinoceros to daylight simulation software Daysim and Radiance is capable of merging this workflow, accelerating a previously laborious design process required for validating the EAP system variables. DIVA-for-Rhino is a design tool within Rhinoceros that directly exports geometries, material properties, and sensor grids into the Radiance/Daysim format. This format is capable of calculating a series of performance indicators including monthly or seasonal solar radiation (Lagios et al., 2010). Using Grasshopper to model the EAP system, the design parameters of shutter scale, opacity, and color can be changed incrementally and simulated using the DIVA plug-in. The simulation results are then combined into an animated building performance simulation. This simulation provides a dynamic visualization of the effect of these design variables on the daylight availability within the scene.

Simulation parameters

Preliminary experiments used DIVA to evaluate Daylight Glare Probability (DGP) for a large range of shutter scales. The previous model of a south-facing 3’x4’ IGU in New York City with a single checkerboard surface of EAP shutters at 100% opacity was used for the simulations. Shutter scale was linked to the Grasshopper slider tool, and the simulations were run for three times of day (9am, 12pm, 3pm) for three times of year (June 21st, September 21st, and December 21st). Since discomfort glare from low sun angles is most prevalent during winter months in New York City, a range of shutter sizes for December 21st were selected for evaluation for differences in glare. The DIVA ‘Image’ tool produced an animated series of Radiance high dynamic range (HDR) images for varying shutter sizes, which identified glare sources with color as well as luminance (cd/m²) with selected points. HDR images of large-scale (6.5”) and small-scale (2”) shutters
were used for direct comparison to evaluate the DGP for December 21st, 12pm (Figure 7).

![Image 1](image1.png)

**Figure 7.** Radiance image viewer using the Evalglare tool to identify DGP for large- and small-scale shutter sizes on December 21\textdegree, 12pm.

The areas of yellow, green, and blue denote locations of high glare probability, indicating where shutters are ‘open’ and where the direct sunlight reaches the back wall. The DGP difference between the HDR images for the large- and small-scale shutters is relatively minimal (40% vs. 39%). However, when calculated and compared for three times of day over the course of the year, the large-scale shutters produce an overall greater DGP than the small-scale shutters (Figure 8).

![Image 2](image2.png)

**Figure 8.** Glare probability for large- and small-scale shutter sizes on a south-facing New York City façade indicate that larger shutter sizes could cause more glare over the course of a year.

The DGP was also calculated for two layers of large- and small-scale EAP shutters within an IGU (surfaces two and three) using the same environmental parameters from the prior simulation. Between the two layers of the IGU, two checkerboards of shutters are positioned to block direct solar rays, as seen in Figure 3. Initial results of this simulation series suggest that with two layers of EAP shutters within the IGU, the larger-scaled shutters would be more effective in reducing glare for low winter sun angles (Figure 9).

![Image 3](image3.png)

**Figure 9.** Glare probability for a double-layered IGU of both large- and small-scale shutter sizes on a south-facing New York City façade.

The simulation results imply that for a single-layered system, a smaller shutter scale decreases discomfort glare at this particular site and orientation. However, when double-layered EAP shutters are positioned to intercept solar rays, effectively modulating solar gain, larger-scaled shutters could potentially lower discomfort glare. One of the trade-off design decisions to be made in this case is the negotiation between the mitigation of glare and the privileging of views, since smaller shutters permit greater visible transmittance through the EAP system, and therefore greater ambient daylight. Another design parameter to consider in this scenario is decreased shutter opacity, which could significantly improve the ambient daylight quality while still blocking unwanted glare. However, the DIVA workflow does not yet consider material opacity and color in its current version, although methods to incorporate these modification tools are in progress (Lagios, et al., 2010). While shutter scale and number of polymeric layers are just two of several variables to consider in the design of the EAP system, the DIVA workflow provided a quick and extensive analysis for comparison of a large number of design possibilities.
Trajectory and speculations

In addition to designing and analyzing combinations of EAP system component variables, parametric modeling was used for explorations in surface patterning. Studies in Grasshopper uncovered methods for achieving certain visual effects in addition to the baseline EAP ‘checkerboard.’ Through strategic EAP shutter placement within multiple surfaces of an IGU, visual effects of texture, depth, and graphics could emerge while simultaneously mitigating glare and provide diffused daylight with views.

Additional studies were generated in Grasshopper to design the movement of the EAP shutters from morning to night, shifting shutter density for desired effects (Figure 10). These designs are currently being analyzed for visual comfort using the DIVA analysis tool (i.e. visible transmittance, glare probability, and interior illuminance levels) to determine appropriate pattern selections for certain times of day and year.

Methods that examine the relationship between surface patterning and optical and thermal performance of the EAP system reveal ways in which parametric modeling can provide an evolutionary tool for linking visual effects to energy performance. This initial parametric framework for the EAP system provided real-time visualizations for the relationship of system variables to daylighting and visual comfort. The parametric framework also has the potential to operate at the micro-scale, linking pattern configurations to the thermal performance of the EAP system. Parametric models that control shutter placement within an IGU for shedding or capturing infrared heat could be directly linked to simulations for calculating solar heat gain coefficient (SHGC), U-value, and visible transmittance (Tvis). Pattern configurations could take on an entirely different visual meaning when their movement is in accordance with the modulation of light, heat, and human desires for visual effect.

Introducing design variability and individual choice over the visual quality of architectural envelopes and interior surfaces has the potential to satisfy the diverse needs of building occupants while reducing the energy consumption in buildings. The promotion of individual participation in the production of variety in the visual effects of the EAP system allows for occupants to partake in the modulation of natural light and information display through surface patterning. The glazing system’s flexibility in response to bioclimatic, biological, psychological, and socio-economic demands and desires could create a visibly dynamic socio-cultural identity within the façade. These architectural possibilities raise questions with reference to the socio-cultural implications of dynamic building envelopes that merge energy performance with the opportunity for information exchange at the building scale.

Presently, modern facades lack a visual registration of the...
bioclimatic energy flows that are being circulated in and around buildings. Consequently, our existing building envelopes have become monotonous barriers against the infiltration of the solar resource, often impermeable to meaningful socio-cultural exchange, while missing the opportunity to benefit from the valuable visible spectrum of daylight. Visual variation through daylight and surface patterning can provide an atmospheric experience that collapses notions of energy, identity, and cultural expression within the façade. Through the potential for switchable patterning and information display, the dynamic façade may introduce opportunities for the existing modern curtain wall to visibly channel symbolic significance through user participation in the control of dynamic windows and interior surfaces, thus breaking out of the legacy of increasingly homogeneous modern architecture into a more culturally rich and expressive form of building.

### References


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1. In order for the EAP system to perform most effectively for shedding or retaining heat, a triple-pane IGU with multiple pixilated layers is preferred.

2. The daylight glare probability (DGP) illustrates the probability that a person is disturbed by daylight glare and is described by an empirical equation, based on the vertical illuminance at eye level and a term considering the glare sources (Wienhold, 2010).
A Swell Project: Between Parametrics and Fabrication

Gabriel Esquivel1, Ryan Collier2
1Texas A&M University, 2Corgan Associates, Inc.

Abstract

As a case study, S well serves as: 1) an investigation into architectural ornamentation using a contemporary framework, as directed through specific modes of research, 2) a study in fabrication materials and methods, especially through the realization of form, and 3) as a pedagogical tool, loosely assembled through real and virtual space. This essay will focus mainly on the fabrication methods in terms of why and the pedagogical research initiatives and reactions that went into the design of S well. The project was conceived through a summer studio which was formed to investigate tools and methods available at the Texas A&M Architecture Ranch and to further the local pedagogical direction toward fabrication in architectural design at Texas A&M University as a whole. That is to say, there was no specific agenda toward parametrics, form, research, technology, or the like. At the same time, as the research continued, certain decisions were cast in terms of technology, sensibility, site, etc. informed by research, iterative processes, or parametric evaluation that ultimately formed the project as it exists today.
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Abstract

As a case study, Swell (Figure 1) serves as: 1) an investigation into architectural ornamentation using a contemporary framework, as directed through specific modes of research, 2) a study in fabrication materials and methods, especially through the realization of form, and 3) as a pedagogical tool, loosely assembled through real and virtual space. This essay will focus mainly on the fabrication methods in terms of why and the pedagogical research initiatives and reactions that went into the design of Swell. The project was conceived through a summer studio which was formed to investigate tools and methods available at the Texas A&M Architecture Ranch and to further the local pedagogical direction toward fabrication in architectural design at Texas A&M University as a whole. That is to say, there was no specific agenda toward parametrics, form, research, technology, or the like. At the same time, as the research continued, certain decisions were cast in terms of technology, sensibility, site, etc. informed by research, iterative processes, or parametric evaluation that ultimately formed the project as it exists today.
Introduction & Criteria

Initially, the studio focused on research into sensibility. The project had to be manifested as form, but what form? How do you construct criteria to make that decision? But more importantly how to understand that which is conceived internally within the construct of Architecture in itself. Therefore, students were encouraged to seek research that was based mainly on architectural precedent in addition to non-architectural transitional objects. The group focused in on certain detailing generated by Louis Sullivan, namely the more opulent ornamentation about buildings such as the Guaranty Building. The interests for the students were in treatment to the architectural condition, aperture/porosity, feeling or emotional aspects of ornament, materiality, etc. all framed within a contemporary framework, using contemporary tools and fabrication methods. The students framed Sullivan’s work in terms of a Baroque sensibility, that of surface investigation, levitation, tension, and anticipation. Ultimately the Guaranty Building’s cornice detailing was employed as a platform for investigation: a condition in architecture worth reevaluating in terms of ornament and surface treatment.

In looking through Sullivan’s work, the group noted certain porous conditions which would have to emerge within the project, and that these openings in a surface must seemingly be influenced by a force internal to the object itself. The difficulty with internal forces is a) they must react without literal movement and b) the aesthetic realization of the reaction. This was apparent in much of Sullivan’s ornamentation, as sinewy geometries framed certain voids, seeming to stretch parts of the terracotta...
or metalwork against other geometries aggregated and recessed back from those being stretched. Swell was to accommodate these sensibilities: a stretched, aggregated, porous condition which; contained and was stretched by other geometries in one way or another. Thus, another directive arose in that the project should act in a dual manner – one condition should stretch over another.

Once general criteria had been established, as defined by the students, a parallel study was undertaken: one group began to investigate the formal implications of the research, while others began to investigate materiality in terms of affect, durability, cost and other technical properties.

**Investigation**

How then to create the desired effect? The criteria had been established - but then how to test, design, and ultimately realize that design? Initially, the group relied on analog models to investigate the stretched, porous treatment, the implications of various fabrication methods, and the relationship between the two aforementioned conditions. It was soon realized that the project would need to delve into digital investigation for the sake of iteration and variance of patterning studies, which were crucial to the design. The group used RhinoScript to develop a method for creating porosity based on a general surface logic, implicit to any form. This script employed a method of geometry analysis which; informed the porosity condition about a surface based on certain mathematical constraints or parameters. Figure 2 shows an example of the script as applied to a series of panels.

As a pedagogical initiative, it is crucial to encourage investigations into iterative design processes, as it enables architects today to understand design implications in a broader context. That is to say, more investigation can happen in the same period of time, leading to a richer understanding of design. Algorithms break down the elusive and sometimes problematic phenomena of shape. Shapes are never unwilled figures. Deep within them is a struggle between the predilections of the architect and the inherent properties of the geometries encountered. The algorithm mediated between these two acting as a kind of solvent to liquefy and create the potential for crystallization. (Aranda/Lasch, 2006) Generally speaking, architects today apply new strategies that draw on the field of mathematics, genetic engineering and biotechnology, in such that they generate processes which are in so many “ecologies,” understood as material behaviors resulting from the same digital matrix. This radical paradigm shift in the history of architecture has moved us from representation to calculation, from form to code. (Andrasek, 2009) For designers like Alisa Andrasek, it is a matter of moving from “abstract information to material creation”.

**Technical Determinations**

With the use of parametric design ornament becomes once again an important architectural element worthy of discussion. It is important for young architecture students to learn about ornament and abandon all the “modern myths” polluting its application. Sullivan himself neither thought nor designed along dogmatic modern premises during the peak of his career: he often accentuated the plain surfaces with eruptions of lush “organic” ornament,
this project was relegated to constructing the structure that supported the skin (Figure 4).

2. Forming

It involves the generation of multiple parts from a small number of molds or forms. In architecture this translates into the realm of building components. Using a variation of five basic laser cut fabric forms can create a specific definition of a form producing a kind of rustication and ornament.

Because of the desire for a sense of levitation, while maintaining some level of economic control, forming became an option that was not feasible for the exterior development. However, because forming creates mass it worked well in the development of the interior system – the stretching object, which was inclusive of the research (see Figure 6).

3. Aggregation

Aggregation argues that the whole is greater than the parts, and that there is validity in serialization and multiplication of an object in terms of size, scope and scale. While on a superficial level, aggregation works in a similar way to tessellation. However, it is distinct in its fabrication method, especially in terms of detailing. In addition to forming, aggregation can be cost prohibitive in that it requires a multitude of parts to be successful. Although considered initially, a method of aggregation could not satisfy the material constraints required of the project, nor does it readily allow for precise control over the object, instead aiming to overcome this constraint through an additive attrition of objects. In a way, the interior of Swell was created through aggregation of “softbodies” or the interiority of the project. However, because of the softbodies size, density, and spatial relationship, the actual method would not be readily defined as aggregation, nor was aggregation a tool employed in the development of the interior system.

4. Tessellation

Depending on the tessellation resolution, approximated surface can be smooth and precise. When evaluating tessellation strategies, if the aim is to calibrate the initial form with a constructional system, it is better to determine the size and resolution of the tiles relative to the overall geometry and design.

usually cast in iron or terra cotta. It is the reinvestigation into both material studies as well as contemporary technology that allowed the group to reframe Sullivan in that way. For Sullivan, terra cotta was lighter and easier to work with than stone masonry. Sullivan used it because it had a malleability that was appropriate for his ornament. Similarly, Swell was supported through a series of non-regular castellated sections, which supported the object, but whose weight was mitigated through the removal of excess material.

At the same time the geometry/aesthetic was being developed, more technically driven aspects of the work were being resolved. Interestingly, there was a mutual reliance on both modes of work, as they defined each other, or placed certain constraints upon one another. The algorithmic data are connected and constrained by the physical limits of the machine’s capacity. (Andrasek, 2009) These models of tectonic systems set up limitations in materiality, fabrication technique and program used in response specific instances within a general set of design parameters and constraints. A good example of this was in the fabrication method chosen for the project, which was perhaps under a more “technical” facet to the project, but certainly was defined by a certain aesthetic. Before deciding which would be the final technique to be selected. A brief account of this interaction is as follows:

1. Sectioning

Rather than construct the surface itself, sectioning uses a series of profiles, the edges of which follow lines of surface geometry. The modeling software’s sectioning or contouring can almost instantaneously cut parallel sections through objects at designated intervals, effectively streamlining the process of making serialized, parallel sections. This method denies serious surface articulation in favor of structure or mass through aggregation of layers and thus failed to address the specific needs of the project, namely the expression of tension (expressed through porosity), and it’s used in...
this project was relegated to constructing the structure that supported the skin (Figure 4).

Figure 5. Students testing the hard exterior system, the softbodies, and the sectioned ribbing structure.

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Figure 6. A swelling interior.

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intention as well as material considerations.

Digital technologies have revitalized the design world’s interest in patterning and tessellation because they afford greater variation and modulation through non-standard manufacturing, even as they provide an inherent economy of means. Working digitally enables movement from one representational format to another – for example, from digital model to vector line file to manufacturing method. These series of translations allows for more fluid fabrication process while significantly reducing the labor associated with taking one type of design medium and turning it into another. *Swell* was fabricated using tessellation primarily because of the ease of defining the patterning about the surface, the ability to provide for a dual (exterior/interior) system, and the availability of machining methods to help in tooling out the various pieces and parts.

In addition to the exterior treatment, the condition of the interior was still somewhat indeterminate. As the research continued, it was concluded that if the project was to have a sense of levitation, and that the interior was to work in a pseudo-aggregated manner (if such bulbous bodies could be considered as such) then they must be as light as air, though visually dominate a large portion of the interior of the object. The team used large sacks of air that were inflated and inserted into the exterior of *Swell* before it was completed (see Figure 5). In this way, the surface could appear to be stretched and deforming under a load – a load that was mitigated for the sake of material constraints (see Figures 1 and 6).

**Conclusion**

While other methods of fabrication did not suit this particular analysis of Sullivan’s work, there are certainly opportunities to work with ornamentation within the context of the early modernist (or Architecture at large) using other fabrication methods or techniques. It is only through these investigations that Architecture can continue to refine itself, to redefine itself, and to emerge into our era of tooling design into production.

In retrospect, *Swell* should be considered pedagogically successful in that the students, in an abbreviated summer schedule, went through the entire process of research, design, fabrication, and presentation – with all the design decisions laid out for discussion. In the case of fabrication, there is no rendering or drawing that can cover up mistakes or thoughtless acts – the object is naked for the critic. Therefore, through the completion of the project, its reception, and through the retention and continued interest of the students, projects like this will continue to dominate architectural pedagogy well into the future.

**References**


A Curriculum for Integrating Computational Thinking

Nick Senske

University of North Carolina at Charlotte

For architectural educators, a challenge of teaching digital design is maintaining a relevant curriculum amidst an increasing array of constantly evolving software and tools. This paper describes a curriculum proposal under review at the University of North Carolina at Charlotte, which attempts to address this situation through the integration of computational thinking in studios and seminars.

Computational thinking is a developing area of study that originates from the discipline of computer science. Researchers define it as the ability to leverage the strengths of computing in order to study and solve problems. Whereas most digital design education is narrowly focused on the acquisition and application of a limited set of software commands and techniques, computational thinking is concerned with the fundamental concepts at the heart of every piece of computational software and hardware. In future testing, we hope to demonstrate that a more holistic mindset, rooted in these first principles, can assist students with understanding and making effective use of any form of computing they may encounter—now or in the future.
Introduction

At the University of North Carolina at Charlotte (UNCC), the School of Architecture is developing a new integrated curriculum for digital design. The primary impetus for this effort is the growing professional demand for students proficient in the latest software methodologies, namely parametric design and Building Information Modeling. Learning these tools involves more than merely learning a new interface; it requires a change in one’s thinking about design. In addition to representing buildings visually, with digital drawings and models, designers need to understand how to represent them symbolically, as dynamic systems of rules and relationships. While this is a significant shift in how architects conceive of their work, it is only the beginning of a growing trend towards computational design.

As our faculty considered the reorganization it would take to keep our courses up-to-date, we wondered: should our program be looking ahead to the future, towards scripting or other forms of programming? What about data visualization and simulation? Given the pace of advancement in our discipline, how long would our new curriculum remain relevant?

Adapting to changes in technology can be challenging for educators. The tools and methods of digital design evolve quickly, while the pace of administration tends to lag behind. What meaningful lessons can we teach our students about digital design that will not be rendered obsolete by next year's software or the new tools just over the horizon?

In this paper I describe a proposal under review at UNCC that seeks to address this issue of relevance. I will argue that teaching computational thinking can provide students with a lasting foundation; a mindset that is compatible with design, while taking advantage of the most powerful aspects of computing. We believe this new curriculum will overcome flaws in current digital pedagogy, resulting in students who are more engaged and adaptable with digital media.

Problem

In the book Design by Numbers, John Maeda argued that “we implicitly glorify rote memorization as the basis of skill for a digital designer” [1999]. Many students' understanding of software is limited to sequences of commands. As a result, they have a superficial grasp of digital design. Instead of deriving solutions from principles and structure, they look at the surface of problems to determine which sequence to use. When problems arise in the software, they have no mental model of the system to organize their thinking, and so they engage in haphazard “hacking” behavior to seek out a solution. They suffer from what Roy Pea describes as “production without comprehension” [1983].

These difficulties can be amplified when students attempt to learn computational design. There is far more to account for in the creation of a dynamic logic-driven system than in producing a static representation. Learning the sequences of commands to make the system – as one might in a lecture, tutorial, or textbook – does not teach one how or why the steps go together in that particular order. In other words, the command knowledge teaches nothing about design or problem solving.

Furthermore, completing additional computational tutorials does not necessarily result in a more comprehensive outlook. A correct mental model of a computational system is difficult to infer based on surface details. This is because computational systems do not work in simple cause-and-effect relationships. Effects from one part of the system can propagate to others without any visible effect [Sheil, 1983]. For this reason, the models that users infer from computational systems are often full of misconceptions and outright errors.

A student’s incomplete understanding can lead to designs that are inelegant, inefficient, or do not work. Most often, however, it produces designs that are severely limited; example or tutorial solutions with a few minor variations. Learning more tutorials increases the effectiveness of this tactic, but does not solve the problem of comprehension.
Moreover, when the problem or the software changes significantly enough, rote patterns no longer apply.

There is a significant gap in digital design classes that occurs between teaching commands and critiquing designs. In order to improve students’ comprehension of the material, educators need to do more than help them collect knowledge about tools. Studies of performance show that experts don’t just know more commands or patterns; they think differently about problems. They have robust mental models of their working domain and a perspective based on principles, not surface details [Dalbey and Linn, 1985]. The question is: how can architectural educators produce this kind of deeper learning with regards to computation? What goes into the gap?

Computational Thinking

In our new curriculum, we propose to address these challenges by teaching computational thinking. Computational thinking is not a new idea or one that is unique to architecture. It is a growing area of research that originates from the discipline of computer science [Wing, 2006]. Broadly defined, it is the ability to leverage the strengths of computers in order to study and solve problems. Computational thinking involves knowledge of the fundamentals of computing such as abstraction, iteration, and data structures. In addition, it includes the skills to break down a problem or task in terms of the computational steps involved, to test solutions-in-principle and refine them based on feedback, and to use them to study and solve problems. It also refers to a sense of procedural reasoning: the ability to envision the structure of procedural systems and anticipate their outcomes [Sheil, 1983]. When architects talk about the necessity and difficulty of “thinking differently” with tools like BIM, this is likely the gap. Explicit instruction in computational thinking is precisely what is missing from most classrooms and textbooks.

There are significant advantages to computational thinking besides learning to use the latest tools well. First, all forms of computing – all software, all programming languages, and devices – can be understood as different instances or interfaces of computation [Blackwell, 2002]. Therefore, a person that understands computational principles has a basis for making sense of anything computer-based. The tools might change, but the underlying logic does not. Second, software and devices are used most effectively when they take advantage of computation [Crawford, 1987]. Third, understanding how

Figure 1. Student examples of computational design. From a pilot study of Computational Methods, conducted by the author at the University of Michigan, Ann Arbor in 2009.
to exploit these capabilities allows one to represent and solve problems computationally. This has the potential to redefine one’s work [Pea, 1985]. For instance, the way that algorithmic stock trading and “shotgun” gene sequencing transformed the fields of business and biology, respectively. In the words LOGO (and LEGO Mindstorms) inventor, Seymour Papert, computational thinking allows us to “get someplace different” [1993].

To illustrate these ideas in practice, consider an example that everyone has some experience with: Microsoft Word. Most people use Word for little more than typing, formatting, and printing documents. In this scenario, the processing power of the computer is not fully exploited. The software does not substantially change the way one approaches the task compared to a typewriter. However, applying computational thinking, one might recognize that the document is more than a simulation of paper, but is actually a data structure. Instead of editing a repeated mistake by hand, users would apply the principle of substitution and seek out the Find and Replace command. Similarly, one could approach formatting parametrically, designing and associating Styles with elements in the document. Writing a form letter, one would invoke the principle of propagation and use the Mail Merge command to associate data from a spreadsheet for words in the document. These functions save time and help reduce mistakes, but most novices, who operate the program based on surface characteristics, do not know they exist and would not think to look for them. And so, with computational thinking, one does not have to approach the tool as its metaphors might suggest, but from an understanding of what computers do well. A person who uses it this way is almost certainly using it more effectively.

But more than this, a computational perspective can completely change the potential of the software. Returning to the previous example, Malcolm McCullough once described to me how he uses Word as a research tool, counting the number of times an author used important words or phrases. This simple frequency analysis helps him find patterns in arguments and citations. Now, take things a step further and visualize this analysis. A simple script that associates frequency to font size produces a tag or word cloud\(^1\) – a quick way to summarize a body of text. So thinking computationally, even about something as mundane as Word, can transform our way of thinking about the tool and lead to the creation of new knowledge.

Computational thinking is empowering. A student that understands the principles of computation in a program like Word should be able to recognize them in Photoshop, AutoCAD, Grasshopper, and even Python. While the specific uses and interfaces of these programs and languages are different, the ideas of computation, like substitution, parameters, and propagation can be found in all of them. Knowing principles makes it easier to learn the tool and use it more effectively. In addition, a student who can think in terms of these principles will be better prepared for any new program they might encounter post-graduation. And so, learning computational thinking has more lasting educational value compared to other methods of teaching digital design software.

**Curriculum**

Unfortunately, no one knows exactly how to teach computational thinking. This is a well-known problem even in computer science. Studies from this field suggest that it is highly unlikely that architecture students could learn it simply by taking a programming course or one that specifically teaches thinking skills. Without special effort on the part of instructors and learners, novices who study a programming language tend to demonstrate poor performance, particularly in the design of programs [Soloway 1986]. Nor do they gain additional benefits such as improved problem solving skills -- something we might expect as part of computational thinking [Mayer 1986]. These findings imply that developing computational thinking in designers requires a different approach.

The challenge facing educators who want to teach

\(^1\) See [http://www.wordle.net/](http://www.wordle.net/)
thinking skills is one of transferable knowledge\(^\text{2}\). This is knowledge applied outside the context in which it was learned— the very opposite of rote learning. There are two basic types of transfer, known as near and far transfer. We are interested in both. Consider a student who learns a particular technique for procedurally generating a roof panel system. If the student understood that the paneling method could be used to make floor and wall systems in the same software, this would demonstrate near transfer of learning. If the same student applied the logic of the paneling system in a GIS scripting language to distribute plots for a real estate development, this would be evidence of far transfer. And so, transfer is desirable because it makes learning more efficient for both teachers and students. If the goal is to graduate students who can apply programming ideas to design and adapt to changes in technology, teaching for transfer should be a priority.

Transfer rarely happens spontaneously, even with significant practice [Perkins and Salomon 1989]. Procedural knowledge, such as following instructions to use a program, is especially prone to rote learning. It takes a specific kind of teaching to break free of this. As such, in order to help students become flexible computational thinkers, our proposed curriculum uses teaching methods and course materials that have been proven to help with transfer. We design our lessons with three basic requirements in mind. First, software demonstrations need to take into account many contexts. This is so that students get a sense of when a particular technique or idea applies, and whether there are any exceptions to this. Most tutorials rarely explore enough variations for this to occur. Second, and most critically, transfer must happen mindfully [Salomon 1985]. This is to say that students must be guided and encouraged to extract the principle or strategy themselves. They must study examples intently instead of stepping through them in a disassociated manner. In this way, the student takes ownership of the principle. They are not simply told it; they discover it. Lastly, transfer depends upon metacognition or “thinking about thinking” [Perkins and Salomon 1988]. The student needs to be taught how to self-monitor, to examine the kind of task they want to perform, determine which principle applies, and adapt or correct their approach if it doesn’t seem to be working. Each of these requirements takes extensive preparation and careful classroom management, but the net effect is to transform learning digital techniques and methods from a passive experience to an active one.

Another way our proposal supports transfer is in the sequencing of courses within the curriculum. We do not propose one class that teaches computational thinking. Rather, this knowledge is spread across several years of schooling. Research and experience suggest that it takes time and practice to develop this kind of thinking. Moreover, we want to show that computation is not limited to a single semester or to certain pieces of software. Rather, it is a way of doing things that is compatible with design thinking. If students see computation in multiple contexts and in ways that connect to their level of understanding, they will be more likely to integrate it into their work.

Our course sequence is based on an educational methodology called cognitive apprenticeship [Collins et al, 1990]. This is similar to the idea of design studio, in which students encounter a successive approximation of how professional designers think and work. In our case, we hope to inculcate a model a mature computational thinker.

The curriculum divides the teaching of computational thinking into three different stages of apprenticeship. In their second year, students encounter what we call the “awareness” phase. The objective of this phase is to introduce students to computation early in their education, in a way that is motivating and interesting, but not so deep that they find the material overwhelming. In our design studios, students are taught computational strategies while they learn design software like Photoshop, AutoCAD, Rhinoceros, etc. The content of these lessons is similar to the earlier Word example. We

\(\text{ACADIA Regional 2011: Parametricism: (SPC)}\)

\(^{2}\text{For a review of literature on transfer, see [Butterfield, et al 1990]}\)
show students how approaching software computationally makes them more effective designers. This serves two purposes: 1.) it gives computational ideas immediate relevance and 2.) it destabilizes the idea that computation is limited to programming or software such as Revit and Grasshopper.

The strategies are based upon a framework developed by Bhavnani, et al [2008]. Compiled through a careful study of expert users, their framework teaches efficient and effective uses of software that are derived from the powers of computation. An example of a strategy is “reuse and modify groups”. This idea comes from the principles of abstraction and iteration. For instance, when drawing a series of doors, it is faster to make one door and to copy and modify it than it is to draw each door separately. Similarly, making a spreadsheet, it is faster to drag a formula across cells and then modify it than to write multiple specific formulae. This is a basic example, but something than many novices and even experienced users tend to overlook. Strategies like this are interesting to students because they save time compared to other methods. They are not learned by studying software commands and so are not easy for a person to discover on their own. Moreover, they are general enough to apply to nearly any kind of software. Bhavnani’s research demonstrates that students who learn strategies are likely to apply them in new contexts.

In the third year of the curriculum (the middle year for most of our students) we position our keystone class, Computational Methods. This is what we call the “explicit understanding” phase. It marks the transition from peripheral usage of computation to intensive practice. This seminar-style class surveys the principles that underlie computation: variables, conditionals, data structures, etc. Students are not merely shown or taught the principles. Instead, students derive them through rigorous exercises that relate to design. To cite two examples, one lesson teaches students about logic and algorithm design by having them write generative rules for Bauhaus compositions. In another lesson, they hand-code simple parametric systems from scratch. The later example could be done with software like Revit, but by making the steps involved explicit, the programming

Figure 1. Provisional curriculum diagram, University of North Carolina at Charlotte, 2010.
exercise helps the student grasp what is happening computationally as well as the design thinking that goes into creating a parametric object in software.

In the first half of the course, students study the principles using a scripting language such as Processing or Python. Learning to write code is important for architects because most design tools have built-in scripting languages that allow users to automate tasks or associate their information with other programs. Moreover, programming skill addresses a broader domain than drawing and modeling. It connects to other media such as visualization, simulation, physical computing, as well as fields outside of architecture.

The second half of the class reexamines the principles through computational software: parametric programs like Grasshopper and 3D-specific scripting languages like Rhinoscript. In most architecture programs, this would be students’ first exposure to computation. Computational Methods treats these tools as another way to interface with computation and an opportunity to learn the advantages and disadvantages of representing processes in different ways.

Lastly, in their final year, students move into the mastery phase. The goal of this phase is for students to transition to independence, applying what they have learned about computation towards self-directed inquiry and reflection. In a course we call Computational Practice, students work on projects with real objectives, such as competitions and conference papers, in groups and with people from other disciplines. We see this as a laboratory where students can cultivate a personal take on computation, developing a sense of their own process before they graduate into professional practice.

The School of Architecture at UNC Charlotte sees computation as an integral part of 21st century architecture. However, a reliable model for teaching this outlook does not yet exist. To address this challenge, the curriculum committee believes that computer science and educational research can provide valuable insights into successfully teaching computational thinking where intuitive, command-based pedagogies fall short. We forward to testing our hypothesis when the proposed curriculum debuts in the coming fall.

Evaluation

Because the curriculum is still under review, we have no assessment data to share at this time. We are presently collecting control data, with the expectation of following up when the new curriculum launches in the fall semester of 2011. Our assessment plans include both quantitative and qualitative components. In our quantitative tests, we will be looking for evidence of near and far transfer. Respectively: whether students are able to apply computational strategies and principles to effectively use programs they already know; and whether this knowledge helps them to use a program they have never seen before. These tests will be conducted using a protocol involving scripted problems, screen recording, and self-reporting by the subjects. The qualitative half of the assessment will use pre- and post-course surveys, and attempt to gauge students’ values, attitudes, and understanding of digital media concepts. Our plan is to conduct these tests in a long-term study, repeating them which each incoming class, and following students’ progression through the curriculum over several years.

Conclusion

This paper describes an integrated curriculum aimed at teaching students to be more mindful and flexible users of design computing. Rather than software training using rote tutorials, we propose a framework through which students might learn computational thinking: the fundamental principles of computation as they apply to problem solving and design. This framework, based on research from cognitive science and computer science education, consists of a sequence of courses intended to help students experience, identify, and demonstrate key computational principles. Our department’s goal is for students to be able to apply computational thinking towards any current or future software they might encounter. As of this writing, the curriculum is still under
review, but the first stages of our evaluation effort are already underway. We plan to report back on our findings in a future paper.

References


Parameters of a Digital Design Foundation

Erin Carraher AIA, LEED-AP
Virginia Tech (VT)

Students can begin utilizing the computer as a tool in the first year of their education in the same way they begin drawing, modeling, and diagramming as a basis for developing progressively deeper understandings of the capabilities and limitations of these instruments and their particular roles within the process of design. This hypothesis is being tested in Virginia Tech’s School of Architecture + Design over the course of the 2010-11 academic year by seeding a series of digital workshops into the beginning design curriculum.

The fundamentals of design in a digital age are changing. Axioms like color, scale, proportion and part-to-whole relationships form the basis of Virginia Tech’s legacy of strong first year studio curriculum, but advances in computational design and digital fabrication technologies in contemporary practice have broadened the range of tools available for design inquiry and have fundamentally changed the way we work. The importance of integrating these digital tools and concepts early into the education sequence is related to the way students are encouraged to think in the foundation studios, where the pedagogy is to teach the fundamentals of design indirectly in projects that demonstrate these principles through hands-on experimentation.

Considering design education topologically, we are examining the elements that remain invariant while the shape of the profession changes and identifying new parameters to integrate into the evolving lexicon.
Emerging Pedagogies

In the same way that new models of integrated practice are emerging in the profession, new ways of considering foundation design pedagogies are being explored relative to when and how it is best to introduce digital tools into the curriculum. I believe that in the same way students begin to understand drawing, making, and modeling in the first year design studio, that they can also begin to understand the computer as a generative tool and not just a representational technique. By incorporating digital technology into the curriculum beginning in the first year, students are afforded the time to develop progressively deeper understandings of the capabilities as well as the limitations of these tools.

The School of Architecture + Design’s foundation structure, which combines architecture, landscape architecture, interior design, and industrial design students in a common first-year studio, reinforces the idea that the parameters of design cross disciplinary boundaries. Early investigations into the nature of design lead to further development (both in terms of the specialized nature of students’ particular fields of study as well as in their particular fields of interest) of more complex ideas over the course of their education.

Historically, high value has been placed on a pedagogy that encourages development of a ‘durable knowledge,’ the type that once comprehended is with them for the rest of their lives. To this end, the School has a rich history of workshop-based, hands-on learning with materials such as plaster, ceramics, photography and printmaking. Workshops are typically self-contained, intensive, week-long experiments integrated into the design studio that allow students to learn the skills required to work with a material and then to challenge these traditional methodologies. This framework was adopted as the format for introducing digital media to the first-year students with the intent to both provide a basis of knowledge and to encourage students to push the perceived limits of the technologies.

Digital Workshop Structure

Over the course of the academic year, over 200 first-year architecture, industrial design, landscape architecture and interior design students in the Foundation Design Labs as well as approximately 100 upper-year architecture students will participate in the digital workshops. Each workshop is approximately one week long, comprised of one design studio of 22-24 students, and structured around a series of tutorials introducing...
the software program Rhino. In each workshop, a design prompt is given in which the use of technology is integral to the design process. The structure and project for each workshop are generated through discussion with the studio professor, and the workshop format is continually evolving. Each studio is also coupled with a ‘digital mentor’, an upper-year student skilled with the technology who serves as a resource for conceptual and technical questions from the first year students.

Two methods for structuring the workshops within the context of the design lab – integrated and nested – are being tested. ‘Integrated’ workshops build on a previously completed project or are the beginning of one that will continue beyond the week. This approach grounds the new technologies in a material reality and allows students to identify ways to translate between the known and unknown. ‘Nested’ workshops are fully self-contained in terms of the material presented and in terms of the designs produced. These workshops serve as intense introductions to the subject matter and are catalysts for future independent development of the skills learned.

The most successful workshops to date have used a known object or project as a fulcrum to translate from ‘analog’ to ‘digital’ modes of thinking. Operations that had been done by hand during the course of building a model are actually and conceptually translated into the computer, and real material limits help ground the designs within the virtual vacuum.

Actual to Conceptual Translation

The sixth workshop in the series – Cut, Fold, Score – began weeks prior to the workshop in discussion with the studio instructor about the format and content of the project. The prompt was developed, and tutorials were tailored to the specific project. In the studio class prior to the first workshop session, students were given an assignment that explored cutting, folding and scoring as means to generate a construction contained within a 4” cubic volume. Three iterations of the forms were made by hand using a 10” x 20” board with particular constraints given for the ordering systems used and limits on removing material.

Students brought their designs to the first day of the workshop where Rhino commands were presented as having analogous actions to known operations from their previous studio work. Basic shapes were organized under headings of points, lines, planes and solids. Actions were structured as additive, generative, reductive, topological, and Boolean. Two possible approaches for beginning to draw in the computer – constructive and structural – were also outlined, not as prescriptive working methods, but as places for the students to start thinking about translating their designs into a digital language.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Workshop</th>
<th>Year</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 2</td>
<td>Fabrication Process</td>
<td>1st year &amp; 3rd year</td>
<td>“Portal” group project fabrication and installation</td>
</tr>
<tr>
<td>Week 5</td>
<td>Beautiful Line</td>
<td>1st year</td>
<td>Plane from a line that is horizontal and vertical</td>
</tr>
<tr>
<td>Week 8</td>
<td>Regulating Lines</td>
<td>1st year</td>
<td>Field pattern studies</td>
</tr>
<tr>
<td>Weeks 9 &amp; 10</td>
<td>Hand + Machine</td>
<td>1st year grad</td>
<td>Re-fabricate glass vessels/ Topological surface</td>
</tr>
<tr>
<td>Week 14</td>
<td>Analytical Modeling</td>
<td>1st year</td>
<td>Demonstrate the kinetic movement of scissors through drawing</td>
</tr>
<tr>
<td>Week 19</td>
<td>Cut, Fold, Score</td>
<td>1st year &amp; 4th year</td>
<td>Fabricate cubes based on ordering systems</td>
</tr>
<tr>
<td>Week 21</td>
<td>Art of Building</td>
<td>2nd year</td>
<td>Model case study buildings</td>
</tr>
<tr>
<td>Week 23</td>
<td>Questions of Scale</td>
<td>1st year</td>
<td>Model space at multiple scales</td>
</tr>
<tr>
<td>Week 26</td>
<td>Animated Space</td>
<td>1st year</td>
<td>Animate sequences of movement in space</td>
</tr>
<tr>
<td>Week 28</td>
<td>Framed Space</td>
<td>1st year</td>
<td>Form defined by regulating systems</td>
</tr>
</tbody>
</table>

Figure 2. Workshop Matrix. Ten workshops are scheduled for the 2010-11 academic year. Eight first-year Foundation Design Labs as well as several upper year studios will take part in a week-long workshop to introduce digital technologies tied to a physical design project. Sequence order is tracked relative to the 32-week academic year.
The ‘constructive’ approach analyzed methods students had already used and proposed an equivalent digital action to each physical one. In some cases, there was a direct translation to a Rhino command, but where a break in the logic occurred, with ‘scoring’ for example, students were asked to develop a series of operations to achieve similar ends. The ‘structural’ approach analyzed the resulting forms from the first exercise to identify existing frameworks, connections or relations in the work. Students were encouraged to make a digital representation of these ordering systems as a way to begin structuring successive iterations.

For the second day of the workshop, students made at least three iterations of each of their three original forms (nine digital models). During the second session, we reviewed issues with conceptualizing and actualizing their designs and discussed methods for preparing their ‘three-dimensional’ computer models for ‘two-dimensional’ fabrication using the laser cutter. One series of second-generation iterations was further developed and then fabricated. On the last day of the workshop, there was a review of the students’ projects, a discussion of digital working methods, and an analysis of the tool’s abilities.

**Initial Findings**

In the early stages, the workshop approach seems to be working with an above-average success rate. Both during and after the workshops, students ask informed questions that demonstrate a searching approach to understanding digital form and conceptualizing virtual space. They develop methods to track ‘up’ and ‘down’ sides of materials as they move things around in space; they are able to conceptualize physical joints between objects and understand material thicknesses; and they utilize the program’s iterative capabilities to test the limits of design ideas.

Tying the workshops to a physical result forces a slowness and resistance to the seeming ease and fluidity of the software. Students understand that just because they can draw something in the computer, unless they are able figure out how to make it, the design will never be realized. This does not mean that the computer cannot and should not be used as a tool for conceptual exploration, but rather that the students must first be able to ground their explorations in the context of known limits.

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**Figure 3.** Hand + Machine Workshop Projects. During the first week of a two-week workshop with first-year graduate MArch I students, a previous studio project was re-examined as a way to help transition from analog drawing to digital modeling. Each student was asked to make a digital representation of a glass that they had previously studied at various scales through plan, section and elevation hand drawings. Rather than recreating the original glass, the digitally fabricated model was to convey its structure.
Less successful results have occurred in workshops that were situated too close to the end of the semester. At this time, the students are in production mode trying to finish their studio work and are distracted and rushed when learning the new tools. They have more of a ‘get the job done’ approach, and allow less time for experimentation.

I am also finding that some students have a difficult time figuring out the capabilities of tool sets beyond those specifically presented in the workshops. I think this is tied to the brevity of the workshops and am developing a resource that will present a broad range of tools in the context of their analogous ‘analog’ actions. I also believe that as the students recombine in their second-year studios, that the diverse range of skills covered over the workshops will allow students to use each other as a resource. However, this hypothesis will have to be tested over time. The true impact of these workshops will be tracked as the students enter the second year studios, which is the first year in-major, where we will continue to engage upper-year faculty to determine whether more advanced, discipline-specific workshops should be conducted at that time.

**Continued Explorations**

**Figure 4.** Cut, Fold, Score Workshop Review. Each workshop resulted in a physical project – a hand-made or digitally fabricated model, 2D graphic, or some combination thereof.

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**Continued Explorations**

**Figure 5.** Analytical Drawings. During the course of site analysis, students studied the impact of their design on people’s movement through the space where the Portal project was installed. Students use analytical drawing and other tools carried into the Digital Workshops from their previous studio work as methods for conceptualizing, realizing, and analyzing their designs.

In my own Foundation Design Lab, students are using the tools learned during the digital workshop holistically over the course of the year. They participated in the first digital workshop, which took place two weeks into the fall semester. Prior to the workshop, students began working on the first day of class with individual explorations in
form-making. They then joined into pairs to combine those forms into fields, and further reconfigured into teams of 5-6 where they were asked to use their previous approaches to define a 2’ cubic volume. Next, the students individually or in groups made proposals for an installation in the school’s lobby that defined a 6’ x 6’ x 6’ space. A jury of faculty selected a winning design, named Portal by the students, which the entire studio went on to further develop and construct.

After Rhino was presented in the workshop, students used digital modeling as a tool throughout the design and construction of the Portal project – first as an iterative design tool in the development of their group projects, then as a representational tool during the installation proposals, and finally as an evaluative tool during the refinement and construction phase of the installation. Their digital skill set continued to grow through the course of the subsequent studio project, which combined ideas of biomimicry and analytical drawing to develop a form that interacted with light. Their projects were drawn in the computer and fabricated using the laser cutter, CNC mill, CNC router, 3d printer or plasma cutter.

Figure 6. Portal Studio Project. After participating in the first Digital Workshop of the fall 2010 semester, my students then utilized the software as a tool to help design and fabricate an installation in the school’s lobby. The built work was the last in a series of iterations looking at form in ever-increasing scales and how it can be used to define space. The project began on the first day of classes and within one month progressed from drawing and modeling by hand to computer-based representations and shop drawings for the installation.

Figure 7. Biomimetics Studio Project. This student studied fish scales and developed a topography and two-way structural system that allowed for the same flexible movement of a fish’s scales within a CNC-milled wood field.
This integration of emerging ideas and technologies alongside traditional concepts within foundation studio projects is part of larger pedagogical question on my part concerning design education. Contemporary practice is never about one discrete thing, but the possibility of many adjacent things. As such, I believe it is important to integrate concepts from the ever-evolving design professions into the studio at the earliest stages rather than first introducing them as discrete fields of study later in the curriculum.

This context helps students target the relevant in a world of ever-expanding possibilities. Iteration and early integration are keys to developing an understanding of the variables and constants related to an idea and how that idea is situated in the larger framework. I am finding that by bringing these concepts into the studio early on in a grounded way, students begin to recognize the affinity or disjuncture between the ‘new’ and the ‘old.’ They realize the potential of multiple working methods and are able to start making critical decisions about what tool is right for the job. Of course, this is not true in every case. There are still students who use a chainsaw when they should be using a scalpel, but even these mis-steps provide for valuable discussion amongst the group.

Process + Product

Neil Leach states: “We are witnessing a new generation of designers operating within the digital domain, who are not simply using these technologies as a sophisticated tool for testing out designs conceived in a more traditional paradigm, or as a technique for assisting in construction calculations, but rather as a medium through which to pursue design itself.” It is essential that as educators we recognize that this paradigm shift has occurred in the profession. The question at Virginia Tech then becomes: how do you incorporate digital technologies into the design curriculum and not lose the value placed on hands-on learning?

Within the ever-evolving digital world, the idea of developing a ‘durable knowledge’ is difficult to fathom. However, I have found that students are spending more time in the wood and metal shops as a result of their work with digital fabrication. It is through the process of realizing their designs in actual materials that they discover these new ways of making have ties to traditional design principles and construction techniques. This develops an understanding of the affect of digital
tools on both the ‘product’ of design – the thing itself – as well as the ‘process’ of design – the making of the thing.

Early feedback from the workshops is showing that after an initial struggle to gain a facility with the tool, students are able to think spatially about digital design, work iteratively both inside and outside the computer, and make projects that demonstrate an ability to fabricate using related digital technologies. I believe tying a physical project to the media introduction facilitates this transition. Every architecture and design school has digital modeling, representation and fabrication courses in their program, but most of the discourse on the subject seems to surround the results of groups of advanced students with a particular interest and facility with the technologies. I think that there needs to be a broader pedagogical discussion about where and how it is best to begin introducing digital tools in a holistic way into the design curriculum.

Limits

It is important to clearly convey the possibilities as well as the limits of the software to students so that they do not default to standard methods of working. Today’s students will learn countless programs over the course of their educational and professional lives and each one will have different capabilities and constraints. The School of Architecture + Design selected Rhino as the package that each first-year student is now required to purchase because it is a good platform to be able to actually and conceptually translate to other software products, because it is used in practice by all the disciplines taught within the school, and because it supports a broad range of plug-ins that allow for specialized application in different areas of design.

Amongst the foundation faculty, the question of digital fabrication in the first year is still a topic of much debate. Many think that these tools should be reserved until after the students have a firm understanding of more traditional working methods. They believe, with valid concern, that because a technician controls the actual programming and operation of the machines, that the students are not developing the ‘deep knowledge’ that more traditionally built projects afford.

I believe that digital fabrication has an affinity with digital modeling and as such the two are appropriately

Figure 9. Cut, Fold, Score Workshop Projects. The project for this workshop began prior to the first digital tutorial through a series of hand-made models and continued to develop through the week of the workshop via computer modeling, study models made both by hand and machine, and resulted in a final project that was required to be made using the school’s laser cutter.
introduced in tandem. Though different than traditional construction, digital fabrication is not a hands-off process. Students who use the CNC router, for example, are required to understand how the machine works operationally, to make informed decisions about material selection and tooling, to coordinate with the technicians regarding methods for fixing materials during fabrication, to design a way of tracking and joining separate components and layers, and to do all of the material preparation and post-production work themselves. I feel that having gone through this process is a valuable educational experience and one that mirrors the way that designers interface with these technologies in practice.

Educational Invariants

In school, students learn how to think like designers. This time shapes the trajectory of where they will situate themselves within the landscape of design practice. To respond to the current developments in the profession, we must continue to build on the paradigms of the past, continually question and negotiate our position relative to the present, and challenge ourselves to incorporate emerging issues like sustainability, responsive design, parametric modeling, and advances in digital fabrication into the curriculum. Today’s students are tomorrow’s stewards of the built environment. As such, they must have an understanding of the way that world is being and will continue to be designed and built.

Pedagogically, there is much room for debate on where and how digital tools are incorporated into the curriculum and even what tools are introduced. The lure of the quick, the seductiveness of the computer-generated image, and the illusion of the infinitely possible are all traps to be avoided when introducing digital tools to first-year design students. Technologies must always be grounded in a constructive reality where the qualities and limitations of the materials and methods of making inform the understanding of the design itself. Limiting variables and emphasizing the value of iteration are also essential to providing a solid foundation for digital technologies after such a short period of time working with the new media.

References

Digital tools are currently being used in design schools across the country. This paradigm in both education and practice of architecture is continually changing the profession, from the way in which design is conceived, represented, documented, and fabricated. Parametric design can be defined as a series of questions to establish the variables of a design and a computational definition that can be utilized to facilitate a variety of solutions. Parametric thinking is a way of relating tangible and intangible systems into a design proposal removed from digital tool specificity and establishes relationships between properties within a system. It asks architects to start with the design parameters and not preconceived or predetermined design solutions.

Traditionally, architectural curricula are formatted as an aggregation of individual cells, representing courses to be taken, which align in a grid fashion to map a student’s trajectory through the program. This paper suggests that parametric thinking might yield a curricular diagram more reflective of the relational dynamics of the contemporary education, harvesting the synergies between courses and content. This diagram would simultaneously address the small scale of an individual course, as well as the overall structure of the degree.

Can this method of thinking also allow faculty a fresh perspective on curricular structure as well as NAAB’s student performance criteria, seeing them as a set of relationships and parameters to be established early on in the students’ journey?
Parametric Thinking

David Karle, Brian M. Kelly

1University of Nebraska Lincoln (UNL)
College of Architecture

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Situating Parametric

“...one must make the encounter with relations penetrate and corrupt everything, undermine being, make it topple over. Substitute the AND for IS. A and B. the AND is not even a specific relation or conjunction, it is that which subtends all relations, the path of all relations, which makes relations, shoot outside their terms and outside the set of their terms, and outside everything which could be determined as Being, One, or Whole”. 1

Parametric design can be defined as a series of questions to establish the variables of a design and a computational definition that can be utilized to facilitate a variety of outcomes. Parametric design sets up measurable factors of rule-sets to determine behavior. Within architecture, these rule-sets can be; program, site, exposure, views, floor to floor heights; or in the position of this paper, can be a curricular diagram. Within each rule-set, parameters are established and a bandwidth of outcome is introduced. No single rule-set typically regulates until the author gives authority to one over the other. These rule-sets can be either co-dependent or isolated from each other. The more overlap and co-dependency that exists the more integrated the outcome. Throughout this paper we will situate the parametric processes as a series of questions and not a formal driver or generator. This methodology establishes an emergent set of relationships removed from preconceived notions.

In an era of rapidly adapting and evolving processes, educators, architects, and designers must adopt emerging ways of thinking and making. Parametric thinking is a way of relating tangible and intangible systems into a design proposal removed from digital tool specificity. It asks architects to start with the design parameters and not preconceived or predetermined design solutions. Parametric thinking pushes back on the conventional architectural design process and negotiates multiple variables that define a series of rule-sets. It asks architects to operate quicker, more nimble, and smarter, juggling multiple systems with speed and efficiency. Situating a design or a curriculum around a series of questions and variables enables the proposal to be controlled within a certain range based on the performance of the constituent elements. It is a “part to whole” approach, focusing on the behavior at the component level enabling results at the aggregate level.

Parametric thinking offers a significant change to the current paradigm in academic and professional practice. By framing projects and curricula from the beginning as parametrically derived, it puts less pressure on the designer to generate the right design and more pressure on them to ask the right questions. Asking relevant questions and establishing the series of rule-sets with associative variables will enable a generative design process and curriculum to emerge.

Parametric thinking “gives relations another direction, and puts to flight terms and sets, the former and the latter on the line of flight which it actively creates.”2 The “multiplicity which constantly inhabits each thing”3 is expressed through the overlap or relations between the activities. It sets into motion a way of relating activities and thinking processes across curricular years to maximize student potential. Parametric thinking asks the curricular diagram to be thought about as a part and a whole at the same time. The diagram should consider multiple paths through the curriculum where by the collection of pieces is greater than the individual parts (1+1+1>3). Throughout this paper we will situate the pedagogical benefits for thinking parametrically and position a series of questions towards setting up a responsive, dynamic curriculum.

The description and diagramming of architectural curricula

The delivery method for an education in architecture is an ongoing discussion in most schools, and most pointedly today, in the academy as we determine the most effective methods for preparing students to enter the practice of tomorrow. Historically, these discussions have been supplemented by, or resulted in, a diagrammatic expression of the curriculum and a student’s anticipated trajectory. Curricular discussions tend to separate the issues of content, usually structured around the National Architectural Accreditation Board’s (NAAB) Student Performance Criteria (SPC), from the methods (studio,
lecture, analog, digital, design/build, etc.). Pivotal to the
discussion is the questions being asked and how they are
manifesting a framework for the curriculum. We ask, what should the diagram of today’s student look like? Should it be static in the form of a printed document, or only digitally-interfaced to retain dynamic and current properties?

Arguably, the most recognizable curricular diagram for an architectural education is the 1922 Bauhaus model consisting of concentric circles focusing from the outer circumference, preliminary courses, to the center, architecture. Radiating from the center out, the graduate architect was seen as the epicenter, being supported sequentially by materiality, methods, compositional strategies, integration methods, and initial contextual content. This model attempted to describe the movement through the curriculum while the diagram represented a viewpoint on the education as a whole.

A similar expression of a diagram of educational delivery, exemplified during the Enlightenment Period, manifest itself through the form of a school floor plan. The plan of this schoolhouse, in the shape of a circle divided from the center out, was established to overlay control and supervision on the students and supported the disciplinary nature and training intent of inaugural schools. Thomas Markus in his book Buildings and Power suggests that this diagram was appropriated from Jeremy Bentham’s Panopticon prison design of 1791 not only in shape but also in the ideological intent for which it was designed. Michel Foucault contended “the major effect of the Panopticon [was] to induce in the inmate a state of conscious and permanent visibility that assures the automatic functioning of power” and suggested that it was meant to contain “a madman, a patient, a condemned man, a worker or a schoolboy.” One can make the assertion that although a built edifice, this plan served as a diagram and suggested an intentional relation between a shape and the intent of the delivery of educational content.

As a culture and a profession, we employ the steps of analysis and synthesis as a way to better understand something which resists being easily defined. Analysis is defined as “the separating of any material or abstract entity into its constituent elements.” The typical curricular diagram represents this attempt to gain control over a large moving target, the education of an architect. We suggest that it is a moving, dynamic entity because most times in any program of architecture, one can find at least two different student groups moving through with varying degree requirements based on changes made at the program, department, college, or university level.

Most contemporary curricular diagrams take the form of a grid, illustrating hierarchical relations through separation and stratification. The resultant strata are typically labeled as year levels and focus areas such as design, practice, technology, history, theory, and electives. In this configuration, the only place that relational thinking is manifested is through course prerequisites, which clearly draw correlations between the cells and, in turn, its content. The results are a diagram that separates, divides, and classifies an entity (the education of an architect) as a means to gaining an understanding of it. While this may assist in identifying the constituent parts of the whole, the cellular diagram fails to allow for recognition of its highest potential. Generally speaking, by pulling the whole apart, we kill it and, upon reassembly, end up with a version of Frankenstein’s monster. Is the analysis phase, where the whole is dissected, the best point to describe the education of an architect?

A new curricular diagram

“The diagram has seemingly emerged as the final tool, in both its millennial and desperate guises, for architectural production and discourse. Operating between form and word, space and language, the diagram is both constitutive and projective, it is performative rather than representational.”

Synthesis is defined as “the combining of the constituent elements of separate material or abstract entities into a single or unified entity, or a complex whole formed by combining.” Currently, the synthesis of curricular content
happens, we hope, in the mind of the student. We make assumptions that the student is drawing correlations between the content and not compartmentalizing it. Obviously, there will be varying results based on the diversity of the students matriculating through the program, but is the student's mind the first place we should test the synthesis of the content into a dynamic entity?

This paper suggests that parametric thinking might yield a curricular diagram more reflective of the relational dynamics of the contemporary education; harvesting the synergies between courses and content. This diagram would simultaneously address the small scale of an individual course, as well as the overall structure of the degree. While this diagram still utilizes the technique of separation (course, student performance criteria, etc.), none of the constituent parts are allowed to exist independently. Rather, they are always dynamically linked into the aggregation and are constantly referencing the whole. Can architects design a better way of describing the education of an architect as opposed to using appropriated diagrams that look no different than departments such as Mathematics, English, or Business, even though the content and pedagogical methods are vastly different?

The diagram’s diversity is intended to respond to the range of students emerging from schools of architecture every year. Whether their interests are the design of architecture/urban space, or the development of business practice models, or preparing for the reciprocal training of future architects, this diagram can describe how the parameters of the curriculum might be adjusted, combined, overlapped, or removed. The diagram is set up by asking the right questions and allowing for variable change to occur within it. The diagram is loose and agile, it can adapt to specific classes as students move through the curriculum. This new diagram proposes relational concepts such as; can overlapping required and elective courses provide a learning environment that is more holistic (ex. should a structures course be combined with a studio)?

Using a combination of the performative aspects of parametric software definitions combined with the intent of montage (French for “build, organize”) theory, the conception of a curricular diagram may be developed. Montage theory states that “collisions of shots were based on conflicts of scale, volume, rhythm, motion.” Aside from theoretical underpinnings and associations with late 20th century theory, this is at one level parametric and relational, relying upon variables within a definition (“scale, volume, rhythm, motion, context” + “disciplines, requirements, electives”). The adjustment of these parameters has the potential to yield varying results in the pedagogy and thus the educational output.

Bottom-up approach

The organization of the six-year curriculum at University of Nebraska at Lincoln College of Architecture is established into three two-year groupings. The beginning design program is labeled as the “what”, followed by the “how” in the middle two years and ending with the “why” in the final two years. This organizational arrangement charges the beginning design program with laying the foundation and delivering the premise for their education. It also enables the beginning design program to set into motion a way of thinking about space and the environment parametrically. By establishing a critical yet broad way of parametric and relational thinking methods the student body will be positioned to make a positive impact in all phases of the architectural community.

Generative thought processes are essential to the development of a design process in the beginning design student. With the focus of parametric thinking residing in the framing relevant questions, project development becomes less end-focused and more process oriented. This approach requires a suspension of disbelief on the students’ part as they move through the design process, in turn requiring a critical eye to evaluate the products generated. Students continually oscillate between the framing of parameters and the evaluation of results.
Mediator

The fall semester of 2010, at the University of Nebraska at Lincoln, marks the beginning of establishing a new program in the second year design studio, which collects students from the Architecture, Interior Design and Landscape Architecture programs. After moving through the visual literacy program in the freshman year, the second year studio is the first discipline specific studio course in these programs. This new curriculum offered a pilot to introducing parametric thinking as an organizational device and pedagogical intent.

“Mediator” is a project developed as a part of the introduction of this new curriculum. This project is intended as a transition from the visual literacy program, which is not discipline specific, into the culmination of the pre-professional program (second year design sequence). Pedagogical focus is on an iterative, phased design process that eludes the ability to anticipate the project terminus, forcing the student to stay in the moment. The project was also structured to allow for slight shifts to maintain the element of surprise from year to year thus maintaining the “now” focus within the design process.

Out of this developed a layered system to organize the entire 2nd year curriculum of the 2 year beginning design program. These layers allow for change in scale, volume, rhythm, and motion in the same manner as montage theory, while overlaps in content present design process as a dynamic, multi-faceted entity. This pedagogical approach requires students to develop an opinion and results in students attaining keen perception and an analytical eye. It also pushes the limits of learning and learning styles by asking the students to think, operate, and negotiate multiple ranges of thinking.

Conclusion

Throughout this paper we have positioned the role of parametric thinking towards a new curricular diagram. The diagram is conceived of as a series of questions related to design, student performance, individual courses, and the entire curriculum to better advance student performance/learning. By asking questions at multiple scales and academic levels we are able to set into motion a series of controlled yet unknown outcomes. This diagram positions classes sequentially and in parallel with each other in order to maximize student performance and cross course dialogue. This new curricular diagram keeps pace with the contemporary student and generates unique opportunities for advancing student learning.

References

2 Ibid, 57.
3 Ibid, 57.
5 Ibid, 200.
This paper describes a fabrication-centric studio as one example of the combination of digital and analogue design practice. It suggests that this combination, when applied to the constraints of a finite project, overcomes “mutual exclusivity” in favor of mutual dependence. It posits this scenario as a pedagogical model for upper division undergraduate learning.

While the tradition of full-scale fabrication studios has for a longtime been a unique and important part of architecture schools, in this studio however the key aspects of student’s learning were based on a critique of existing methods of computational design. This is seen in the light of the 2007 Boyer Report, this studio has received renewed impetus from the advent of digital design. Today the haptic learning we associate with material experience appears to have been reinvigorated by technical mastery of computational fabrication.

Findings on the perceived need for greater understanding of the role of computers in practice. It suggests that both Sketch-Up and Rhino’s model kernels currently lead to formally prescriptive architectural solutions and that the consequent tropes of form associated with each program presents a damaging acquiescence by students and practitioners alike and prevent active learning.
Digital Haptic – Learning from K-Zell.

Jason Griffiths\textsuperscript{1}

\textsuperscript{1}Arizona State University

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In this studio however the key aspects of student’s learning were based on a critique of existing methods of computational design. This is seen in the light of the 2007 Boyer Report\textsuperscript{6} findings on the perceived need for greater understanding of the role of computers in practice. It suggests that both Sketch-Up and Rhino’s model kernels currently lead to formally prescriptive architectural solutions and that the consequent tropes of form associated with each program presents a damaging acquiescence by students and practitioners alike and prevent active learning.
Student learning - Digital Critique

From the outset this studio aimed to generate a critique of the current trend in digital design. The papers conjectures that you can currently distinguish a Rhino and Sketch-Up design project in that they both have distinct formal signifiers. This critique is also formal. It explores the process of “draping” as a critical methodology in both analogue and digital states that occurs in three ways:

- As a physically draped form as an analogue surface
- As a surface that is generated from a drape that offers a means to challenge the typically curvilinear forms of Rhinos NURBS modeling.
- As a conceptual smothering of the reductivists language implied in Sketch-Up’s predominantly linear and planar modeling tools.

The method is used to raise the periodic discussion about the manner in which drawing techniques are embedded within the architecture of the period i.e. in the way that architecture can be understood as a product of the drawing method of the time. Each development of drawing styles or, more particularly, their means carries with them a resonance in built form. Furthermore it is an assumption that only by actively criticizing those available means do we arrive at architectural solutions of value and that do not succumb to the prevalent managerial solutions of the time.

Together these methods are motivated by an observation that digital procedures always perform some kind of “dematerialization” of the object. Similar to Roland Barthes observation on the dematerialized nature of modern materials like plastic the final outcome of digitally fabricated work adopts a similar desensitization. It suggests that work produce via the computer is imbued with a sense of its “infinite transformation” and “ubiquity made visible” and that these qualities are part of computational design and should be used proactively rather than as a consequence of contemporary means.

Requirement of signification

This critique of computational design took the form of student’s learning from conventional forms wherein they were asked to question the role of archetypal forms in architecture.

This method is played out in the design and production of a project for an entrance sequence to a steel fabrication (K-Zell) plant in Phoenix AZ completed in spring of 2010.

The theoretical propositions of the paper result from a reflection of the conditions that were imposed by the client. While at one level they had very distinct practical concerns the larger issue centered on how the company projected its workings to the public. Our client was ultimately concern that the processes of steel working he deployed grew from traditions as well as highly
contemporary methods. With this in mind we began by discussing the uses of the space in terms of objects that might typify them. We felt that actions could be conveyed through recognizable archetypes. That these archetypes carried a sense of familiarity began to communicate the client’s requirement to express the ongoing nature of steel fabrication (as opposed to a complete break from the past). At regular intervals he would remind us that computational methods stem from manual traditions i.e. the computational emerges from the analogue. Eventually we settled on four archetypical objects that summed up the program.

- Couch (customer waiting)
- Bar (leaning and talking after meetings)
- Plant Pots (horticulture)
- Ornate Gates (security)

However while these objects provided satisfactory assurances against abstraction the client also wanted to deploy them using the most advanced methods of production i.e. laser cutting, milling and NC bending. Therefore we sought a method by which signification could be retained and one which would prevent the fabrication methods and modeling tools taking over i.e. develop a conscious mis-use of common procedures. Our aim was to retain a sense of ambiguity between these extremes.

Proto-Digital – Physical drape.

In the early stages of the design process we developed a method of processing and assessing these forms by making an analogue version of a NURBS surface. While the team had some inclination to use Rhino from the beginning doing this meant the archetypal form lost its familiarity largely because of the NURBS modeling method. To overcome this we began working in a manner that would physically simulate the Rhino modeling method but would allow us to control the level of abstraction incrementally (settling on Venturi’s aphorism to describe Arc International Bureaus being abstract but not abstracted). By gradually building up a surface in papier-mâché we could make periodic judgments about the presence of the original form (and signification).

While each layer of the paper gradually transferred the couch into a continuous surface that allowed us to judge by how close to the point of recognition we could go. Once the final form was removed from the original couch it became clear that the surface was a quasi-rhino surface that simulated the “drape” command. In this way the draping action could be explained in one form (analogue) and translated into another (digital) with assurances about retaining signification.

Sketch-Down.

However working back in Rhino we found that it was more difficult to simulate the archetypical quality of the object that was being draped and that any attempt to redraw the actual couch in Rhino was again subject to the NURBS-like shape and the commonality would be lost. This issue was resolved by using Sketch-up in the most deliberate manner possible and by digging out the most rudimentary Sketch-Up models available in the google warehouse. This warehouse provided an abundant supply of low quality 3D models that, by virtue of their simplicity, provided the kind of rudimentary signification of archetypical object. Sofas plant pots etc. could all be judged not by their digital sophistication but instead by their lack of it. In some cases we started using design classics and although they produced good results they were ultimately rejected because it was felt that their signification lay too close to professional circles and where not widely common. In short they were classic rather that archetypical.
Once the Sketch-Up models had been imported they then became subjected to a kind of re-engineering through the drape tool. Here the process was to choose the best plane from which project a mesh and the best mesh gauge based on security requirements and structural capabilities. At this stage the project was becoming mesh furniture. After reviewing the results we decided that the outcome did successfully represent the couch but that this also cut it adrift from any potential re-associations with the fence. The discussion turned to ways of re-associating the project with the bars of the existing entrance became central to the mesh discussion i.e. could the gridded mesh adopt the functional language of utilitarian security fence? To do this required a second move within Rhino wherein the draped mesh was then treated to a parallel cut sequence that was informed by the language and rules of the existing fence. Here the bars offered a physical variant to the digital procedure in a similar way to the quasi-draping activity of the papier-mâché surface over the couch. The new proposal began to both physically and conceptually emerge from what existed. Accordingly the fence was now to be included in the list of archetypes that together formed the basis of the projects concept.

Once these decisions had been finalized each element was then treated to a similar digital manipulation. Two walls (the third being the projection gates projection wall) of the project were composed of draped and parallel-sectioned couch, plant pots, and bar.

Student concept statement. -"The approach to the K Zell warehouse entrance focused on the emphasis of metal and how it can be manipulated. When contemplating the design, an idea arose regarding abstraction. This word can be viewed in two different ways. Either it is “abstract” meaning vague, and not clear as to its purpose or “abstracted” as a version of the subject but slightly altered. The K- Zell entrance offered an opportunity to test these two ideas. Ultimately, the idea of the “abstracted” became the most intriguing. We investigated ways to portray this idea in two ways. One was the notion of metaphorically draping metal pipe over a sofa to provide outdoor seating, while giving the space a designed quality. The other by creating a folding gate that could give a modern version to a classical art of ironwork. This concept would take an image of wrought iron work and instead of using the standard traditional
means, it would use a modern technology to laser cut the image. This would give the illusion that the ironwork was present but instead of being made of iron, it would be the pixilation of the original image laser cut onto sheet metal. Both the sheet metal and metal pipes are a primary focus of K-Zell's production, and offer an opportunity to showcase their potential and talent in metal work.”

Fabrication and NC bending

The final phase of this project involved translating the profiles into a bending schedule that could be read by the companies NC push bender. The bending schedule was developed using several different software packages in an attempt to create less postproduction work. The Rhino/Grasshopper model required converting the NURBS profiles into CNC code friendly drawing in that they had to reduce their curvature down to a C1 polyline. Then for a smoother fabrication each polyline was filleted at the corners with a 3” radius fillet that matched the available bending dye and that satisfied the minimum bend radius for the section of tube we were using i.e. bend radius is 6 times the (1/2”) tube radius. The Rhino/Grasshopper model could then interrogated for bending schedule by streaming the content of different parts of the expression to excel. As each tube is made up 15-17 bends this meant we were able to batch process key information (bend angle and the coordinates of the curve center) to the CNC benders bench computer.

Conclusion

This paper offers an overview of a fabrication based studio (ASU – SALA ADE 422 Integral Studio) and describes the process and involvement of key learning phases. This studio, akin to the design build studio, is rooted in digital design and based on practice-like constraints though collaboration with local fabrication companies and paying clients. In short the parameters of this course are that the “digital” is constrained by material affordances that in turn are constrained by the clients requirements. It charts the conceptual standpoint of the design via both analogue and digital forms of “draping”.

This process then lead to practical understanding of the forming process and how to establish protocols for information exchange especially “file to factory” procedure, batch processing of bending schedules and cutting patterns along with the use of Grasshopper in automating this procedure. This was followed by student’s direct experience of fabrication procedures in Figure 03. Bending schedule for ½” pipe sections of fence/couch. Part of the entrance to K-Zell Metals. Phoenix, AZ. Schedule angles automatically processed for NC bender from parallel sectioned NURBS surface.
terms of their professional involvement in shop drawings and visits to the fabrication plant and site. This experience allowed them to assess the potential of greater complexity against time saving through parametric design. In this respect student could gauge the amount of time both they and the machine operators needed and where this could be reduced.

In addition to this the project demonstrates a new pedagogical model of instructor-lead studios. Here the role of the instructor is altered from traditional design build studios in terms of facilitating collaborative networks, scheduling and design.

In this respect the students experienced a critical approach to computational design. Here “draping” was used as both a physical and digital procedure to provide incremental reduction in signification to the point at which likenesses have almost disappeared (this effect could be compared to trying to recognize a toy car by the vac-formed plastic box) i.e. to reduce tangible meaning to make the object more compelling - a process of reduction as a strategy for criticizing formalism. In this project we have suggested that this technique can be explored by coupling Rhino modeling methods in an unlikely treatment of basic Sketch-Up models. This process stands in opposition to the complete de-signification that appears to be the first compulsion on working with Rhino lofts and NURBS surface control point editing (often described in terms of paradigm shifts in architectural production) wherein any formal associations that tie the model to a tangible counterpart have been irrecoverably and enthusiastically rejected. In this realm the notion of quasi-Darwinian procedure (“adapt or survive”) finds its deceptive counterpart in an architecture of organic or quasi-naturalistic form. As a counterpoint to this trend we suggest that a return to signification can be afforded by considering an attendant archetype via a digital process that ends up returning the original in a dematerialized condition. Here the couch remade of NC bent pipes is experienced as both legible and illusive while its final form is imbued with the digital procedures that brought it into being.

Figure 04  Completed Couch/Fence seen from back and front
This may be considered as the legacy of the Morrill Land-Grant Colleges Act i.e. to “promote the liberal and practical education of the industrial classes in the several pursuits and professions in life”. See http://www.law.cornell.edu/uscode/7/304.html

2007 Practice Analysis of Architecture. NCARB


David Greene - Book of provisional Information

Lucy Lippard – Six Years – The dematerialisation of the art object


Our use of archetypes here is intended to convey an overt familiarity to the final project. In this respect the project is influenced by the term “reality effect” coined by Roland Barthes and used to denote the descriptive style of Gustave Flaubert's Madame Bovary.

Stacking Hommage is Dirk Winkel's redesign of The Barcelona Chair, The Eames Lounge Chair and Le Corbusier’s LC2 as low-price stackable plastic chair. Hope the fresh graduation work of this German designer will find its way to production soon and start replacing 'those white plastic chairs'. http://www.dirkwinkel.com/

The project refers to chairs by Harry Bertioa, and Shiro Kuramata (Begin the Beguine) – 1000 Chairs by Charlotte and Peter Fiell. Taschen

There are many examples of this perhaps the most accessible would be Chistos series of wrapped national monuments bridges etc. In design this finds outlet in the work of Gaetano Pesce. Golgotha Chair. 1972.

Thom Mayne TED lecture 2009.
Abstract

To the architect, city zoning ordinances that pertain to site setbacks and building envelope profiles are often viewed as restrictive and introduced late in the design process. Conversely, to the urban planner, building design that is more individual, varied, and/or formally sculptural can be viewed as having a negative impact on the urban fabric. Is there a way to create a healthy dialogue between these seemingly polarizing disciplines with a common language?

This research proposes a parametric model for schematic building design that integrates any city’s zoning ordinances and gives visual feedback to the designer regarding the setback, profile, and Floor to Area Ratio of their solution. Furthermore, through the integration of real-time geospatial input, the parametric model adds specificity accounting for site coordinates, neighboring plots of land, and zoning designation in the solution. Two parallel streams were simultaneously investigated, one that examined the localized condition of a single parcel and one that more globally considered the urban condition.
Meta-Zoning Logistics

Dave Lee¹

¹Clemson University (CU)

Abstract

To the architect, city zoning ordinances that pertain to site setbacks and building envelope profiles are often viewed as restrictive and introduced late in the design process. Conversely, to the urban planner, building design that is more individual, varied, and/or formally sculptural can be viewed as having a negative impact on the urban fabric. Is there a way to create a healthy dialogue between these seemingly polarizing disciplines with a common language?

This research proposes a parametric model for schematic building design that integrates any city’s zoning ordinances and gives visual feedback to the designer regarding the setback, profile, and Floor to Area Ratio of their solution. Furthermore, through the integration of real-time geospatial input, the parametric model adds specificity accounting for site coordinates, neighboring plots of land, and zoning designation in the solution. Two parallel streams were simultaneously investigated, one that examined the localized condition of a single parcel and one that more globally considered the urban condition.
1 Introduction

The Tenement House Act of 1903 (OASIS, 2010) and the Zoning Resolution of 1916 (NYC DCP, 2010) were written in response to unsafe and unhealthy building conditions that had emerged in New York City as it underwent rapid growth. These documents aimed to remedy widespread problems with construction practices – primarily concerning structure, lighting, and accessibility – but were also innovative in their designation of districts within municipalities that would each have specific building regulations. With these publications, a modern zoning code was first established in the United States. While building codes have evolved some over the past century, the basic structure and much of the terminology used in the original document remain consistent and relevant today.

Of all limiting factors in the design of a building, site geometry and zoning designation are two early indicators of potential design outcomes. Ironically, these conditions – zoning ordinances, in particular – tend to be introduced late in the design process or as restrictive to the architect. One reason for such disjuncture may be the lack of visualization tools designed specifically for pre-design and schematic design of buildings. Even with associative modeling becoming increasingly popular as an integrated design tool, such software largely overlooks the impact of zoning and site on building design.

Zoning information is almost exclusively found in a text-based form and when found graphically, is rarely presented as a volumetric representation. When read from the perspective of computation, zoning codes are essentially a set of parameters written to describe a range of possible conditions to design and build within. Building code is necessarily written in an explicit manner and its clarity of purpose makes it a perfect candidate for parametric modeling. With parametric modeling tools, translating the text of building code is a relatively simple procedure, making it possible to visualize design variations in a dynamic manner with respect to building codes.

The first aim of this exploration was simply to recreate a single zoning code using parametric tools in order to better understand how to best visualize them in a functional manner. This was done using all parameters defined in the original New York City zoning documents that relate to site type and building envelope (Figure 1).

Figure 1. Aggregation of building code parameters. Building lot, Percentage of lot occupied, Maximum building height, Rear yard provision, Side/court yard provision.

Two limitations of this method are that only generic site conditions are explored and only a single city’s zoning code is applied. Whereas the aforementioned parametric model creates a finite list of solutions from which the architect must select, this research is meant to offer a flexible way of designing within the framework of zoning regulations and offer possibilities not yet realized within it. In order to do this, specific site conditions and zoning codes must be integrated into the model. The next approach of this research was to develop a method for integrating a Geographical Information Systems (GIS) database of site data into a parametric model and applying local zoning ordinances to the model.
2 Parsing the Data

GIS have proven to be an invaluable resource for gaining access to an extensive database of relational mapping information, making them ideal for collecting site data. Their widespread influence can be largely attributed to efforts in the standardization of geospatial data structuring. Indeed, the dissemination of this information through commercial mapping software has offered architects and planners a powerful and dynamic analytical toolset for associative data visualization.

There remains a potential, however, for GIS data to be cross-referenced with other important sets of information that are integral to the design process. One such area concerns local zoning ordinances and their impact on site and schematic design. Zoning ordinance data, in association with readily available GIS information such as land parcels, roads, and other physical information can provide a framework to examine building location and envelope. GIS contain very large datasets, but they are well structured (ESRI, 1998). Because of this it is relatively simple to cull particular sets of information from the database.

This workflow is implemented using a plug-in for Rhinoceros, Grasshopper, that incorporates a graphical algorithm display. An important goal of this project was to be able to read data from remote files and cleanly write to various components within the Grasshopper interface without having to import/export with other software packages. Doing so streamlines the system and makes the design tool a much more accessible and practical option for architects in what is typically a time sensitive period in a design project.

Building on the work of Nicholas Monchaux et al (2010), who have created a method for importing and organizing Rhinoceros files in Grasshopper, GIS data is brought into a Grasshopper component scripted the using VB.net programming language. VB.net was used because it is supported by current builds of Rhinoceros and Grasshopper. The component outputs geographical information read directly from GIS Shapefiles through the Grasshopper interface as parametric data, meaning there is no need to first import into Rhinoceros (figures 2,3).

Because of the volume of data contained in GIS, only the information necessary for the algorithm is imported.

3 Site Specific Zoning

A major hurdle to overcome in the integration of zoning data with geospatial data is the nature and complexity of the information being collected. There are two significant factors that contribute to this. First, each municipality has its own political and cultural complexion, and therefore its own guidelines for how it chooses to manage and develop land. Second, geography and...
climate can vary widely. Data contained in zoning ordinances does have common categories, with many shared definitions and labeling procedures, but there is not a universal standard. To make it possible to define a set of parametric conditions that can adapt to any code without having to customize for every city, some standardization must occur.

4 Visualizing Zoning Data for Pre-Design

The parametric model that was developed can account for neighboring plots on three sides as well as street width and specific building setback designations as per zoning district.

4.1 Setbacks

Ground level setbacks were given three designations: road frontage boundary, site connection lines (site/site boundaries), and rear yard. All sites have at least one of these conditions, but not all sites have all conditions. A second variable determines whether neighboring sites have existing buildings and their current setback values. In the algorithm, setbacks are treated as a minimum offset value.

4.2 Vertical Setbacks

The notion of establishing vertical datum to respect a human scale at the lower portion of buildings as construction technology pushed their heights to new extremes was first introduced by Dankmar Adler and Louis Sullivan (Twombly, 1998). It was among several planning concepts introduced in their work and writings of the late 19th century that contributed to New York City zoning code.

A simple formula, establishing a datum calls for building exceeding a given district height to be recessed a minimum number of feet at any point above said district height. However, buildings constructed under differing zoning conditions, be they along a seam between districts or a product of changing rules over time, often have different setback heights. Variations that were explored include averaging corner height between neighboring buildings, connecting a straight line between neighboring buildings, and a b-spline connection between neighboring buildings (figure 6). These experiments point at broader potential research as to how other civic factors such as street width and landscaping might contribute to the establishing of a building datum.
4.3 Sky Exposure Plane

The vertical sky plane, which accounts for adequate ground level lighting conditions, is input here. By default, the sky plane is calculated perpendicular to the curve at the midpoint of each road frontage boundary line. It is defined as a ratio of vertical distance to horizontal distance, beginning at a designated height above street level. Variations that were explored include curved site boundaries, multi-edged site boundaries, and composite profiles.

4.4 F.A.R. + Maximum Building Height

These characteristics are calculated together for the obvious reason that an F.A.R. value lower than the maximum allowed on a site can easily be achieved while keeping a very large structure. By keeping a height limit in the calculation, the visualization will automatically cap the building height at the last complete floor level. The algorithm will also allow for real-time editing of floor plate dimensions to optimize a design. The algorithm allows one to adjust floor-to-floor height to display maximum F.A.R. build-out and also allows customizable floor plate depth (figure 7). Incentive programs such as inclusionary housing that offer an increase in allowable F.A.R. in return for meeting certain criteria are generalized in the formula by including an F.A.R. override option. It would otherwise be impossible to predict or account for all permutations.

Figure 6. Datum variations. Straight line and b-spline corner point connection types.

Figure 7. Floor Area Ratio variations testing geometry variations.
4.41 Population Density

Zoning designations as a result of urban planning strategies can have a dramatic impact on the quality of life and economics of a city. One factor that is heavily influenced by the maximum height and allowable F.A.R. of a zoning district is the resulting population density of a neighborhood. In general, the higher the F.A.R. value, the higher the potential for increased density, particularly in the case of residential designation. However, the infrastructure necessary for some high-density outcomes is not possible with a formula that does not consider density and land-use together.

As an alternative planning scheme, this experiment uses potential population density as a primary control for the build-out of cities. The algorithm accounts for density, maximum height, and a weighted percentage of building/land use (figure 8).

4.42 Topography

Topography is not typically a factor that is considered in general zoning calculations, however its geometric relationship to the buildable area and possible impact on the building height, as particular concerns, make this data interesting to consider in the context of this project.

The buildable height is typically a fixed number and is calculated from the centroid of the site. When site topography is considered over multiple parcels of land, the resulting elevation profile of a series of buildings at maximum build-out will not be level, but stepped as a result of the averaging of site elevation conditions. In cases where cities have extreme topographical changes the elevation profile becomes more pronounced.

This experiment questions the absolute vertical offset typically specified as a maximum built height on a site (localized) by posing an alternative flexible (global) maximum height. The flexible height is set at a specified distance above sea level, creating a unified datum for initial, human scaled, setbacks as well as maximum building height (figure 9).

Figure 8. Population density control of maximum building height.

Figure 9. Topographic control of maximum building height.
5 Geographic + Infrastructural Anomalies

Elements such as bodies of water, landmarks, mass transit, and institutional and mass assembly structures often require special zoning considerations and their zoning considerations are often more politically driven than shaped by existing code. For these reasons such elements have not been included in this study.

6 Future Explorations

6.1 Importing Building Volumes

The initial motivation of this project was to create a self-contained design tool that would allow for exploration of possible building location, orientation, and profile solutions. In recognition that a tool capable of analyzing building envelopes that have been modeled previously would also be desirable, an option to import geometry was tested. Because the algorithm is only concerned with building locations, dimensions, profile, and volume, it was not necessary to incorporate models of a fine resolution. Imported models that performed best were those with a simple bounding volume. An item that will require further study is the parametric control of building envelope with imported models.

6.2 Sun Path Optimization

As a variation of the vertical sky plane requirement that is a component of some zoning designations as a right-to-light solution, a more complex calculation of actual sunlight-to-shade ratio at ground level can be calculated to optimize a building profile. There are several examples of research exploring building profile with regard to building issues such as heat gain, however this research would aim to more precisely control building profile as a function of desired lighting conditions in the open environment.

7 Conclusion

When site and zoning information are introduced graphically, through a dynamic toolset, architects are provided more opportunity to explore design variations with building placement, organization, and envelope. The result is a parametric model that incorporates both site and zoning information as input and returns dynamic representation of possible solutions. Additionally, with this parametric model defined, it is possible to explore design variations that look beyond the given rules outlined in a zoning ordinance to ones that aim to experiment with new possibilities. Although zoning ordinances vary from city to city, both zoning and GIS terminology are consistent enough for any location to be used with this parametric model.

An item not otherwise discussed in the scope of this paper, and subject of further research, is the opportunity for a parametric model to be exported and further investigated on other platforms that support associative modeling and real-time visualization.

References


The Tenement House Act (1903). NY, Tenement House Department.

Within contemporary architectural design, a significant shift in emphasis can be detected - a move away from an architecture based on purely visual concerns towards an architecture justified by its performance. (Leach) Architects have developed and employed parametric design strategies to both address these performance-related concerns and improve their production. Though these strategies have improved architectural design, they are not being used to their full extent in the design process. I propose taking the use of computers in aiding architectural design one step further; information and data should INFORM the project, driving the creation of a FORM enabling it to PERFORM at higher levels than traditional design.

As architects continue to improve these tools, owners and developers tend to choose an opposing strategy. They often finance cheaply built (and poorly designed) buildings in an effort to reduce the upfront costs of the project. However, in economics reducing costs is only part of a sound financial decision. The other half of the equation is increasing the revenue generated by the project. I further propose that by investing in an informed design/decision making process, investors would be able to fund projects that perform better and sustain significantly higher revenues.
“Within contemporary architectural design, a significant shift in emphasis can be detected - a move away from an architecture based on purely visual concerns towards an architecture justified by its performance.” (Leach) Architects have developed and employed parametric design strategies to both address these performance related concerns and improve their production. Though these strategies have improved architectural design, they are not being used to their full extent in the design process. I propose taking the use of computers in aiding architectural design one step further; information and data should INFORM the project, driving the creation of a building FORM enabling it to PERFORM at higher levels than traditional design.

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1.0 Information Based Design

The use of computers within architectural design has been fully accepted as a design tool. However, using it only as a tool limits the true power of digital design. As Carlos Marcos described it "Digital consciousness is a design strategy to be found in different degrees among [...] architects or designers that rely on the computer not only as a tool but as part of the team" (Marcos). This type of digital consciousness is growing. Parametric programs such as grasshopper now have a generative potential though the various add-ons such as Galapagos, Kangaroo and Rabbit, which are bringing the power of raw computer code into terms that designers can harness.

As projects become increasingly complex and owners continue to press for higher performance and outcomes, the levels of information integrated into the project grow rapidly. When working through a design process heavily loaded with information organizing and navigating the data can bog down design decisions. Allowing the computer to weigh different options and make proper choices based on optimal solutions and given parameters substantially improves the design work flow.

Working with the computer as opposed to controlling it allows for a unique combination between two entirely different types of rationality. The computer can compute massive amounts of data extremely quickly but under the restraints set up by the code. Designers, however, can make intuitive judgments and jump from one aspect of the project to another. By sharing design tasks and passing information back and forth they can increase their collective design potential. This “real-time bidirectional exchange of information between the designer and the system is a reciprocal relationship that continuously changes the designer’s understanding of the project as it is being developed, which, in turn, influences the decisions the designer makes” (Verde)

As a case study I am working on a design proposal for a mixed use residential tower in downtown Seattle which strives to fully include the computer as a creative addition.

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**Figure 1.** As an integrated team the designer and computer work in parallel. Information and design decisions should be divided and shared both cooperatively and in series.

**Figure 2.** Field of results generated through the information based process showing a digital selection awaiting designer preferences.
to the design team. The project seeks to become more than a visual addition to the skyline; the project must perform as well, through program specific optimizations and profit maximizing design concepts.

2.0 Inputs: site, views, values, preferences

The informed design process begins with gathering data and organizing it as various inputs. Good, accurate information is vital to this process because each change in inputs can produce different final results. The primary communication between the designer and computer in this process is a 3d model of the immediate site and its conditions giving the system knowledge about heights, views, proximities, zoning restrictions and proportions. Within the 3d model points and lines represent specific areas of interest such as transportation stops, public plazas and shopping districts.

In addition to the physical context the information driven process uses preferences from the designer and owners to make appropriate decisions. Programmatic breakdowns, emphasis on particular relationships, and adjacencies, etc. become powerful determinants of how the massing will take shape. Many of these inputs are set as sliders representing the designer preferences. Each quality is ranked on a scale of 1-10 which allows the computer to weight the different resulting outputs to find a solution based on the expressed design intent. Additional inputs, such as construction costs and building requirements, are assigned as global variables which can be read from or written to a spreadsheet.

2.1 Massing: Lower Floors

The initial massing strategy for this proposal optimizes the base of the building for retail and leisure, and the upper portion for residential use. It blends the two together to create the building form with office space in the middle. Each design element has its own requirements and therefore results in opposing design strategies which the computer is able to balance appropriately based on preferred design qualities in order to find an optimal design solution.

The key design strategies for laying the retail base focus on increasing access and proximity to potential customers. The Grasshopper script focuses on four conflicting qualities to achieve these strategies; proximity to public transportation, access to sunny outdoor space (a premium in Seattle), proximity to existing retail, and the distance from existing public plazas. Other more practical design requirements are the area of the footprint, zoning requirements, and maintaining a compact layout with maximum exterior access.

Figure 3. A 3d visualization of the site context used to communicate design information to the computer. Heights, zoning, solar access, transportation, retail locations, etc. are all input through different geometries in Rhino.

Figure 4. A portion of the Grasshopper script showing pairs of sliders Galapagos controls to generate the base footprint of the building mass.
The integrated team creates the profile of the base level from the intersection of several squares approximately sized from programmatic data. Galapagos, the evolutionary solver within Grasshopper, adjusts the location of these squares by moving two sliders for each square, to try and maximize the benefits. Each pair of sliders controls the respective x and y values for the center of the square.

As the primary driver of the form finding process within these Grasshopper scripts Galapagos deserves an explanation of its own. Galapagos optimizes through an evolutionary process which creates and tests one generation of possibilities (by adjusting the input sliders), determines the highest ranking solutions and breeds them together. It takes either matching pairs or contrasting pairs (dependent on user selection) to create the next generation of hybrid solutions. The process continues breeding successful iterations until it narrows in on a maximized result. This type of optimization can lead to a type of inbreeding where Galapagos finds a locally maximized result as opposed to the absolute maximum. This gives designers the opportunity to evaluate multiple optimized solutions from the same input. Though one may perform better, the other results could provide unique characteristics worth considering. What makes the integration between the computer and architects so intriguing is the different ways they view and interpret information. Computers understand numbers, values and linear logic; in contrast designers look at the problem not as a series of random numbers but as architectural space which has certain intuitive criteria. By stopping the solver occasionally to adjust a piece manually, the designer can seed the system by pointing it in the right direction and starting it again from a more intuitive base point which the computer can optimize.

2.2 Massing: Upper Floors

Within residential real estate there are many value determining factors beyond location which the architects can control. The most directly correlated with value increases are views, balconies and unit sizes. According to Mark Wade a residential unit with a good view (i.e. a luscious green park, Ocean view, or a terrific skyline) can demand twice the sales price as a comparable unit with a bland view (Wade). Similarly, having a useful balcony can add up to 4% to the unit value (Leung).

![Figure 5. The Galapagos display window showing a graph of the optimization process in the top display, and various statistics about the distribution of test results in the bottom displays.](image)

![Figure 6. A 2D visualization of the optimization process. Galapagos controls the black squares and measures their distances from nearby points of interest. It Systematically optimizes their locations to generate the ground level floor plan.](image)
This study uses the coastline along the edge of downtown Seattle, as the primary view. The Seattle skyline wasn’t included as a valuable view because the three potential site locations are all too close to see more than the nearest adjacent buildings. Using a similar optimization process to control the profile of the top floor, Galapagos adjusts a matching set of squares to maximize the potential the length of the perimeter that has a direct line of sight to the waterfront, thus ensuring that more units have windows oriented towards good views. Other factors influencing the upper profile are the distances between the squares and zoning requirements.

Each time Galapagos runs it becomes an opportunity for the designer to work with the computer in determining the best solutions. For example one might set the geometry in a position that logically works before letting the solver run to further optimize their locations. More specifically in the optimization of the upper floor plate, as the solver narrowed in on a given solution it often leaves small awkward gaps between squares or excludes a square from the primary cluster for whatever reason. The designer can easily stop the script, slide the square into a more intuitive alignment and restart the Galapagos process, saving both time and processing power.

2.3 Massing: Types

Using these two optimized floor plate profiles Grasshopper creates the massing of each building by blending the two profiles together. Each square from the base floor plate is lofted with its twin on the upper level and then joined together with the other pairs to create the generic form of the building. (See figure 7)

The primary criticism of this massing type is that only two of the floors are truly optimal and that the remaining floors could potentially achieve a higher value. However, optimizing each floor individually becomes overwhelming due to restraints in time and processing power. Because the results of optimizing additional floor plates follow the law of diminishing returns, using only two additional optimal floor plates becomes a viable solution. The floors are chosen by the averages of the different heights of neighboring buildings. This allows the massing to rapidly

Figure 7. The primary building form is generated from a series of optimized floor plates. The far left image shows the four optimal floor plates stacked above each other. The images on the right show three different formal typologies for generating a building mass from the floor plates.
shift into more profitable configurations once new views became available. With the addition of two more floor plates the multi-loft between matching sets of floor plates generates a significantly different massing type than the single loft. A third typology also exists by extruding these four profiles vertically, resulting in very abrupt shifts in the form of the building at each of these levels.

3.0 Evaluation: Cost, Value, Etc.

The quick speed of this process allows the design team to generate dozens or more study iterations of optimized building masses. Through digital analysis, the computer can sort and present to the designers the top versions for analysis. It also generates 3d printed models and tables of information to accompany each iteration. The design team can narrow down the selection and move forward with only the best options to develop and further analyze. Before moving forward with any one solution, both additional value and cost increases are calculated in order to determine any potential gain in profit. In some projects this may be the only evaluation criteria. These numbers are calculated using basic valuation techniques in grasshopper and then compared against the results of a similarly sized building consisting of nothing more than an extruded box shape. Using grasshopper to perform these evaluations requires additional information from the designer. The cost of the building is determined by the overall area multiplied by a base cost/s.f. and a variety of cost multipliers to represent the different cost increases in building design and construction; such as height which represents a direct cost increase because both structure and complexity of construction increase as the building grows taller. Cantilevered areas, length of perimeter, complexity of geometry, and building splits are also assigned multiplier values. Similarly the total project value is determined by calculating the cumulative benefits of the optimal floor plates such as significantly...
higher proportions of views, and proximities to attractors at the retail level. Other evaluations such as aesthetic qualities, size, proportion, and core locations can be performed in a similar fashion.

4.0 Floor plate Division

Once a building form has been selected for further development the next step is to sequentially use the massing to generate the intermediate floor plates (see figure 5). Then the design team can work with the computer to build them back up into floor plans and eventually an architectural design. The residential floor plate division process allows the computer and designers to excel as a team. The process starts by creating a hallway between the primary elevator/stair core locations. Then the computer draws a series of division lines through the floor plate radiating out from the centralized hallway and cores delineating the room separations. Galapagos adjusts their locations along the hallway sequentially testing the results against the user input requirements for minimum, maximum and desired room sizes along with the length of exterior windows. Once the designer and the computer derive an appropriate solution Grasshopper separates the rooms into categories based on their size and how many bedrooms their proportions permit to provide feedback through charts and a cumulative spreadsheet.

4.1 Unit Sub-division

A secondary grasshopper script takes a series of flexible room layout prototypes and applies them parametrically to the different sized units, choosing the appropriate style based on the location, size and proportion of the room. This process creates a rough bubble diagram of room layouts within the space that the designers can use to provide drawings/data to the owners and later develop into floor plans.

Figure 9. The floor plate division process. From top to bottom: Level selection, Hallway and unit division, Preliminary unit analysis, Parametric bubble diagram.
5.0 Results

Through each phase of this design process the integrated effort between the Galapagos solver and the designer produced successful results. Though not every test created optimal conditions, the information based generative process proved viable. According to the values and parameters laid out in the inputs and output criteria, this process produced multiple building forms that each had a higher increase in benefits (Value) than increase in costs, leaving the developer with a higher profit and perhaps a more architecturally significant project.

The case study tested this process on three different sites within downtown Seattle each of different shapes, sizes and zoning restrictions. Two of the three sites generated mostly successful results, meaning the increase in value surpasses the increase in costs. The site that failed to produce successful results had a lower maximum building height and thus didn’t allow the form to grow tall enough to capture views of the waterfront. In the other two sites all three of the massing types showed positive results, though a clear distinction existed between them (see graph in figure 6). If one looks purely at the number of rooms able to achieve a view of the waterfront through the floor plate division process the benefits of such a system become even greater.

This study also led to the discovery of new typologies or groups of building shapes that maximize views of the waterfront. This type of finding within the generative process allows designers to see different possibilities outside of their preconceived notions. Within this case three distinct types became evident; a wedge shape with the slightly larger end facing the view, the ‘W’ shape and something more closely resembling a skinny box. (See Figure 11)

Figure 10. The primary spreadsheet for organizing and charting the results of the different iterations, and a graph representing an increase in value (x axis) vs an increase in cost (y axis). Any result below the diagonal black line represents a positive increase in profit for the developer, the results for the different sites are grouped with dashed lines. Letters A, B, and C represent the Loft, Multi-loft, and Extrusion massing types respectively.
6.0 Conclusion

As a result of the generative information based process the computer in combination with a design team can rapidly produce a wide variety of results optimized towards different input parameters. Each input as either a variable in the larger Grasshopper script or a seed into the Galapagos solver has the ability to drastically affect the output result.

As the computer and designer mesh into an integrated design team Cynthia Ottchen thoughtfully warns: the architect "is still ultimately responsible for design intent and needs to be able to look at the big picture to decide which factors to parameterize, to give limits to the parameters, assign a weight to each factor and determine the order and method of the information modeling process"(Ottchen). This requires a unique new understanding of design, as Marcos called it ‘design consciousness.’ As the amount of data available to architects continues to grow there is a need for a new generation of designers, those who can not only work with computers but are willing to embrace their generative potential within an informed design process.

**Figure 11.** Diagrams showing the different view angles available for different typologies generated through Galapagos.

**Figure 12.** Images showing the view calculation for a particular floor plate, cost evaluation, and balcony optimizations based on solar shading.
References


Figure 13. A 3d visualization of one iteration, showing both structure and mullion patterns, with an enhanced retail base.
The Hangzhou Tennis Center: A Case Study in Integrated Parametric Design

Nathan Miller

NBBJ

This paper will provide a detailed overview of the parametric methodologies which were integral to the design and development of the Hangzhou Tennis Center. The tennis center is a 10,000 seat facility located in Hangzhou, China and is a part of a larger sports and entertainment master plan which features retail, public recreation, and an Olympic-size stadium to be completed in 2013.

The design of the stadium envelope is based on a modular system of sculptural steel trusses which provide shade and house the arena’s technical systems. To design the exterior, an integrated parametric system was created to conceptualize, simulate, and document the complex geometric systems. For conceptualization, the parametric system was set up to explicitly define the control surface geometry and study formal variations. Physics simulation tools were used to test basic structural behavior. For detailed analysis and engineering, custom scripts were used to automate the communication of centerline information to the structural engineering team. For the documentation process, parametric workflow systems were invented to link together disparate design and documentation environments for a more seamless international collaboration.
Introduction: Design Computation at NBBJ

Computation is playing an increasingly important role in the design process at NBBJ. The demand for formal innovation and performance-driven systems have necessitated that designers search for novel processes which extend their capabilities beyond ‘out-of-the-box’ 3D modeling and BIM packages. Additionally, the accelerated drive towards global practice have required design teams at NBBJ to negotiate the complexities associated with coordinating international design and delivery efforts.

The topic of design computation is ultimately a topic of relevance for the AEC professional practicing in the 21st century. What emerging technologies will help us extend our ability to navigate the complexities of a global economy? What tools will help the designer realize their visions and enable new constructions to perform better than their predecessors?

The Hangzhou Tennis Center design team had to negotiate a range of challenges whose solutions were enabled, in part, by the customization of parametric tools in addition to the implementation of new computational processes. This paper will provide a detailed overview of the computational methodologies that were used for the successful design and delivery of the Hangzhou Tennis Center.

Project Context

The Hangzhou Tennis Center is a 10,000-seat tennis stadium located in Hangzhou, China. (Figure 1) NBBJ, in collaboration with CCDI, designed the Tennis Center as part of a larger sports and recreation master plan which includes an 80,000 seat Olympic-size stadium, an extensive retail development, and a public recreation park. The main stadium and the tennis finals court are the two main structures on the site. Both facilities share a common architectural language of repetitive sculptural truss geometries which compose the exterior envelopes.

Construction documents for the main stadium were completed by NBBJ and CCDI in December of 2009 and the facility has since entered into the construction phase. Rhinoceros 3D with the Grasshopper plug-in were instrumental tools for the design and documentation for both stadiums.

Figure 1. The Hangzhou Olympic Sports Center featuring a 10,000 seat tennis stadium.
Process

For the tennis center finals court, a parametrically-driven process was implemented. An elaborate parametric algorithm was developed in Grasshopper and was used to study the stadium geometry and coordinate information with the team of collaborators. Exceeding the capabilities for the main stadium system, the tennis center algorithm was significantly expanded and included integrated capabilities for:

- **Geometry Design**: Parametrically defining and controlling the exterior geometry.
- **Form Variations**: Rapid refining of the building form and testing alternatives.
- **Structural Collaboration**: Systems for producing analysis-ready structural models.
- **Conceptual Simulation**: Integrating intuitive physics simulation for an intuitive understanding of complex structures.
- **Surface Analysis and Cladding**: Surface property visualization and detailed parametric paneling systems.
- **Coordination**: Organizing and exporting parametrically generated models for use in external documentation software.
- **Documentation**: 2D descriptive geometry systems for elements which cannot be represented using orthographic projection.

Geometry Design

The exterior envelope is composed of a twenty-four truss modules arrayed around a circular arc. Referred to as ‘petals’, the trusses create a large-scale repetitive pattern which encloses the stadium seating bowl. In addition to giving the tennis stadium its visual image, the shell also functionally provides shade and rain protection for the seating bowl. The structure also houses the stadium technical equipment such as the sports lighting.

Figure 2. The algorithm for defining the geometry of the exterior shell. A point cloud driven by circular arcs creates the control system for NURB control surfaces.
The initial surface geometry served as a constraint system for building additional complexity into the envelope at later stages. The modular system was defined parametrically by establishing a point cloud system which would serve as control points to define the edge curves of the surface. A ruled surface is then spans between the edge curves. (Figure 2)

Due to the stadium’s symmetry, only one quadrant of the entire envelope was computed at this stage. This approach improved the computational performance of the system allowing for much quicker iterations while still enabling the designers to evaluate the overall appearance.

**Form Variations**

The parametric definition of the exterior geometry allowed the design team to efficiently explore design alternatives and variations within the conceptual constraints. Parametric control of the point cloud was the primary means of controlling the form. Parameters for manipulating the point cloud (sorting, transforming) enabled the design team to study different configurations of the exterior surfaces. (Figure 3)

While much of the evaluation was based on aesthetic judgment, parameters for shade, drainage, structural performance, and sports technical systems were also drivers for arriving at the final form.

**Structural Collaboration**

Given the integral relationship between the form and the structure, the design team engaged in a very close dialogue with the structural engineers. NBBJ worked with CCDI structural engineering team to coordinate the 3D steel model. A truss centerline model was parametrically driven from the ruled surface control geometry. Parameters were established to allow control over structural member spacing and truss depth.

The engineers required a structural centerline model which could be used for analysis. To facilitate this process, the Grasshopper algorithm would automate the generation of a wireframe structure which was compatible with the tolerances of the engineer’s analysis software. (Figure 4) This allowed the teams to eliminate, with some minor exceptions, the design-analysis turnaround time associated with rebuilding an engineering-specific model. In addition, adjustments could quickly be made to the model based on the engineer’s calculations.
Conceptual Simulation

While the structural team was able to perform a comprehensive analysis to engineer the structural systems, additional functionality for conceptual simulation was added into the Grasshopper algorithm.

An experimental physics engine was tested with the structural centerline model to simulate gravity loading on the steel truss structure. (Figure 5)

Kangaroo physics, in combination with a visualization script, was used to provide an intuitive display for how forces moved through the structure. Tensile and compressive forces could be visualized in addition to areas of maximum stress. Having this capability embedded into the design model at a conceptual level allowed the design team to make more informed decisions and engage in a more nuanced dialogue with the structural engineering team.

Surface Analysis and Cladding

Surface analysis was also integrated into the parametric algorithm in order to visualize and quantify areas of curvature in the geometry. The ruled surface of the petal

Figure 4. The parametric structural design model. Centerline information was exported for structural analysis. Member sizing was coordinated with NBBJ’s parametric model.

Figure 5. Using the Kangaroo physics engine to visualize gravity loading on the truss centerline model.
was paneled using the UV coordinates of the surface. Each panel was tested for planarity. The curvatures informed the selection of a standing-seam aluminum cladding system. (Figure 6) The cladding system was parametrically modeled in order to more accurately study the visual appearance of the panel seams, spacing, and perforation ratios.

The fabrication process of the aluminum panels allow for continuous spans from each edge of the surface with tapered configurations. This resulted in façade components which remained true to the ruled surface UV parameterization.

Coordination

For the design development phase of the tennis center, the tennis stadium geometry needed to be documented.

In addition to being an essential tool for geometric development and structural design, the Grasshopper algorithm also facilitated coordination with other external documentation tools. Custom scripts were created which automated the export process of key model elements to a file system of 3D DWGs. The script enabled automatic updating of converted files so external applications could make use of the most up to date information.

The design team used this method as the primary means of translating the 3D information into the Autodesk Revit model.

Documentation

Revit was used to generate documentation sheets.
containing orthographic drawings of the exterior shell. The drawings of the exterior shell were exchanged with the CCDI team for inclusion in the 2D documentation set. (Figure 7)

For geometry which could not be described using orthographic projection, the algorithm was also used to produce 2D descriptive geometry. In the case of the petal truss surfaces, a custom Grasshopper script automated the unrolling of the ruled-surfaces. These drawings were used in conjunction with a surface quantity spreadsheet. The algorithm also produced a live spreadsheet which contained information on surface curvatures.

Future Work: Design the Process

Historically, the AEC industry has been slow to adopt new technologies into the design process. Many of the tools popular in architecture offices today support design and production processes that have been in place for decades or longer.
However, the rapid acceleration towards global practice coupled with advancements in information-based economies necessitate that architects develop their systems and processes to be adaptive and flexible. The Hangzhou Sports center is an example of process a where new design tools were invented, developed, integrated, coordinated, modified and shared for the purposes of delivering a project of special civic value in China.

Acknowledgements

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References


Simulations: Quantitative and Qualitative

Beyond Quantitative Simulations: Local Control Strategy Using Architectural Components
Beyond Quantitative Simulations: Local Control Strategy Using Architectural Components

Taro Narahara\textsuperscript{1}

\textsuperscript{1}New Jersey Institute of Technology (NJIT)

Design of universal components that can tolerate technological, environmental, and circumstantial changes over time is a challenge for an architect. In this paper, I would like to propose a scaled prototype of architectural components that can reconfigure themselves into globally functional configurations based on feedback from locally distributed intelligence embedded inside the component. The project aims at demonstrating a design system that can respond to dynamically changing environment over time without imposing a static blueprint of the structure in a top-down manner from the outset of design processes. The control of the subunits are governed by the logic of a distributed system simulated by the use of multiple microcontrollers, and appropriate geometrical configurations will be computationally derived based on physical-environmental criteria such as solar radiation from various sensors and social-programmatic issues. The system’s goal is to provide qualitatively optimum results through the use of quantified information acquired from surrounding environmental conditions.
1. Introduction

In recent years, many scientists have started to gain an understanding of self-organizing systems in nature through their computational models in areas such as telecommunication networks and robotics. These systems display advantages such as robustness, flexibility, and adaptability over many conventional systems (Camazine 2002). Self-organizing computation is a computational approach that brings out the strengths of the dynamic mechanisms of self-organizing systems: structures appear at the global level of a system from interactions among its lower-level components. In order to computationally implement the mechanisms, the system’s constituent units (subunits) and the rules that define their interactions (behaviors) need to be described. The system expects emergence of global-scale spatial structures from the locally defined interactions of its own components.

In past years, the author has conducted agent-based simulations to investigate collective behaviors seen in pedestrians and has studied emergent phenomena such as lane formation. “Lane formation” is a fascinating emergent phenomenon we can observe from simple agent-based pedestrian simulation (figure 1). In crowds of oppositely walking pedestrians, the gradual formation of varying lanes of pedestrians moving in the same directions are observed. This is an empirically observed collective phenomenon and has been recorded in many real-life locations such as crowded pedestrian streets crossing in the city of Tokyo (Katoh et al. 1980). The emergence of this spatiotemporal pattern is a result of non-linear interactions among pedestrians, and groups of pedestrians can find efficient walking formations solely from locally embedded individual behaviors without imposing any global geometry.

Another example of self-organizing computation using local interactions by agents is Close packing of circles within a circle. Circle packing is one typical case where simulation using dynamics excels the performance of any analytical means, and it can be implemented by relatively straightforward codes. Simple, locally implemented physical motions of bubbles – pushing and squeezing against each other – can eventually lead a group of bubbles to form a globally cohesive structure.

In this paper, these characteristics will be further explored in the context of architecture through a robotic device with locally embedded sensors and microcontrollers. Bottom-up control strategies will be employed, allowing the device to optimize its orientation with respect to a light source, independent of how and where the unit is placed, and similar strategies can be applied to a wide range of digital and physical applications in architecture.

2. Method

In this section, I would like to propose a scaled prototype of architectural components that can reconfigure themselves into globally functional configurations based on feedback from locally distributed intelligence embedded inside the component. The project aims at demonstrating a design system that can respond to a dynamically changing environment over time without imposing a static blueprint of the structure in a top-down manner from the outset of design processes.

Figure 1. Pedestrian simulation by the author and emergence of lanes (bottom). Circle packing using a Bubble Mesh Method (Simulation by the author) (top).
2.1 Distributed Systems

Distributed control is one technical strategy to realize a feedback process inside a bottom-up system, and this strategy can be applied to the control of multiple structures. Inputs for this feedback system are fed from separated nodes and can be triggered by participation of independently acting agents with some intelligence. The entire system’s behavior is a result of feedback from multiple distributed intelligent sources, and such a system is often called “collective intelligence.” The assembly and control of the subunits are governed by the logic of a distributed system simulated by the use of multiple Arduino microcontrollers (Arduino is an open-source electronics prototyping platform; http://www.arduino.cc, 2010.) Appropriate geometrical configurations will be computationally derived based on local communications among the components and feedbacks based on physical-environmental criteria such as solar radiation (from various sensors) and on social-programmatic factors.

The objective of the experiment is to establish a system that can dynamically respond to changes of light source locations in order to increase light exposure by reconfiguring its components’ locations and angles toward the light source. Reduction in response time for dynamic reconfiguration is expected from the application of the logic. Each component is connected at the joint with two degrees of freedom provided by a pair of servo motors, which offers sufficient variations in configurations when multiple components are forming clusters. This mechanical set-up allows them to configure all possible patterns in orthogonal geometry as long as all components are contiguous in series. Each microcontroller is responsible for the control of several adjacent components (only two controllers are used for the current experiments), and neighboring controllers can, in principle, send and receive their states, such as their orientations in degree, levels of solar radiation, thermal conditions from various sensors, architectural programs of components, and so on. Based on feedback among the neighbors (informational exchanges among the components), each microcontroller will send a signal to change its components’ states in order to locally optimize its condition. Consequently, multiple interactions among the locally defined actions lead us to obtain globally functional configurations rather than a final form being imposed in a top-down manner.

To construct the present system, firstly, a graphic user interface which can display and control four components’
movements was developed using Java/Processing language. This allows bi-directional communication between physical and virtual environments (Figure 3).

As a starting point of this experiment, each component was supplied with a photodiode (light sensor) to measure the level of solar radiation at the panel surface (Figure 7). Sensors returned the values to assigned microcontrollers based on the current orientations of the components, which can be varied by rotations of the motors in tandem at the joint. If components change their configurations with different rotation angles, naturally the results from the four sensors will have different values. There are four panels connected in series at three joints, so that there are, in total, six motors to govern all the configuration patterns. In order to find better configurations to maximize average solar exposures for each component’s panel surfaces, we have to find ways to derive better combinations of the six rotation angles of the motors. This framework for the problem led to the use of multi-dimensional optimization algorithms.

2.2 The Nelder-Mead Method: Physical Implementation

The Nelder-Mead method is a commonly used nonlinear optimization algorithm and is often used for minimizing an objective function in multi-dimensional space. In the case of this experiment, the search is in six-dimensional space formed by independent variables of six angles of motors, and the mechanical components literally become a physical objective function to provide values (average values of four light sensor outputs) which need to be minimized (the lower the sensor value, the higher the light input value). First, the algorithm configures seven different physical configurations to sample light values for each case, which will form a polytope of 7 vertices in 6 dimensions (using the simplex concept). Then, the algorithm will rank them based on sensor values’ feedbacks from the physical machine and search for vertices which provide better configurations of new motor angles. The robot will show the best configuration and turn the LED indicator on. The algorithm will repeat the above processes until it stops improving the value above a certain minimum. This method is also nicknamed “the amoeba method” (see Figure 6) since the way the
polytope finds the new vertices and moves towards a better solution inside the multi-dimensional space is similar to the movements of amoebas. In case the directions of light sources are altered, the system will dynamically react to the changes and will run the algorithm based on the values returned from the new condition.

For searches in two-dimensional space, a polytope forms triangles (3 vertices), and Figure 6 shows examples of amoeba processes applied to a simple 2-D objective function. Each vertex of the triangle \((B, G, \text{ and } W)\) in Figure 6) has a different value for the function \(F\) (i.e., \(F(B) < F(G) < F(W)\)). In each iteration of the Nelder-Mead method, the worst point, \(W\), with the largest value from the function will be replaced by a point with a better value by using the Nelder-Mead algorithm. (In this case, the objective is to minimize the value of function \(F\).) Acquisition of the new vertex is based on reflection, expansion, contraction, or multiple-contraction of the current triangle in 2-D space based on the function’s returning value of the newly defined vertex. The algorithm finds a better vertex using one of the geometrical transformations of the triangle (Figure 6).

There are many types of multi-dimensional optimization methods similar to the Nelder-Mead method (NM), such as the Levenberg-Marquardt algorithm. The choice of the NM algorithm for the project was merely based on its simplicity of implementation and its geometrically intuitive logic. Other nonlinear optimization methods can be selected for different frameworks of problems in order to gain optimally better performances.

Prior to the Nelder-Mead method, the simpler random search method was tested. In this method, an algorithm rotates each joint continuously in one direction until it stops improving the assigned sensor values for the joint, compared to its former state. Then it rotates the joint in the other direction to test the improvement. It is a simpler strategy for preventing the system from stagnating at local optima. The results show that the use of the Nelder-Mead method reduces the number of trials needed to find better configurations compared to the simple random search. In addition, using the Nelder-Mead method, responses of reconfiguration to dynamic changes of light source directions are better (which means that fewer trials are required to obtain appropriate orientations of panels for newly defined lighting conditions in changing environments).

Figure 7. Components autonomously find better configurations to maximize light exposure at 4 sensor nodes at the middle of the panel using two different optimization algorithms.

Figure 6. Amoeba processes by Nelder-Mead Method Algorithm and Amoeba processes applied to a simple 2-D objective function.
Having physical mechanical components be an objective function providing fitness values is a unique and original approach in this experiment. However, it is debatable whether this approach is practically feasible for large-scale architectural applications. Beyond a certain physical scale of application, moving architectural units physically to test different configurations will be inefficient as the weight of the units becomes prohibitive. Furthermore, the numbers of trials that are required to find optimum configurations will increase exponentially as the numbers of components grow. The virtual controller in this project reports the physical orientations of the components. For future explorations to find more practical applications, it would be desirable to have more comprehensive simulation environments that can virtually estimate structural, programmatic, and environmental fitness, including energy calculations, without physically moving the components. Bi-directional control combining the use of both physical and virtual objective functions will allow error corrections between the two environments and appears to be a more promising approach. More specific application examples of this approach could be an architectural shading control that can respond to unknown or un-programmed conditions by using direct feedback from physical conditions. Another advantage of the application of a distributed system is robustness. Unlike conventional central control systems, failure of several controllers does not imply failure of the whole system, and this type of robustness is promising for applications of architectural elements in exterior or inaccessible areas.

3. Discussion and Critique

Development of flexible and adaptable architecture has been a recurrent theme among practitioners. There have been several inspirational projects in the past. During the
60s in Japan, Metabolists introduced mega-structures that could constantly grow and adapt by plugging prefabricated pods onto the infrastructural core; however, original visions of metabolic growth and adaptation were rarely realized physically, as the sizes and weights of the pods were practically very difficult to reconfigure. In the 90s, construction automation (Shiokawa et al., 2000) by general construction companies in Japan shed light on the concept of self-reproduction in architecture: architecture that can produce architecture. However, there was still a clear division between assembler and assemblee relationships. Mechanical components that could produce buildings were far from actual livable architectural spaces. Thus they could only repeat, producing an identical or similar building each time, and no future adaptation was available. Finally, some of the speculative researches by computer scientists in recent years have started to show viable prototypes representing self-reconfigurable systems using swarm robotics (Lipson, 2000; Murata, 2006). In architecture, it is our responsibility to consider how these advanced technical concepts can be applied to enhance our living space, and our design processes may well be on the brink of a necessary transition from conventional methods to methods that require evolutionary processes.

For this project, it is worth noting that the Nelder-Mead method is a heuristic method. A heuristic method is a solving of a problem by iterative processes of trial and error and is intended to find optimal solutions rather than to find a single deterministic solution. Traditionally, we have a tendency to seek and construct an analytical problem-solving framework due to the invisible pressure to find the final and best solution. Finding a single solution, static in time, that satisfies various clients’ needs has been a typical architect’s responsibility, and generating comprehensive plans as a blueprint is normally anticipated. Conventional design problems in architecture may be more easily reducible to an analytical problem-solving framework, compared to finding optimal solutions over time every step of the way. As can be seen in this project, calculations of dynamic reconfigurations for gradual growth of structure can be fairly extensive.
Figure 10. The process of dynamic reconfiguration and search.
This fact implies that the deterministic analytical means are less adequate where we need concurrent solutions for dynamically changing conditions, and we may need to rely on heuristic search as the complexity of the project increases.

As for the implementation in architecture, it is extremely important to consider not only physical and quantitative issues but also internal and qualitative issues. Environmental issues such as lighting can be quantified and may be resolved to some degree; however, more programmatic issues relating to logistics of architectural planning will need to become a new focal point of research among our profession. An aim of the present thesis is to show how self-reconfigurability can be incorporated into architectural design processes in order to realize an adaptable growth model through an extremely simplified working conceptual prototype.

The experiments in this section are not at the stage of providing a direct application to existing architecture. In principle, the numbers of components can grow and reconnect to expand the structure to respond to increasing and differentiating spatial demands. Solar radiation was one criterion selected for the reconfiguration; however, various different criteria can be technically implemented in the system. For instance, affinities among various occupancy types and their adjacency relationships can be used as a selection and morphing process of various architectural programs. This selection process can be achieved by cellular automata-based logic, similar to the method introduced in (Arduino, 2010). Allocations of different architectural programs such as residence, office, and retail spaces can also be optimized virtually by the use of various simulation programs and physically by tracking the movements and behavioral patterns of occupants in the future. Further investigation will be required for implementations of additional architectural applications. The intention of the project has been to clarify the concept of dynamic form-finding technique based on the bottom-up approach through a rather simple and clear form of prototype.

4. Conclusion

In architecture, few structures have ever been built or conceived based on the active application of distributed systems. Excluding some of the emergent formations of cities on larger scales over longer spans of time, adaptation of distributed systems and collective intelligence to architectural creations is an uncultivated area worthy of investigation. This project is one such effort to demonstrate a novel design system through a conceptual physical prototype that simulates the concept of dynamic adaptation in architecture.

References

Perforating Material Performance: Ceiling Cloud

Andrew Vrana, Joe Meppelink

University of Houston College of Architecture (UHCoA), METALAB Architecture + Fabrication

The focus of this project was to design a ceiling system within a new Materials Resource Center in the Architecture Building that would embody the potential of parametric design and digital fabrication to rethink a generic interior architectural system. The instructors and students in a combined design studio and digital fabrication seminar developed a Ceiling Cloud that clips on to a modified suspended ceiling grid using lightweight folded aluminum panels that are designed to incrementally change dimension and drape into the space below. Constraints and variables within the parametric models allowed for the optimization and extraction of 150 unique panels that are also perforated with their own individual pattern. The variations in the folded surface disburse and dissipate sound through refraction and absorption created by the corrugation in the panels and their perforation. The holes are also calibrated as a gradient to allow more light to penetrate in the center of the space away from the perimeter walls. The project was prototyped by the students as the College of Architecture and partially realized with the help of industrial partners in Houston. The studio was co-directed with Visiting Critic Scott Marble who provided a framework to conduct the studio’s exploration and several successful projects as precedent.
Our work and research into the potential of building parametrically designed alternatives to typical interior architectural systems with fabrication techniques of cutting and forming thin-gauge sheet metal is exemplified in the Ceiling Cloud. The digital design process was initiated after successive physical experiments with a virtual component model that was parametrically linked to a 2D cutting process. An assembly was developed that connects to a typical suspended ceiling grid with a standardized coupler. Material performance, structural analysis, surface optimization criteria and an intuition about inventive detailing were essential tools that we used. Perforation as a precise method of material removal has afforded the manipulation of sheet materials to produce a differentiated array of potential surface geometries. It allows pliant materials to become robust structures that interact with their environment through controlled porosity. Through formal transformation at the scale of the component and logical systems of consistent assembly sequencing, the complexity of construction is managed and explored.

The Ceiling Cloud is a prototypical suspended ceiling system designed for a site-specific condition through the use of parametric software. Our group was retained to build out an existing space into a new Materials Library. Lighting needed to be ambient and/or directional with the ability to alternate throughout the day given different patterns of use from lecture space with directed focus, event space with multiple conversations occurring concurrently or exhibition space with illuminated walls. Our focus became a custom designed and fabricated ceiling system that could clip on to a conventional inverted exposed inverted t-spline railing system that typically accepts acoustic panels. The product could not be much more expensive than the generic material, needed to be performative with regards to lighting and acoustics and installation had to be quick, easy and reversible to allow access to the plenum. The parametric design focused on two scales of modulation. The global geometry of folded panels consisted of an “A” and “B” panel that varied along the free dimensions within a range while maintaining constraints relative to the suspended grid and sheet material sizes for fabrication. A perforation pattern was used to create porosity in the surface for acoustic and lighting performance and to

Figure 1. Ceiling Cloud. Scale model with lighting
allow the panels to be formed easily into their corrugated shape. The holes vary across the system from large and sparsely deployed to small and dense in the center. Activity in the space will concentrate. The parametric design operated on the two scales simultaneously to produce the unique tessellated panels that were adjacent panels. This flat-pack technique of forming by hand was a repetitive condition in each unit that was a consistent presence along with the variable dimensions produced by the parametric model.

Environmental performance was implicated in the design of the Ceiling Cloud for exploiting acoustic and luminous qualities of the surface above a public exhibition space. The corrugated profile of the panels varied in depth from the edge to the center of the space expanding from a compressed section to a deeply draped module. The texture of this surface is active in fragmenting the low frequencies present in the space and refract them away from the source of the sound. This was coupled with a perforation pattern that varies in size, quantity and density which modifies the high frequencies that tend to pass through the surfaces and dissipate in the plenum cavity above the ceiling. These two systems were integrated and independently controlled through a parametric model that allowed the designers to tune the space to merge performative criteria with aesthetic intuition.

The transformation from 3D information to 2D toolpaths to 3D assemblies using folding and forming was the critical path for our parametric process. A system of tessellation was designed where surface faces were constrained to remain planar and angles to fold were maintained consistent through the rules of the parameters. The differentiation of the algorithmic pattern was made legible against a continuous ceiling grid substrate that connected to the building’s structure. The Ceiling Cloud performance based design initiated with two basic panel typologies that alternated through the array. One was consistently convex and the other concave in section creating a corrugated spatial system that changed incrementally from edge to center. This was done to affect the acoustics and ambient lighting in the space.

Perforation was used for component transformation as a fabrication strategy. The seams between the planar facets in the Ceiling Cloud are marked with stitch perforations that allow the panels to fold along prescribed locations to exact angles by referencing the

Figure 2. Prototype, full scale. Laser cut aluminum. constrained within a defined set of limits.

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Figure 3. Prototype, full scale. Laser cut aluminum.

Designing Parameters

This project utilized parametric design systems as a technique to connect and correlate the qualitative relationship between interior ambient lighting and
performative acoustic performance. This was achieved with a model that maintained a quantitative relationship between modularity and patterning of the ceiling system. In broad terms, parametric systems are used to manage complexity and have been utilized in architecture either as a generative technique to quickly and efficiently produce design options based on a limited set of algorithmic variables or as an organizational system to manage designated constraints between components. Constraints and variables within the parametric models allowed for the extraction of 150 unique folded panels that are also perforated with their own individual pattern. Nested parametric models are essential in using interactive software to address design criteria on different scales simultaneously. The Ceiling Cloud’s aforementioned variegated paneling and algorithmically changing perforation pattern was driven by separate sets of variables that were nested within each other. The global paneling strategy was linked to the deployment of holes through quantitative links that allowed a fluid connection between the two or each could be unlinked and designed independently.

Designing Assemblies

In contrast to the modernist logic of built up details or managed assembly by combining standard pre-manufactured parts, we worked toward a logic of designed assembly from the performance of specific parts that fused concept, design, fabrication and assembly. The correlation of the effects created by slight variations between individual adjacent panels is legible over the entire ceiling when seen in its totality.

Designing the assembly sequence as an integral part of the process is key to an effective translation of the digital components to physical integers of construction. The Ceiling Cloud had to connect to a conventional suspended ceiling grid for ease of installation and for future maintenance. A layered system of parts created a critical path of assembly that allowed the panels to be formed and placed very quickly without cutting or measuring in the field. Gussets and tabs completed the alignment of the folding faces for closure and to complete their structural form. The perforation allowed the forming to be completed quickly and accurately.

Designing Performance

Proof of concept was in the analysis of the Ceiling Cloud during design optimization using acoustic simulation and parametric software in tandem. The variegated surface and micro-perforation pattern were developed to dissipate and absorb noise at low and high frequency ranges using particle animation. This will be tested empirically after the full realization of the project beyond the 20% of the system that we prototyped. We will compare the acoustic performance of the actual constructed system with the visual and quantitative data observed in the simulation software as a case study for
further understanding of how to interpret these tools.

Lighting performance was tested in analog models instead of rendering software. Physical models are always part of the design process and in this case were the drivers of surface morphology and perforation strategies. Individual panels and arrays of them were tested with varying types of light from above and below the ceiling datum. Ambient indirect light was coupled with direct lighting to create atmospheric effects that could change according to programmatic use.

A flexible and integrated method of design emerges from the concept to installation of the Ceiling Cloud. The use of the modeling software to accurately extract components allowed the project to go seamlessly from prototype directly to production. The use of parametric software allowed for minor changes and infrastructural adjustments to be made to accommodate the acoustic and lighting criteria as well as the adjacent mechanical equipment. The revisions update through the entire assembly which is a series of associated parts that reference each other. The analysis software was used to test the performance on the global faceted system and the micro perforation pattern on specific areas on the design and to inform the next iteration of the variable design.

Figure 5. Designing Performance: Ceiling Cloud. Scale model with lighting

The digital design strategy and fabrication tactic of perforating sheet material to engender performance is a product of our broader research. We see these parametric tools as a means to tease out new potentials in generic materials and architectural systems through digital fabrication.

Influences

We referenced several works of architecture and art in the initial research phase to set of the direction to design on the ceiling system. The dramatic effects that Bernini’s work achieved through the control of light from discrete sources into spaces of extreme surface modulation and material and geometric contrast were studied. The fluid form of the gown and concealed body of St. Teresa in contrast to the vectors of light and angel’s spear that penetrate her were strong dichotomies that we sought to carry forward into this work.

The atmospheric effect of the luminous cloud-like quality of Tara Donovan’s work with nested Styrofoam cups creating hive-like aggregations in the corners of rooms was another interesting example to our team. These served to influence our perforation system that would allow for subtle contrasts between the surface of the panel in the foreground and the existing building slab beyond that is ambiently illuminated from lighting above the ceiling datum. The swelling effect that Donovan achieved with geometry was achieved in our case with varying the size, quantity and density of perforations...
Arabesque patterns were also influential in the way we indexed the differentiation of panels and perforation while maintaining self-similarity throughout the system. The patterns that populate the surface of Islamic architecture often transform from 2D tiling to 3D vaulting as they move up the ground and project horizontally over spaces. The coupling of rectangular and radial arrays with alternating colored tiles creates larger complex patterns within the aggregation of simple repeated units. We sought to overlay the rectangular array of the ceiling panels with the radial expansion of the perforation patterns to conflate the two systems in one composition.

Finally the generic suspended ceiling system of the modern office space was a constant presence that had to be appropriated and absorbed. The ubiquity of aluminum t-rails and expanded cellulose arranged in 2’x2’ grids emerged in the 1950’s as systems that informed the modulation of open office plans by informing the placement of interior partitions and furniture. The regimented control of corporate space created a predictable and flexible way to expand the workflow of capitalist efficiency and eliminate the chaos of the exterior urban condition. Our goal is to appropriate and literally connect to this type of system while teasing out the latent potential to modulate along the z-axis to deal with acoustics and lighting in an alternative manner to greater dramatic and performative effect.

Pedagogy of Collaboration

Architectural education is moving away from the classic example of one student working alone on an entire building for a semester with the professor acting as the master to the apprentice. Collaboration as a model observed in actual architectural practice between

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**Figure 6.** Influences: St. Teresa in Ecstasy, Bernini; Tara Donovan, Untitled and Set of MadMen
designers, consultants and clients is now being engaged and is expanding to include fabricators, software developers and other types of engineers beyond structural and mechanical. Students now work in larger collaborative groups and instructors organize the workflow as a lateral effort rather than a sequential linear one. This allows for projects of rich layering and greater complexity to be achieved with a high degree of resolution. Students become specialists in an aspect of the process while observing the amalgamation of the groups efforts into a realized project. In this project, five design teams were organized around Lighting, Acoustics, Modulation, Patterning and Display. A critical path was then initiated to manage the schedule along the development of performance, parameters, assemblies and prototypes. This collaborative model proved to be effective in that the project was completed and 20% of the final product was fabricated and installed for display at the end of the semester. The balance of the project will be installed in the material resource library in the near future.

Expanded Alliances

Visiting Critic Scott Marble worked with the instructors and students and employed a studio instruction model that he initiated at Columbia GSAPP. This approach was used on their award-winning projects for the Fine Arts Slide Library project and Stabile Hall School of Journalism on the Columbia campus. Scott initiated the discussion with the following excerpt from a report on integrating collaboration and technology in an architecture studio and applying this expertise to projects on university campus projects:

Schools of architecture have pioneered the first digital revolution through exhaustive formal experimentation and elaborate visualizations of these new forms. While this was occurring, the construction industry has focused more on stream-lining the manufacturing and building processes through CNC technologies with little or no emphasis on innovation beyond efficiency. The core goal of Expanded Alliances is to foreground the potential and urgency of a younger generation of architects to begin pioneering the second digital revolution in architecture. Because this revolves around actual building itself, the only effective way to do this is to build...at full scale. More important is the application of digital technology as a tool to generate the organization of projects, to form networks of collaborators to realize projects and finally to design, manage, fabricate and assemble innovative architecture.

![Figure 7. Installation into ceiling grid](image)

**Conclusion**

Proof of concept will be achieved with empirical analysis of the acoustic properties of the space once the Ceiling Cloud is installed. We seek to compare data from digital simulation software with the built project in order to understand the potentials and limitations of these tools to predict the outcome of complex relationships between the system’s performative potentials in the environment. Perforating material performance seeks to merge a qualitative understanding of materials and fabrication with a quantitative set of parametric and simulation digital design tools.
Simulation by Design: A Parametric Design Tool for Zero Energy Buildings

Troy Peters
California Polytechnic State University

Abstract

To address the shortcomings of integrating building simulation in architectural design and to make it more appealing to students, a simple interface to Energyplus was created. This interface models a simple rectangular building that is passively heated by direct gain and cooled by ventilation. A simple photovoltaic interface has also been added to supply fan energy. This tool has an OpenGL modeler for visualization and uses Energyplus for calculations. The interface will run a full year simulation and graph the results. The results are reported in a yearly graph that shows the outdoor and indoor temperature. The indoor temperature range is based on adaptive comfort level. The interface was tested and used in an introductory design studio in order to comply with the 2010 imperative. The students simulated a simple box and changed the buildings parameters until the building fell within the adaptive comfort zone for most of the year. The climate simulated was Chicago, IL. Using these parameters the students then designed the building. The resulting designs show that even though the students were restricted in parameters, such as window percentage, they were still able to creatively design unique buildings that use zero to negative net energy for heating and cooling in a climate such as Chicago.
Introduction

The 2010 Imperative states: “To successfully impact global warming and world resource depletion, it is imperative that ecological literacy become a central tenet of design education. Yet today, the interdependent relationship between ecology and design is virtually absent in many professional curricula. To meet the immediate and future challenges facing our professions, a major transformation of the academic design community must begin today. To accomplish this, The 2010 Imperative calls upon this community to adopt the following: Beginning in 2007, add to all design studio problems that: “the design engage the environment in a way that dramatically reduces or eliminates the need for fossil fuel.”” How does the “2010 Imperative” fit into an introductory design studio where the students have limited knowledge of building materials and have not yet taken an environmental control systems class? A new simulation tool was developed to allow students in the second of a five year accredited Architecture college to explore energy use in buildings at the very beginning of the design process. This type of building simulation software will have an impact on the built environment.

The Problem

Architecture students who want to design sustainable, green and energy efficient buildings frequently find it difficult or too time consuming to use and learn building simulation software. Therefore, building simulation software should be designed in a way that makes it easy to use in the early stages of a building design. This early design phase is the time when the greatest impact can be made on the energy use of the building. (Grau and Wittchen, 1999) A tool that helps make crucial decisions at the very beginning of the process would then have the greatest impact.

An energy simulation tool, SolarShoeBox, was developed to help students discover parameters that would achieve a zero energy building that is comfortable before they started their design. The interface for SolarShoeBox was built on the following guidelines.

1. Very little information about the building will be needed in order to use the program and get results. This will allow the designer to explore different ideas and configurations of building elements that helps to actually use the software to design.
2. All information (both input and output) is presented in a single view. Nothing is hidden from the user so they can see all of the variables. 3. The manipulation of the data can be explained in a few sentences. The user can master the program in minutes without using a manual or needing any special training just to use the program.
3. The input of data can be done with a mouse. This helps to put parameters on the input data. The program can put reasonable limits on the properties of materials, freeing the user from having to know what values to enter.
4. The calculations and output should happen automatically and almost instantaneously. This gives the user feedback so they feel free to explore and get a sense of what design changes have the greatest impact.
5. The program should already contain data when the program is opened so the user knows what to expect in terms of input and output. This gives the user an example of how the program works when they first open the program.

SolarShoebox

SolarShoeBox models a simple direct gain passive solar building. A direct gain passive solar building uses only the energy supplied from the sun to achieve thermal comfort for the occupants of the building. The architect of the building will need to use their knowledge of the climate where the building will sit and their knowledge of the yearly movement of the sun to manipulate the fabric of the building in order to maintain a comfortable interior environment for the occupants. One can think of the building fabric as a filter between the outside climate and the inside thermal environment. The architect using SolarShoeBox can manipulate the filter by changing the quantity and characteristics of these architectural components and strategies; Building Orientation, Building Form, Building Thermal Conduction, Solar radiation Collection, Solar Radiation Control, Heat Storage/Distribution and Controlled Porosity, in order to
make the interior thermal environment as comfortable as possible for a given climate without using any fossil fuels.

This tool has an OpenGL modeler and uses Energyplus for calculations. Energyplus is a new generation energy simulation program developed by the U. S. Department of Energy and has been validated. Optimization in SolarShoeBox is based on indoor comfort levels and not on fuel usage, since no energy will be used to heat the interior. On the graph below, January 1 is on the left and December 31 is on the right. The top is 1 AM and the bottom is Midnight. The Top graph shows the outside temperature and the bottom graph shows inside temperature. The color blue represents temperatures less than the set comfort zone temperature and the color red represents temperatures higher than the comfort zone. The color green represents temperatures in the comfort zone. The goal is to make the inside temperature graph turn completely green.

Using SolarShoeBox

Seven main parameters can be changed when using SolarShoeBox. Figure 1. These parameters can be changed in steps with intermediate simulation runs by Energyplus. It takes approximately 6 seconds for Energyplus to calculate the results and to refresh the graph, allowing many iterations to be done very quickly. All of these steps can be performed before the design process begins and should be the basis for the building design.

Basic Steps to design a comfortable solar building with SolarShoeBox

Choose a weather file and Run Energyplus. The weather file is selected by a pull down menu. The menu list all EPW files available in the Energyplus weather file on the users hard drive. This step is needed for Energyplus to run and it sets the latitude for sun shading design. To download more weather files available from the Internet click on the Weather button. The web site that opens in your browser has weather files for 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. Download the EPW file by left clicking.

Adjust the season start sliders based on outside temperature patterns. Most climates will have a cold, cool to hot transition, hot and hot to cool transition season.

Energyplus can be run at anytime during the following steps. The steps can be done in any order but this sequence first.

Adjust Building Orientation. The building can be rotated 45° East and West from North by using the rotation slider. General Rule: 0° from South is best for optimum solar gain through south facing window and easy shading control.

Adjust Building Geometry (Height, Length and Width). The building height, length and depth are changed using sliders. As the sliders move the OpenGL modeler is updated in real time. The model can be zoomed in and out using the mouse wheel and rotated by click dragging. General Rule: Buildings elongated towards east/west will allow more southern exposure, allowing more solar gain and higher indoor temperatures.
Turn off all shading.

Adjust hot season ventilation until hot season comfort chart is mostly green.

Adjust Insulation levels and South facing window (Percentage, Type) until average cold season temperature is about 20 °C or 68 °F. The insulation value is chosen for the envelope. This differs from most energy simulation programs because it reverses the decision order. Instead of choosing a wall type and figuring out the insulation level, the designer discovers what the required R-value should be and then designs a wall to that specification. General Rule: Higher insulation values will raise indoor temperature levels. Window orientation, type and area as percent of wall area can be changed using sliders and pull down menus. General Rule: Larger south facing windows will increase indoor temperature levels.

Adjust the amount of mass (Thickness and Surface Area) to decrease the indoor diurnal temperature swings during the cold season. Mass type, area and thickness are manipulated to decrease the indoor temperature swings. The internal mass modeled has both sides exposed so a thickness of 12 inches or 30 cm will act like a mass of half that thickness or 6 inches and 15 cm. General Rule: Mass area of 11 times the south window area and mass thickness of less than 6 inches or 15 cm are good starting points.

Turn on south shading and adjust length until one of the transition seasons is mostly green without decreasing cold season comfort levels. Horizontal shading devices can be added to any wall. A slider changes the length of the shading device. Shadows are cast based on the

![Figure 2. SolarShoeBox interface.](image-url)
latitude, date and time. The date and time can be changed to visually decide how long to make the shading device. General Rule: Adjust shading to create comfort during the transition seasons.

Adjust ventilation levels for transition seasons until indoor temperatures are in the comfort zone. Each season can have a different ventilation rate. A minimum ventilation rate of .35 air changes per hour should be kept to meet indoor air quality standards. Thermal comfort in the summer is usually achieved by raising the ventilation rate. The ventilation rate is controlled by an electric fan, which is powered by photovoltaic panels on the roof.

Go back and fine-tune settings until the indoor comfort chart is mostly green. The building parameters can now be used to begin designing a non-shoebox direct gain passive solar building.

When the comfort level is achieved for entire year the student can then export the model to another design program and really start the design process. They will be able to refine the building shape, design the wall components, window patterns and shading devices. They still need to figure out internal mass placement and roof design for integrating the photovoltaic panels. They will be able to concentrate on design instead of how to make the building more efficient, since they know it is already a comfortable building that uses zero net energy. The model can be carried through the whole design process. The SolarShoeBox model can be opened in Sketchup and used with the plugin OpenStudio + Energyplus, the Sketchup model can be used in Revit + Ecotect + Green Building Studio so nothing is lost. This helps the student refine the building while always having access to an Energy Simulation tool.

**Example Building**

The students in the first studio of their second year at a five-year school of Architecture were asked to design a cube shaped building. The dimensions of the building were 24 feet on each side and would be a place for two people. The building had to have views in each direction. The location was Chicago and it had to be comfortable for the entire year without using any fossil fuels for heating and cooling. They started by modeling the building in SolarShoeBox and extracting the particular specifications for the amount of glazing, the insulation values, shading devices and internal mass. The wall R-value called for a R-70 wall which when designed was approximately 24” thick. The internal mass was placed as a floor slab with the remainder used as internal walls. The Southern glazing was 70%, West 3%, East 5% and North 10%. The
students then started to design their buildings using the given solar specifications much as one uses the site to constrain views and shape of the building.

Lessons Learned

SolarShoeBox makes energy analysis part of the process, not an after thought or additional step. Since the initial energy analysis was performed before the building was designed, the students had a better understanding of the building components that must go into a zero energy building. A simple design tool used early in the design process can have a greater impact on the final energy use of a building than a complex tool used at the middle of the design process. The student should use this information similarly to using the information of how big a column must be to hold up a building; the combination of components given by SolarShoeBox are necessary for their building to be comfortable while using no fossil fuels. It is also important for the student to imagine, for example, that a window that takes up 50% of the area of a wall does not have to be a single window, but can be many windows arranged in an infinite number of ways. Using the column analogy, a thin steel pipe or a heavy timber post might perform in a similar way but are aesthetically and sensorially very different. As building simulation becomes more sophisticated, it can also become more user friendly. When this merger of sophistication and ease of use takes place, more designers will be willing to use building simulation tools at the beginning of the design process.

8. ACKNOWLEDGEMENT The author wishes to thank the students who tested the programs and provided feedback.

References


Race track modeler. Developing an iterative design workflow combining a game engine and parametric design.

Roly Hudson¹, Drew MacDonald², Mark Humphreys².

¹Dalhousie University, ²Populous

This paper documents the continuing development and testing of a novel digital workflow established and implemented for the design and redevelopment of formula one racing tracks. The Race Track Modeler (RTM) tool uses a game engine to simulate driving around proposed track designs. Performance data from the simulation is combined with real data acquired from analysis of vehicle mounted accident data recorders (ADRs). The output of the tool is a graphical representation of simulated stopping positions of vehicles that have lost control and left the track. This information directly informs the design of motor racing facilities; the zoning of spectator facilities, position and specification of crash barriers (if required), and surface material selection for the run-off zones (the area where vehicles are expected to stop after losing control and leaving the track). The RTM can suggest further design changes to the track geometry which are then fed back into the game engine. The project involves methods of binding analysis of design directly to geometry together with input from interactive controls. The RTM has been developed and tested during the redevelopment of Silverstone race track in the United Kingdom (figure 1) this paper documents the current state of the tool and concludes with proposed future developments.
Introduction:

Background to the design of race tracks

In the past the design of race tracks has been dependant on the Fédération Internationale de l'Automobile (FIA) throughout the design process. The FIA generated the speed profiles (estimated speeds of vehicles as they travel around a track) and provided the corresponding trajectories (estimated path of out of control vehicle) over course designs submitted by track designers. The time required to submit a design and receive the FIA generated data was lengthy and this delay stifled innovative design. The ability to make quick changes to the design of the track is thought to lead to safer tracks, more exciting races and better spectator facilities drawing both bigger crowds and bigger television audiences.

The RTM workflow allows a more flexible and dynamic approach to the design of race track and facilities by allowing more design iterations to take place in house. The authors believe the result of this is a more efficient process to design better racing and spectator facilities, prior to sending to FIA for final approval.

Track safety

One of the primary concerns during the design of a race track is the safety of spectators, drivers and officials on duty. Vehicles competing must be enclosed within a secure boundary. Where this boundary is in close proximity to the edges of the track rigid crash barriers that prevent out of control vehicles leaving the boundary may be required. The need and specification of crash barriers is dependent on predictions made about the path and speed of an out of control vehicle. These predictions determine the direction that the vehicle leaves the track, the rate of deceleration and stopping position. If the run-off zone overlaps the secure perimeter crash barriers are required.

Crashes in Formula One have been studied since 1997 using data collected in vehicle mounted accident data recorders (ADR). Rates of deceleration over different surface types have been deduced from statistical studies undertaken by the FIA. These rates of deceleration form the basis of equations defined by the FIA safety guidelines for calculating vehicle stopping distances. Vehicles are assumed to leave the track at a tangent from the racing line. At regular intervals round the track (as the vehicle speeds vary) an algorithm is used determine the tangent to the racing line, stopping distances and final stopping locations (crash trajectories). The crash trajectory directly informs the design of the track both in terms of barrier specification and spectator zoning. Manually performing this analysis is time consuming and it conflicts with the desire to explore design options. It is this conflict that has led to the development of the RTM.

Use of simulation engine in design

A simulation or game engine is a software system designed for the creation and development of video games. The core functionality typically provided by a game engine includes a rendering engine for 2D or 3D graphics, a physics engine or collision detection (and collision response), sound, scripting, animation, artificial intelligence, networking, streaming, memory management, threading, localization support, and a scene graph. The process of game development is frequently economized by in large part reusing the same game engine to create different games.

Game engines have received recent interest in architecture as a means of collaboration, visualizing design (Pelosi 2010) and reconstruction of historic buildings and landscapes (Tredinnick, Harney 2009). In this paper we describe the use of a game engine to
Use of parametric design

Parametric design involves the use of a computer to automatically modify a design as the values of parameters change and to make corresponding changes to the computer models during the design process (Hudson 2010). Parametric design is the process of developing a computer model or description of a design problem. This representation is based on relationships between objects controlled by variables. The parametric model then forms a part of the design process where the variables are changed and the results examined in order to find better design solutions. In architecture, applications of parametric design involve the determination and control of the geometry of buildings and the definition of manufacturing data.

The RTM is an example where a parametric modeling tool is used to combine the simulated physical data from the game engine with analogue data collected from Formula One race vehicles and a proposed track geometry. Processing this combination of data provides predicted crash trajectories that are imposed on the track layout allowing the designer to visualize the impact of their proposals and respond to them either by:

- Modifying the track.
- Defining and adjusting spectator zones.
- Specifying the construction quality of crash barriers
- Defining the location of crash barriers.

Workflow: Overview

Figure 2 illustrates the project workflow starting with an initial track design that defines the track edges and racing line geometry. The track geometry is imported into the simulation engine and a professional simulation driver is employed to drive a fastest possible lap. After some practice, lap telemetry is generated and recorded. A speed profile is extracted from the telemetry and together with the racing line and track geometry provides the input to the parametric safety analysis model. The vehicle crash trajectories are then defined. The parametric model also maps vertical track profile and corresponding curvature against the permitted vertical curvature. The results are scrutinized by the architectural design team and their conclusions inform the next design iteration. This may involve returning to the track geometry, developing spectator facilities in zones indicated by the analysis, specification of crash barriers or finalizing design details and preparation of project documentation package which is then sent to the FIA for safety approval.
Track geometry

Track design is undertaken at Populous by an expert track designer with 15 years experience in motor sport facility design. His responsibility is to define the race track and racing line. The track and racing line are modeled first in two dimensions using Bentley System’s Microstation (Bentley 2010a) and then in three dimensions using GeoPak (Bentley 2010b) to combine the 2D plans with site topography. The track designer’s skills are based on experience of both the race vehicles and spectator experience of races. Using this knowledge a racing line is created. A racing line is the path that the vehicle is thought to move fastest round the track. It is known that the racing line will vary depending on the driver and driving style and vehicle setup so its definition is partly subjective. For the RTM it is currently drawn manually by trying to fit the largest radius arc through each corner to minimize loss of speed. Corner arcs are linked together with tangential lines and then converted to a closed b spline curve (figure 3).

Figure 3. Track geometry through Luffield corner at Silverstone – edges and racing line (shown dotted).

Tangential arc and line geometry defines step changes in curvature at tangents. A race car on the track would actually transition smoothly from straight to corner (continuity of curvature). The curvature continuity achieved with tangent geometry is an approximation which is currently considered sufficient for the purposes of design. The definition of the racing line is discussed again in the further work section.

Implementation of the game engine

From Geopak the proposed track is imported into 3DSMax where using a plugin it can be exported to the game engine Gmotor2 developed by Image Space (2010a). This game engine has been used for simulation in the development of Formula One vehicles, and is used in both commercial and military applications. The rFactor (Image Space 2010b) racing game is based on Gmotor2. The strength of the Gmotor2 engine lies in the vehicle setup configuration which can be tuned to mechanical settings specific to Formula One vehicles. Vehicle set up relates to adjustable parts that would be set on race days in response to weather, driver/rider preference and race track characteristics. Adjustable vehicle parts include shock absorbers and anti-roll bar (suspension), gear ratios and differential, tire pressures and type, wing angles, wheel toe-in and camber angle, brake bias, steering lock and ride height. This degree of user specification makes Gmotor2 popular for Formula One simulations by the racing industry.

The design team pay professional drivers specialized in driving in simulated environments. Vehicle setup is configured using data from Formula One vehicles currently in use, in addition the driver can then make further adjustments according to their preferences. The driver sits on a Formula One seat within a monocoque chassis with force feedback steering wheel and pedals (figure 4).
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Parametric model

Parametric safety analysis is undertaken with Bentley Systems’ GenerativeComponents (Bentley 2010c). Four referenced files as inputs are required, three drawing files in the Microstation dgn format and an excel file with the speed profile data. The drawing files define the track edges, racing line and zones of gravel beds all as bspline curves, in addition the track edge file must contain a short line representing the start line.

Figure 4. Example of set up for driving on simulated track.

The race simulation is either projected onto a screen or displayed on monitors. After several practice laps the telemetry is analyzed and further attempts are made at fastest lap. At this point the driving team has the option of using the racing line defined by the driver along with the game engine’s artificial intelligence algorithms to try and drive a faster lap. Telemetry readings are taken at specific time intervals and provide the vehicle speed and position around track. This data is stored as a comma separated value (CSV) file and imported to excel. The speed profile for the redesigned Silverstone track is shown second from the top with other telemetry in figure 5.

Figure 5. Telemetry from Gmotor2/rFactor for the redesigned Silverstone track.

The user has to ensure the files are in the correct format and are present in a folder with the RTM GenerativeComponents script file. The script file can then be opened and the user then steps through a series of transactions defined by the script. This sequence of transactions imports the track and racing line geometry and reads the speed data. Lastly the trajectory generator algorithm combines the referenced geometry and the speed data to produce all crash trajectories around the track (figure 6).

The user can manipulate a series of input parameters that define the deceleration coefficients for asphalt and gravel, gravity, a constant k and the direction around the track. The constant k is a value that has been found from analysis of the accident data recorders and relates the deceleration coefficients to current vehicle specification. Input parameters are initially set to default values to allow the designer to focus on the track.
When trajectory generator algorithm is executed the RTM creates deceleration curves as a graphical look up tool (figure 7). These are based on data from the ADRs which define equations that relate speed to stopping distance for a particular surface. The stop curves for gravel and asphalt are shown in figure 7 and key points used in calculation of one crash trajectory are shown in figure 8. Figures 7 and 8 should be read in conjunction with the algorithm diagram in figure 9.

Counter to intuition, stopping distances on gravel surfaces are greater on asphalt, this is due reduced friction as the vehicle slides over the rougher looser surface. The dotted lines on the deceleration curves in figure 7 illustrate the steps that the trajectory generator algorithm executes until the vehicle’s final stop position is found.

The RTM allows the designer to interrogate an individual crash trajectory to find the speed of the out of control vehicle at any distance as it moves away from the racing line (figure 10). If a crash barrier is required the anticipated speed of the vehicle as it hits it is used to specify the barrier construction.

Application

The RTM tool was used extensively on the redesign of Silverstone in the UK (figures 1 and 11). Approaching the design of a racing facility in this way is novel for the domain. This approach is closely aligned with the design of the vehicles where simulation plays a significant part. Developing a new design tool using a current project as a test case forces a degree of focus that cannot be obtained in a hypothetical scenario. The success of the tool is in its continued use throughout the project, and by the positive response of Formula One drivers that raced the British Grand Prix in 2010. Application of the RTM to the Silverstone project highlighted the need for additional functions such as the trajectory interrogator (figure 10). The modular design of the RTM allowed for this type of modification.
The development team was small and consisted of a CAD manager, expert designer and parametric modeler. The size of the team meant it was simple to establish a common language required for the naming of variables in the application and for discussions during development and initial use.

The small team working on Silverstone required clear definition of responsibilities in terms of tool management with the practice and tool maintenance. The tool specification was supplied by the expert designer who was also the primary user, this meant no training or training manuals were necessary. In a situation with a larger user group the need to specify responsibilities and provide training and documentation would be necessary.

Future work

Currently work is under way for further development of functions for analysis of the vertical profile of the track (figure 13). The FIA specify guidelines to determine maximum radius in relation to vehicle velocity. Two equations are given to accommodate convex and concave profiles. At this point the RTM includes a rudimentary system that provides graphical comparison linking vehicle speed (dashed), proposed track profile (dotted), proposed track curvature (solid) and permitted curvature (dash dot) (figure 12). The comparison enables the designer to see when proposed curvature exceeds permitted or where there are opportunities for increasing proposed curvature. These zones can be identified from the comparison graphic. Areas exceeding permitted curvature are where the solid curve (proposed curvature) is above the dash-dot curve (permitted curvature). Further effort is required to provide
interactive control so the designer can manipulate the track profile in response to the analytic comparison.

Future work yet to be addressed will investigate the development of algorithms for determining racing line through the track by minimizing curvature. As the definition of the racing line requires expert knowledge the curve generated will require interactive control to allow the designer to provide further input. One possible avenue of exploration is the use of evolutionary design.

Figure 12. Comparison of permitted and proposed vertical curvature.

Figure 13. Vertical profile of track.

Conclusions

The Race Track Modeler tool allows Populous to rapidly assess many design iterations and track proposals before sending to FIA. Designs are now sent to FIA for approval and not design assistance and subsequently more design alternatives can be investigated.

The architectural implications of this process may not seem obvious however; the tool has been developed by architects for architects. It is the latest in a series of design decision support mechanisms developed for Populous. Earlier tools include a stadium seating bowl design and analysis tool (Hudson 2010) and a custom tool for developing geometry, cladding, structure and coordinating construction for an international rugby stadium (Hudson 2008, Shepherd and Hudson 2007). The use of parametric design in this context is primarily concerned with developing tools for expert designers which aim to formalize expert knowledge and experience. In contemporary architectural design practice this is a growing area of specialization. Working in a mixed parametric mode, part algorithmic and part expert knowledge has come about due to several reasons: availability of customizable tools, increasing specialization of design task and individuals in industry with skills in design and algorithmic methods.

The authors make the following recommendations for engaging in this kind of process.

- Develop a logical common language for variable and object naming.
- Develop the model in a modular or fragmented way to simplify extension and changes.
- Establish who is going to use the tool and what their skill levels are.
- Develop default parameter sets.
- Establish who is responsible for maintaining the tool.
- Establish who is responsible for managing the tool within the practice.
- Allocate time for developing a user manual and documentation.
- Allocate time for training users.
- Allocate time for modification following training.
- Anticipate longer term (on-going) support

The notion of binding analytic data directly to geometric objects is at the core of this paper. This kind of data visualization presents new opportunities for architectural design processes some of which have been explored by Peters and DeKestiler (2006) and Dritsas and Rafailaki (2007). Further work is required to investigate methods.
and possibilities obtained when dynamic interactive control is embedded with design analysis.

References


Form-making Without Form Making

Andrzej Zarzycki

New Jersey Institute of Technology (NJIT)

This paper looks at form-making as a result of parametric explorations of material, light, and dynamics-based behavior. Parametric explorations of materials and light aim beyond representational photorealism, and are used as speculative tools to pursue imaginative designs, to ask “What if...” questions in the context of material research.

This paper showcases a number of student projects that investigate digital materiality through visual and behavior-based properties. While the digital tools are still limited in scope and offer only fragmented capabilities, selected projects focus on aspects of digital design practice that effectively combine these fragments and apply them to design education. Furthermore, student projects reflect potential for a strong connection between design studio and technology courses in the context of Student Performance Criteria (SPC) guidelines. Parametric tools provide a fertile environment for design explorations, evaluation, and experience-forming.

This paper focuses specifically at the applicability of special effects software and dynamics-based tools such as soft/rigid dynamics, bones, and cloth simulations in architectural design education. The dynamics-based tools not only introduce generative quality into design by facilitating explorative and “accidental” form-making, but also can validate design decisions through the use of simulations and physically based parameters.
Introduction

Parametric design is commonly (mis)associated with design tectonics, or traditional form-making. In such instances parameters are responsible for defining geometric coordinates, degrees of curvature, and the spacing or positioning of individual components. They provide a fluid and flexible definition of a form, with an instant way to modify it without the necessity to recreate it from scratch. In biological terms, in this approach parameters describe the outer—phenotypic—layer of design, addressing visual reading of a form that often exists outside physical and material considerations—its genotype. While recent developments of building information modeling (BIM) expand this narrow usage of parametric thinking by associating geometry with database information, they still fall short of delivering the full potential of parametric design that would act as a meaningful alternative to physically based modeling and simulations. BIM models are “preoccupied” with mathematically defined geometries and database attributes associated with them. Material and behavioral characteristics—how individual components interact between each other—are not presently part of the “information” component in BIM.

Other, less commonly discussed aspects of parametric design are material properties, system behavior, and performance. While performance simulations are recently gaining wider attention, they still often refer to architecture as a surface-deep object without considerations of materiality, element composition, and interrelationships of assemblies.

Although material considerations have long been present in computational design, their use was limited to primary visual reading with a narrow range of properties. Features such as diffused reflectivity and associated color bleeding, subsurface scattering (SSS), and transparencies with an ability to account for the index of refraction (IOR) (Figure 1.) brought physical reality into the digital picture. However, these individual functionalities often worked as unrelated fragments without the ability to form a comprehensive digital model. The model that would facilitate information transfers from one assembly component to another. While it is hard to interrelate these individual functionalities and effectively use them for material explorations, parametric-based models could provide unifying framework for digital models that not only could look like real live objects, but also behave like them.

Parameters with Physical Behavior

While creating virtual environments outside physically based constraints is educational and allows freedom for experimentation, there is a strong benefit of physically driven and parametric form-making in design explorations. The combination of flexible parametric definitions and an instant feedback resulting from consideration of an actual material behavior grounds virtual designs in physical reality. This helps students to ground their thinking, address a number of issues associated with Student Performance Criteria (SPC), and demonstrate their ability to incorporate these issues in their studio work.

![Figure 1. Multilayered glass panel with multiple reflections and refractions visible on the surface.](image-url)
Form-making without Form Making

Parametric design is commonly (mis)associated with parameters that describe the outer —phenotypic—layer of a design, addressing visual reading of a form that often results from numeric procedures. In biological terms, in this approach geometric coordinates, degrees of curvature, and the instances parameters are responsible for defining design, addressing visual reading with a narrow range of properties. Features in computational design, their use was limited to primary performance simulations. BIM models are "preoccupied" with their "information" component in BIM.

Values related to materiality, element composition, and performance. While performance simulations are meaningful alternative to physically based modeling and full potential of parametric design that would act as a unifying framework for digital models that not only could look like real live objects, but also behave like them.

Since generative digital design can be a product of a parametric formula, designers are able to derive any value used in a formula that went into defining this particular form. This is achieved by reversing the "design equation" (switching output with input) and treating the parameter in question as the unknown, while the final design is treated as a variable that informs design assumptions. Consequently, we can ask: "what parameters are necessary to achieve a particular form or performance criteria?" This ability is critical in design evaluation and analysis, since it provides feedback based on final delivery criteria. For example, instead of studying sunlight within a space throughout a day (Figure 2), one could study the form as a morphing continuum (Figure 3) and pose the question: what a space or form wants to be to allow for optimal illumination, or perhaps more evocative reading of an interior space? This transposes the question from what is the best lighting scenario for a particular design, to what is the design that uses existing lighting possibilities most effectively.

Materials and performance. While creating virtual environments outside physically based constraints is educational and allows freedom for explorations. The combination of flexible parametric definitions and an instant feedback resulting from explorations. This helps students to demonstrate their ability to incorporate these issues in their studio work.

Physically-based light simulations. Parametric definition of sunlight and incandescent light allows for quantitative and qualitative design explorations.

Defined through illumination, either at the source (lumens) or on the surface (lux, candlefoot). Similarly, material properties, such as flexion, shear strength, or reflectivity, can be parameterized to facilitate quantitative design thinking. This allows for parametric definition of design, but more importantly, provides parametric output that can be also used for design validation.

Figure 2. Physically-based light simulations. Parametric definition of sunlight and incandescent light allows for quantitative and qualitative design explorations.

Figure 3. Animation of a building envelope allows for an in-depth lighting analysis and form-making while considering lighting.

Cloth, Materials, and Physics

Special effects (SFX) tools such as dynamics, cloth or inverse kinematics (IK) can facilitate form-finding in a more intuitive and visually accurate way than traditional digital modeling tools. This intuitive and visually accurate way is coupled with an instant feedback typical to dynamics-based simulation. This combination of increased accuracy and interactivity brings a new promise of integrated thinking into digital architectural design. It also provides a new tool to address Student Performance Criteria (SPC) requirements.

Dynamics tools such as cloth, particles or IK bring a combination of unique characteristics into architectural design. On one hand, they are very suggestive, visually inspiring modeling tools that function well as generative tools. On the other hand, they consider material and form behavior, and as such bring a component of real live performance into design. Both of these interactions are processed interactively, unlike more involved simulation tools such as Finite Element Analysis (FEA). (Figure 4)
Cloth behavior exemplifies generative properties of performance-based simulations. Cloth simulations, by the very nature of this material, follow the stress flow exactly and visualize the logic of a form. (Figure 5a) In structural design they are often described as funicular or form-active. For these reasons, students were asked to develop a number of cloth simulations that would mimic a fabric-based architectural structure and test material and geometric limits. To ground designs in numeric (parametric) and physical values, students were asked to consider material properties, such as weight, flexion, stiffness or friction as well as physical forces including wind and gravity. In result, students not only could model spatial configurations of the cloth object as a response to acting forces, but also include material properties allowing for tearing limits and fractures. (Figure 5b,5c.)

This interdependence between performance of a form and material parameters brought a certain level of reality into design discussion, even when particular units or physical values are not immediately understood by students.

Cloth dynamics-based simulations are analogous to rigid and soft body dynamics in their ability to incorporate physically driven behavior. An architecturally interesting extension of these capabilities is the ability to animate a cloth behavior with the use of colliders. Colliders in this application provide a skeleton for a canvas-like membrane that has the ability to react dynamically to skeleton’s reconfigurations. In such a designed object, cloth becomes a dynamic skin, similar to the rigid origami discussed later, that repositions itself based on the changed geometry of the collider framework. This can be achieved in the context of animated mesh or dynamics-based objects such as particles or bones.

Cloth engine functionalities can be extended beyond simple funicular simulations, as discussed earlier, and allow for interactive tensioning of fabric to enclose an object, or an entire assembly, with a minimum surface skin. This can be achieved by controlling the amount of tension and a desired size of the final fabric patch. Based on the initial parameters (properties) of a cloth object, the final form results in a slightly different funicular shape. These cloth surface parameters correspond with
various material characteristics and behaviors of real-life objects. Models can also consider acting forces and the integrity of a fabric material evident through localized rips or total disintegration of the fabric/skin system.

Figure 6. Parametrically controlled lattice structure. (Borth, Cozens, Mitrovic, Ordonez, NJIT)

Skeletal Systems and Rigid Origami

Inverse kinematics techniques, adopted from character animation modules, were used investigate structural skeleton systems with integrated and interconnected framing members that mimicked architectural structures. (Figure 6) The ability to rig complex bone arrangements into a hierarchical system with a small number of control points allows for interactive and intuitive structural configuration. New skeletal shapes can be quickly derived from repositioning a small number of control points. After solving IK chain and hierarchical structure of the bone system, IK framework was connected with a cloth object. Resulting in composite design integrating cloth with bone framework and was simulated dynamically as a single, morphing object.

While using IK in defining structural frameworks creates certain limitations in the type of design solutions one is able to achieve, it also allowed students to pursue unusual and imaginary designs without need to resolve constraint requirements necessary in BIM system.

A rigged, IK bone system can demonstrate behavior similar to parametrically controlled composite beam-column. Both are defined by degrees of freedom as well as controlled by a set of constraints. While there is still a need to develop ways to effectively bridge these two digital design environments, the strategies for forming this connection emerge with parametric simulations and dynamics playing key roles. Dynamic based simulation not only create an opportunity for design validation, but also form a natural stepping stone towards parametrically defined architectural models (details) that could be utilized throughout the entire design process.

Constraint-based systems using either parametric definitions or entities such as hinges, pivots, and strings allow for instant, interactive, and accidental (unscripted) design uses. On many occasions these tools mimic rigid origami models, which on a building scale are called flat plate structures.

Rigid origami structures (Figure 7) can be realized with a number of software tools. Digital origami generators, such as: TreeMaker\(^1\) or Origamizer\(^2\) are effective dedicated tools for realizations of origami structures. However, from an integrated design perspective, the same results may be achieved equally effectively using other software, particularly, when one is interested in data model portability and in using a created model to interact with other object or environments.

Figure 7. Rigid origami geometry relates to flat plate structures

Certainly, these structures can also be modeled with programming or scripting tools. Grasshopper, a Rhino
plug-in, could be used to script origami-like forms. However, the same functionality can be realized without resorting to code, by using easy-to-master and intuitive tools. Examples are bone systems and hinge-type constraints in Maya, 3D Max, and other advanced modeling software. Additionally, using software packages such as Maya or 3D Max allows for the integration of rigid origami forms with other elements such as cloth or parametric transformations without a need to leave the modeling environment.

**Figure 8.** Adaptive designs use hinge based constrains (Benson, D’Angelo, Darling, Emara, Morrow, Piccone, Siegel, Tait, NJIT)

Research into rigid origami, facilitated by these unorthodox software uses, provides an effective platform for investigations into kinetic structures and adaptive buildings. (Figure 8, 9) Since the nature of the rigid origami allows for a change in overall physical form without the damage to individual components, these objects can be resolved structurally and be adaptive at the same time. Further developments along the same trajectory are responsive kinetic structures utilizing either a rigid origami approach, parametric structural systems (discussed later), or both.

On the building scale, rigid origami systems address two fundamental needs of architecture by acting simultaneously as a supporting structure (folded plate) and as a skin-building envelope, both of which can function in an adaptive mode without compromising the integrity of either system. This combination of two critical components of building assembly in a single system provides a broad area for future design explorations and experimentations. (Figure 10) Examples of future directions include the recent developments in adaptive systems involving kinetic structures that utilize origami-like geometries and combine physical computing with folded plate structures. (Narahara 2010)

Particle systems are used to analyze aerodynamic properties of an architectural form and to simulate air movement within buildings, such as smoke distribution. (Ophir, 2008) Presently, these functionalities are employed as after-design testing and evaluation. Depending on the level of precision required, this could be brought into interactive workflow where air flow or smoke distribution could be used as one design parameter. While we are still dealing with software and hardware limitations—particles and fluid dynamics are computationally demanding—a more critical question is to what extent architects are interested in incorporating this data into design. Can we quantify the benefits of a better-designed building and convince clients or developers to concur with our judgment? Finally, how do we weight and prioritize multiple design criteria (parameters) to produce well-designed buildings? These questions are pointing into issues outside digital tools and are closely associated with SPC discussion, which requires students in accredited programs to possess “the ability to build abstract relationships and understand the impact of ideas based on research and analysis of multiple theoretical, social, political, economic, cultural and environmental contexts.”

**Figure 9.** Digital mock-up in the site context combines elements of cloth design with the constraint-based system. (Benson, D’Angelo, Darling, Emara, Morrow, Piccone, Siegel, Tait, NJIT)
Certainly, the way we balance a number of design parameters can be significantly enhanced through computational tools due to their capacity for interactive feedback loops and bidirectional interactions. However, design priorities are values which architects, and students, bring into practice and to a great extent reflect the type of education and experience they have acquired. Computational tools will not set priorities that we, as architects, have difficulty sorting out. However, computational tools can make our decisions more explicit, help to track decision-making logic, and on occasions show us contradictions in our design expectations. They also start making us consider design as a quantitative, not only qualitative, science. Parametric design thinking is fundamental in this shift. It also allows connecting individual aspects of the overall design with particular performance criteria for both buildings and students.

Consequently, the limitation of present software tools is in how to employ them and what to expect from them, not in the computational method/paradigm itself. Parametric software brings to our attention the fact that we, as designers, are not always sure how we prioritize different aspects of our design.

**Student Performance Criteria (SPC)**

**Discussion**

In the National Architectural Accrediting Board (NAAB) criteria there is a distinction between knowledge and application, awareness and comprehension of the subject. This two-tier system fits well with how students learn and later gain the ability to apply knowledge. Parametric design and discussed methodology facilitates the advancement of student knowledge (*understanding*) and provides opportunities for its direct applications (*ability*). While there is still continued discussion regarding the relationship between virtual and actual (physically) gained experiences, there is a qualitative educational improvement in the way students can contextualize their learning through a “learning by (virtually) doing” approach. An ability to test conceptual design logic, not only to understand it, provides an immediate feedback loop for student learning and grounds it in similar ways as is advocated by proponents of Experiential Learning.  

While looking at Gaudi’s catenary studies is fascinating and these studies serve as good lecture material, the ability for students to virtually replicate them—test, explore and extend applicability—contextualizes learning and brings it from a distant metaphor to a hand-held model. This next level of student engagement, SPC calls for, can be achieved with dynamics-based simulation in combination with parametric manipulations. Parametric definitions allow for reiterative explorations that can be tied to quantitative design thinking.

![A Kinetic Tunnel](image)

**Figure 10.** Adaptive designs combines kinetic framework with skin like surface enclosure. (Alsieux, Djuric, Patel, Petersen, Seredyak, NJIT)

The software tools discussed here extend a number of traditional design applications in ways that allow students not only to better understand but also to demonstrate their ability and the applicability of their ideas. This elevation of students’ “understanding” to the level of “ability” relates directly to two tiers of accomplishment as described by the SPC outline. This increased engagement is possible due to software’s ability to simulate real-time material or structural behavior, and, to some extent, compensate for students’ lack of experience. While the extent to which virtually gained experience can substitute for real-life experience is still debated, the fact of its relevance seems to be settled. This is supported by other disciplines that rely on simulation as an important
component of experiential learning, as is the case with pilots, equipment operators, and military personnel.

Closing Points

While a cloth object is a direct adaption of the special-effects tool into architectural form-making, similar results can be achieved with other software tools, such conceptual massing with finite element analysis in Revit Structures Extension or Inventor. However, these tools lack the bidirectional feedback mechanism that dynamics-based tools such as cloth can offer. Bidirectional relationship between an input and output is critical because individual parameters not only can be used to drive design, but also can be informed by it. These output values can be passed for further manipulation or used to validate design.

The examples discussed above point to the need for better bidirectional relationships between parameters used in design, and particularly a greater understanding of how to handle systems of multiple parameters and complex evaluation criteria. While present architectural software seldom provides bidirectional functionalities with abilities to comprehensively redefine design at any stage of its development, the lessons learned from SFX software could be applied to set the expectations for future BIM software. These lessons can also point to software functionalities that are particularly effective in “mentoring” students and facilitating their learning.

Digital tools, through their ability to interactively simulate design, allow for developing forms of virtual experience that could, to some extent, compensate for the lack of real-life experience. Finally, parametric and quantitative approach to design problems can help students to navigate difficulties with prioritizing various design criteria and developing authentically comprehensive projects.

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Architectural Drawing: A Prospective Requiem

David R. Scheer

Scheer & Scheer, Inc., Salt Lake City, UT

Abstract

Drawing has been inextricably entwined with architecture since ancient times. Today, architectural drawing is moribund if not already dead, replaced by technologies that encode and store design information in digital databases. This change has taken place with unbelievable rapidity, especially viewed from an historical perspective. This paper examines how drawing has affected our fundamental ideas about architecture and what effects its demise may have on architecture in the future. The aim is to appreciate what drawing has meant for architecture and to assess the latter's drawing-less prospects, hence a "prospective requiem".

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Drawing has been inextricably entwined with architecture since ancient times. Today, architectural drawing is moribund if not already dead, replaced by technologies that encode and store design information in digital databases. This change has taken place with unbelievable rapidity, especially viewed from an historical perspective. This paper examines how drawing has affected our fundamental ideas about architecture and what effects its demise may have on architecture in the future. The aim is to appreciate what drawing has meant for architecture and to assess the latter's drawing-less prospects, hence a "prospective requiem".

What is a drawing?

Until the advent of computer-aided drafting (CAD) systems in the mid-1980's, it would not have been necessary to define what we mean by an architectural drawing. We commonly refer to a CAD plot as a "drawing" but in several important respects doing so devalues the term. CAD plots share with drawings a conventional language of representation, but the resemblance ends there. Before CAD, a drawing was the product of a human hand manipulating physical media. Drafting was a craft that involved lengthy practice to arrive at a mastery of pencil, pen and paper in order to produce a useful artifact. In the process, draftsmen were inducted into a culture that fostered and perpetuated the craft of drawing. This culture codified and transmitted the values of accuracy and composition that are the hallmarks of good architectural drawings (Figure 1).

Figure 1. “Sharpening the pencil”, an illustration from a 1924 manual of drafting.

A transformation in architectural design due to digital visualization and documentation tools has been underway for about two decades. These tools fall into two basic classes. The first provides a means of visualizing the finished building or parts of it. This is primarily of interest in presenting ideas to clients or the public and secondarily as a means of architects' testing their ideas. The creation of such visualization models is laborious in proportion to the realism of the result and is almost always outside the design process itself, in that the visualization tools are usually different from the documentation tools. The second class of digital tools is used to design and document buildings for construction, known as building information modeling or BIM. The difference between BIM and digital visualization tools is that the former is structured in terms of objects that represent actual building elements and contain data concerning these elements relevant to their construction. The latter merely contain a geometry of surface planes sufficient to represent the building's appearance. Although it is theoretically possible to document an entire building in BIM without recourse to drawings, BIM is presently used primarily for making "drawings" of the traditional types. There are many reasons for our continued reliance on two-dimensional and textual information, mostly having to do with the difficulty of changing the working methods of a large and diverse industry. Nevertheless, the use of BIM to produce drawings is a transitional phase between two dimensional drafting (whether manual or CAD) and the three-dimensional design and documentation of building projects. Architecture thus stands at the threshold of the first truly fundamental change in its methods since the first use of drawings millennia ago.

Drawing has been the chief medium of design and communication in the building industry and, like any medium, it is not transparent. It has deeply affected our ideas about space, construction and the nature of design. To explore this, we will consider two aspects of drawing: representation and artifact.
Representation

Drawing has conditioned architecture much as a spoken language conditions the ideas it expresses. No language is transparent: there is always a distance that separates an idea from its expression in language. This separation of ideas from their linguistic expression is an integral part of thought and communication. Thoughts and their expression are distinct yet inseparable. When we seek to express a thought, the thought itself is the goal towards which we strive but never reach. Conversely, the way we express the thought reflects back on and conditions it.

A representation in the strict sense is a description that has its own intrinsic qualities that create a crucial distance between the representation and its object. There are crucial ambiguities in representation as to which of its effects are proper to it and which emanate from its object. Some discourses seek to narrow this distance and make the representation more transparent (e.g. science) while others make creative use of it (e.g. literature). In architecture, drawing has done both. Its precision and well-established conventions lend it clarity, while the obvious difference between a drawing and a building create a space for constructive ambiguity and creativity.

In the case of architectural drawing, the referenced object is usually a building that may exist in reality or in the imagination. The primary characteristic that is intrinsic to a drawing but not to its referent is that it is two-dimensional. Depending on the type of drawing in question, there will be many other such intrinsic characteristics, such as being composed entirely of lines, being a view that is impossible in reality (e.g. an orthographic projection), using a conventional rather than a realistic representation of materials or light effects and so on. In any event, a drawing omits or distorts many of the qualities of the building it refers to while treating others with varying degrees of abstraction. The quality of abstraction is not a shortcoming of drawing; it is in fact its entire reason for being, the secret of its purpose and function.

Those aspects of building that can be readily communicated in drawings have been the primary objects of the architect's thought. These are all in some way related to form. For most of human history, building construction was of a few well-understood types: stone, brick and wood. Architects since the Renaissance have not needed to have direct experience with construction techniques; they need to understand only their capabilities, not how they are performed, much as a composer doesn't need to play the violin to write music for it. Under the domain of drawing, form was the architect's chief work product. Certainly architects were concerned then as now with their clients' budgets and programmatic needs, and spent much of their time working with builders. Their main role, however, was to translate these practical considerations into an appropriate form. Orthographic drawings (plans and elevations) are perfectly suited to this task. They show the placement and profile of building elements. The architect can choose to provide additional detail where the construction is critical to the finished appearance of a part of the building, but the manner of their construction is largely left to the builders.

Orthographic projections are ideal, in that they are never actually seen in a building. No one can ever see the plan of a building. The plan may be synthesized in the mind by walking through a building's spaces, but it cannot be directly perceived. Likewise, no one can ever see an elevation. The experience of a building's exterior is always from a particular point of view and its parts appear larger or smaller in relation to the viewer's vantage point. The elevation shows the actual distances between the building's parts without the "distortions" of vision. Thus plans and elevations are visual ideas, objects of thought; they translate the experience of a building into a form the mind can comprehend. This is to say that they are abstractions that reduce a rich, multi-sensory experience to quantified spatial relationships. Drawing is perfectly suited to convey this kind of information by its two-dimensional, graphic nature. Form is the intersection of the experience of a building with the capabilities of drawing. Using such tools, it is logical that architects value the ideal aspect of their designs, that is, form.
Such is their interest in the formal aspects of building captured in drawings that architects often value qualities of a drawing rather than considering their impact on the actual experience of the building. The drawings come to have a value that is quite independent of the building they describe. They become esthetic objects in their own right, things to be collected and admired for themselves.

For centuries, architects have learned, not only to communicate, but to think about building with drawings. Our conceptual apparatus is based on a notion of space that can be represented by projection onto two orthogonal planes (plan and section/elevation): the Cartesian representation. Many other representations of space are known. Whatever the virtues and limitations of the Cartesian representation may be (and recognizing the value of the work being done to explore the architectural possibilities of other geometries) it remains true that our naive idea of space is cubic. This leads us to the idea that drawing is a reflection of our experience of space and that the privilege accorded the Cartesian representation is not an arbitrary cultural convention.

Ideal plane geometric figures, such as harmonically proportioned rectangles, have played a major role in architects' composition of building elements from the Renaissance up to the present time. These figures are created in the ideal projections of plan and elevation (Figure 2).

This practice is based on the idea that observing harmonious proportions in the abstractions of plan and elevation results in visually pleasing facades and spaces in our experiential space. This idea illustrates that, in the thinking of such architects, the abstraction is in a sense more real than our experience, that relationships in the abstract space of a drawing govern how we respond to the built, three-dimensional reality.

**Simulation and performance.** By contrast with drawings, the digital information models that have replaced drawing do not represent, but simulate, buildings. These models "behave" in a computer like the buildings they describe behave in reality, allowing them to be used to predict the buildings' performance. Performance of various kinds becomes the predominant design criterion. The distance between description and object is ultimately eliminated and with it the space needed for creative ambiguity.

The effects of this are already being felt by architects. Believing that architects now have the tools to perform quantitative analyses of their designs, many clients now expect us to predict energy consumption, thermal comfort, lighting, acoustic properties, visual qualities and other things as part of their design process. Building design is in the way of being redefined as a quantitative optimization problem. This is how engineers have always understood design but it is radically at odds with any notion of architecture as an art.

The digital description of buildings also affects how responsibility is shared among members of a design and construction team. As abstractions, drawings necessarily filter information and transmit only a portion of what an architect knows about a project. This has had enormous consequences for how architecture is practiced and its role in the building process. By choosing what information to share, architects can limit their responsibility for their projects. The acknowledged partial nature of the information contained in drawings distributes responsibility to other parties to a project and
implicitly defines their roles. Much of the practical training architects receive when they begin their careers has to do with learning what information to include and exclude from their drawings. It may seem paradoxical that architects purposely play dumb and withhold information they possess, but the distribution of responsibility that this upholds is the existing basis for the construction industry in this country. Drawings have been the choke point in information transfer that architects have used to distribute responsibility in an acceptable way.

With digital information and the tools to store, organize and share it, the opportunity exists to forego drawings and transmit the digital data to other parties directly. Building owners are well aware of the high cost of inefficient information transfer inherent in traditional practice. They exert financial pressure on the profession to adopt technologies that allow information to flow with fewer intermediate translations that create errors and add cost. Many view this as the main reason for adopting digital technology in the industry.

Due to these effects, the replacement of drawings with digital data is not neutral as regards how architects work and think. Architecture in our time has lost its romance. Very few practicing architects see themselves as artists: their experience is far too involved with meeting the expectations and requirements of others to entertain such an idea. Yet architects have been a limited but invaluable counterweight to the forces that would co-opt our built environment for narrow, venal purposes, bringing to the building process a vague yet deeply-held belief that society has other, greater interests in how and what we build. Perhaps in light of the foregoing it may not be implausible that our ability to do this has depended on the crucial role of drawing in our work.

Performativity (value based on optimizing objective criteria) has been widely recognized as a hallmark of this period in our cultural history.

This impending transformation due to digital tools gives special urgency to the question of what effects the crucial role of drawing has had on architectural thought as a way of considering what changes it may undergo (or be in the process of undergoing). There are three qualities of drawings that have had a determinative influence on architectural thinking: their emphasis on form, their ideal quality and their status as representations.

Artifact

Traditionally, architectural drawing was a craft painstakingly acquired by young architects. Draftsmanship was a prized skill as the ability to draw clearly and precisely was essential to the architect’s ability to communicate with builders and clients.

A culture based on exacting standards of precision and composition unified the architectural profession. Aspiring architects began their careers as drafters. They learned building composition and construction by drawing the designs of their employers. Achieving these standards required complete mastery of one’s hand and of a specialized set of tools: T-square and triangle, pencil and ruling pen, compasses and dividers. A skill as apparently simple as sharpening a pencil so as to produce the desired line quality could take months to master. Nineteenth and early twentieth-century drawing techniques were unforgiving. Drawings were often made with ink on linen and erasing a mistake was difficult. A well-made finished sheet of drawings was an object of pride for the draftsmen and valued by his employer as well as by the builder.

Draftsmanship was thus a craft in the same sense as carpentry or masonry. During their everyday work, architects had intimate experience of the properties of physical materials like graphite and paper, the resistance these materials can present to human intentions, the effort of bending the materials to their will and of knowing how to exploit and when to yield to the materials’ inherent qualities. They achieved that specific kind of mastery that comes of knowing one’s materials intimately that allows the creation of a beauty that depends on their inherent qualities.
These superbly crafted drawings were the distinctive product of the architect. No other trade or profession in the building industry created them. They were the tangible evidence of the unique skills of the architect, as much by their appearance as by the information they contained. Even reproduced for use in building they were beautiful, as one can see by looking at the fragile blueprints on linen that are still in the records of city building departments around the country. The drawings contributed to and reinforced the architect’s authority in building, portraying him as the master of both intellectual and physical creation.

The mastery of a craft in a sense joined architects and builders, giving them a common experience and uniting them as an industry. The time, effort and skill embodied in a set of drawings was visible to everyone. These physical products must have spoken to builders and produced a sense of kinship and respect. The intellectual mastery they displayed then could establish the architect as the master of the building process. Drawing was the cornerstone of the architect’s prestige.

Like any craft, drawing could be elevated by an inspired practitioner to the status of an art, expressing far more than mastery of technique. Architectural drawings (when they were manual productions) were often beautiful in their precision, the delicacy of the linework, the composition of sheets, the harmonious relationship between images and (handwritten) text (Figures 3 and 4). Some types of drawings, such as those produced by students at the Ecole des Beaux-Arts, added color and became paintings (Figure 5).

Figure 3. In this sketch of his Einstein Tower design in Potsdam architect Erich Mendelssohn captured in a few deft pen strokes the dynamism he wished his project to convey.

Figure 4. (Top) A sketch by Frank Gehry of the Disney Theater. (Bottom) The Disney Theater as built.

Figure 5. An example of a watercolored elevation drawing typical of those made by students at the Ecole des Beaux-Arts.

Often these drawings communicated a feeling or
emotional tone that added to or even overwhelmed the quantitative information they contained. The powerful (orthographic) drawings of the project for a Cenotaph for Isaac Newton by Etienne-Louis Boullée (Figure 6) convey a sense of the grandeur and revealed mystery that Newton evoked among many of his contemporaries.

Much has been written about the intimate connections between the physical act of drawing and architectural thought. It is well established that the drawing techniques chosen by a particular architect reflect his/her primary interests in the design. Pen and ink has been used by architects chiefly interested in line (Figure 7). Colored pencil calls attention to surfaces (Figure 8). Collage highlights a built environment where successive projects relate to one another by juxtaposition, without a strict formal framework (Figure 9).

Figure 6. Etienne-Louis Boullée, project for a Cenotaph for Isaac Newton. Night-time section and elevation.

Figure 7. Top: Karl-Friedrich Schinkel (late 18th century). Bottom: Leon Krier (late 20th century).

Figure 8. A drawing by Michael Graves.
Architects also choose drawing techniques to suggest their affinity with certain historical periods or even specific architects from the past (Figures 7 and 10).

Since computers can also generate a wide variety of types of images, it might be objected that manual drawings are no more expressive by nature than computer-made drawings. This overlooks the fact that manual drawings are more than images: they made things. The parts of a drawing are not merely layers in Photoshop, different in content but identical in nature. A drawing is composed of disparate materials that are physically placed together. The similarity of this experience and that of building has sustained the relationship between architecture and construction. It has put construction in architecture and allowed architecture and construction to share a material culture. Now that drawing has disappeared from architecture, what will provide this critical link?

**Prospects**

Drawing provided architects our intellectual and emotional connections with the built world. As a conceptual tool, drawing provided the geometric framework within which we made meaningful built form.

As a physical artifact, drawing was a craft akin to the building crafts and provided a physical experience of making that allowed us to enter the world of made objects, joining us with building. How will architects replace it? How will we establish our connection with building, in what will our craft consist? The economic and technical forces that have called BIM into being will ensure that its domain is extended as quickly as the technology can evolve and old habits can be shed. As architects, we must meet this change head on.

The first thing to note is that, as architecture is changing, so is construction. The same forces that favor BIM are demanding that construction become more industrialized and automated, that information generated during design and construction be seamlessly, losslessly transmitted to the building's operators. It is not only architecture, but...
the entire building industry that is becoming data-driven. Craft in the traditional sense of a discipline of making is being lost on all sides. This is not what will provide the glue that binds design and construction in the future.

Building is increasingly about information. This has always been true in a sense, but most architects did not think of their drawings as information-bearing devices. Now it is information that is clearly at the core of our activity. We no longer draw; we create information models that contain data about building materials and systems. We focus on how information is transmitted from one party to another, making transmission as transparent and lossless as possible using digital media. We have realized the age-old dream of living in the clouds, where our data (and our designs) now reside.

As a result, the old divisions between design and construction are blurring. Understanding design and construction as information management favors getting a particular piece of information from the entity best able to provide it accurately, minimizing the need to re-create or transmit it later during the process. Thus, mechanical subcontractors are building the 3D models of ductwork and piping because they can use the same model for design, coordination and to drive the CNC machines that fabricate the components. The model becomes the shop drawings. Architects delve more deeply into construction techniques, sharing their models with fabricators to economically produce geometrically complex building systems. We can "mass customize" buildings by making aspects of the design parametric so that variations can be produced automatically without the need to re-draw each variation.8

Architects will need to create a craft of computer-based design. The discipline we found in drafting must be replaced by another, just as rigorous. We will need to find ways to insert materiality into this disembodied process or risk losing our connection with the delight building materials can yield.

Finally, we will have to answer the question of whether the basically two-dimensional thought processes we relied upon, that were sustained by drawing, are the result of the limitations of our tools, or of an innate human understanding of space. Our tools now offer us the freedom to create forms that our minds could never imagine without their help. Freedom entails choice and responsibility. Because something that is possible does not mean it is good. We are living at a time when architecture is being challenged at its most basic levels: can we put technology to the uses we desire and avoid becoming its servants? What is the nature of our experienced space? Where is the balance struck between how our lives shape how we build and how our buildings affect our lives? Ours is a time for a complete re-thinking of architecture.


3 FormZ was introduced in 1991. This event signals as well as any other the emergence of computer graphics from academia into professional practice.

4 Construction technology only became part of the architect’s purview with the advent of new structural materials in the 19th and early 20th centuries such as steel and reinforced concrete.


Parametric Affordances presents a theoretical framework for development, use and implementation of parametric models in a design setting. This paper presents fundamental background theoretical concepts and proposes an approach to separate tasks and actions of the design process in different kinds of parametric models to take advantage of them.
Parametric Affordances
What, When, How

Carlos Barrios, PhD
Design LAB, The Catholic University of America

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**Introduction**

The use of flexible geometry in computer graphics dates from the very first inceptions of computer modeling software such as Ivan Sutherland’s sketchpad, a computer program he developed at MIT in 1963. Among the many features of sketchpad was that geometrical figures could be moved, copied, rotated or resized (scaled) while retaining their original properties, which allow under some cases to create *duplicates* (identical clones) or instances of the *master geometry* while transformations propagate to the instances without additional editing. Although powerful, sketchpad’s features were somewhat burdensome and limited by the computer power of the time. This idea of flexible geometry became the holy grail of computer graphics software that was pursed in many cases with the implementation of the history stack, tools like the “undo” and “oops” commands, or the hierarchy tree, but once again limited by the memory and processing capability of the computer hardware.

However, it is only until recently that efficient forms of flexible tools for editing geometrical models have become available as standards in most mainstream computer graphics software. Different software packages have implemented their own flavors for variable and flexible geometry, and today there are a myriad of *variable geometry gizmos* grouped under the umbrella term *Parametric Design*. Parametric Design remains as the customary name given to computational procedures that allow flexible editing of geometrical entities without erasing and redrawing. But, what exactly is *parametric design*?

**Fundamental Concepts: WHAT**

Before defining what is Parametric Design (PD) let’s take a quick step back and define some fundamental concepts. First and foremost is the distinction between *Parametric Models* or *Parametric Modeling* (PM) and *Parametric Design* (PD), two different terms that are very often confused or used interchangeably.

In generic terms, a Parametric Model (PM) is defined as a group or cluster of geometrical components that have attributes (properties) that can vary and other attributes that are fixed. The fixed attributes can be of two kinds, *static*, when the value does not change (fixed value) or *constrained*, when the attribute is associated with a fixed location or position. In this last case, if the value of the parameter can change, then it is not a considered a fixed attribute.

The variable attributes are called *parameters* and they can be of several types. Generally speaking, a parameter is a placeholder for variables to exist allowing different values within certain possible limits (range), hence allowing variation to take place. Parameters (variable attributes) can be of different kinds, but most can be grouped in the following six categories:

1. Independent: those attributes that can take any allowable value that is valid within the range of possibilities.
2. Dependent: are those attributes that vary but with respect to the value of other attributes or parameters. They can take the form of mathematical equations or numerical relations. For example, the value of the parameter can be the result of the solution to a mathematical function. The value of the dependant parameters can be the result of a linear or non-linear dependency.
3. Relational: Parameters that depend on a relation or sets of relations with respect to other attributes. Examples of this kind are relations between geometrical components (perpendicularity, parallel, concentricity, etc), adjacency or location.
4. Boolean: parameters that, based on a specific condition can take values that are usually opposite, by either being “on” or “off”, or in an “active” or “inactive” state.
5. Conditional: are those parameters that will take the value depending on the evaluation of an initial conditional state. If a condition is met, then the parameter will have a specific value, or allow values within a specific set. If the condition is not met, then the parameter will either have a different value or allow values of a different set.
6. Temporary: is a parameter which value is constrained, or dependent of a condition that might be temporary, or will have a value or set of values that will be valid as long as the condition is still valid.
In this context, Parametric Design is defined as a design process where parametric models are used, thus making a clear distinction between the process and the tools used for the process.

**Fundamental Uses: WHEN**

In the context of architectural design, and in particular in academic environments, PM have been used primarily for three purposes: exploration of formal design ideas, refinement, and integration through building information modeling.

Design exploration refers to the process of initial design ideas or Design Discovery (DD) during the initial phases of the design process. Through variations in the generic geometrical arrangement of geometrical components, a Parametric Model (PM) will allow flexible exploration of a design idea when some of the geometrical components are not fixed. This is particularly useful in the early stages of the design process when a generic idea might be defined, but there is a high degree of uncertainty in the final geometrical and formal configuration of the design. During this stage a high degree of flexibility is desirable in a parametric model, at least until some decisions of the overall building configuration are made. Parametric Models for Variational Geometry (Barrios, 2005) are the most common used in this initial stages of the design process. These are PMs with geometrical components that have a high degree of freedom and where hierarchies and dependencies are built with ease. These kinds of models have the ability to resemble rubberband-like behavior where geometrical components are easily adaptable.

Models for Design Refinement (DR) are used in an intermediate stage after the initial ideas in Design Discovery have been determined, but right before design development stages. In this stage a generic form has been found or determined, but certain configurations are still under exploration. A level of feedback is sometimes implemented at this stage through performance or aesthetic evaluations that can occur within the model or with an external based measuring criteria. Design is progressively refined through an iterative process of variations and evaluations to indicate optimal results, or tradeoffs between the different design solution candidates. It is very often that in these kinds of models the geometry is accompanied by the use of spreadsheets, tables or other kinds of figurative elements that will inform the designer of the consequences of the actions when varying the model, thus indicating when a specific action will yield closer solutions to the desired results. Designers will use this data to make informed decisions when evaluating possible candidates for the design solution.

The last form of PMs used is for coordination towards building a complete and realistic geometrical model with attributes that contain data and information about architectural elements in a building. In this case, a successful model will have a minimum set of flexible geometry that will be independently variable, while the rest of the geometrical components will necessarily become dependent parametric entities. A typical scenario is a Parametric Skeleton© with a few points and lines that controls a surface as independent parameters (as few as possible) and a large array of geometrical objects dependent on the surface configuration that will respond to any changes occurring in the underlying geometry. Another typical scenario is the where complex surface and solid geometry is dependent on lower level entities either as basic point-data, or numerical values that control geometrical configurations which can be input in spreadsheets. In both cases serveral highly complex geometrical objects or collections of objects are attached to the simple geometry as dependent entities in the parametric infrastructure©. In this kind of PMs, and for the most part, the objects are created as parameterized and dependent entities of the underlying parametric infrastructure. Usually this models are very complex in their structure, and seldomly varied as they demand extensive use of computing resources with frequent unpredictable results when geometry is changed. In some cases forcing designers to freeze the parameters to avoid undesired changes. This is perhaps one of the most difficult challenges in current modeling systems.
Alternative Uses: HOW

Traditionally a parametric modeling software serves for the purpose of creating geometrical entities that allow the designer the exploration of different design alternatives by making variations on the geometrical components of the model and responding to them. This affords the designer to navigate through possible design solutions without much effort. However there are far more possible applications that a parametric model can be used for.

In 2007, the author published a paper and proposed five different cognitive models for parametric design to aid the designer in different phases of the design process. In that paper, it was clearly identified that different stages of the design process would require a different kind of parametric model. In just a few years later, new developments in computer programs have incorporated some of the features proposed in the paper, such as reusability of parametric features, such like the ones existing in BIM modeling programs. The proposed model aimed to provide a robust structure in which changes in geometry would be related to other features in the model. Although the flexibility of reusing parametric geometry in different models has existed in Feature-Based Design modeling software, this did not existed in the context of architectural design as stand alone integrated package.

A second model proposed that has caught up very quickly is flexible interactivity between variable geometry and properties associated with it. This particular class of PM is referred to the Interactive Feedback Model (Barrios, 2007) In an interactive feedback model, the geometry has a level of intelligence associated with evaluators that will inform the designer the consequences of their actions in real time at the moment of performing parametric variations. Although computers have had the capacity to perform in this manner, it is still not necessarily integrated in current software platforms. Therefore it is up to the designer to build the geometry containing the appropriate links, attributes and evaluators to create a model with such behavior. It is clear that such enterprise might represent a challenge since it is very difficult to predict what a design will look like and how it will behave until a model is done. The default solution from most parametric modeling software is to provide generic tools to allow the designer customization at will and for each case, although some effort and progress has been made in recent developments to make this seamless.

is defined as a geometrical entity composed of geometrical elements that have attributes (properties) that are variable and other attributes that are fixed. The fixed attributes are called static when they have a fixed value, or constrained when they have a fixed location. The variable attributes are called variables, or parameters and can be independent or dependent. The dependent attributes will take their value from another external parameter creating a dependency relation. The independent attributes are free to take any value that the designer assigns.

Affordances

One of the most important questions to ask is what is the purpose of using a parametric model, in other words: WHAT kind of parametric model or parameterization scheme to use; WHEN to use it for the purpose of helping the designer and the design process; and HOW to take advantage of the parametric model to better suit the needs of the designer. The fundamental premise that a PM can and should help the designer create a multitude of candidates for design solutions, evaluate, sort and rank them, inform the designer of possible outcomes or warn him of possible conflicts, and finally allow the proper management of data contained in the geometry seems a rather straightforward task for a computer to perform, but experience shows otherwise. On one hand, as design develops and the complexity increases, models require immense resources to handle enhanced amounts of data, while at the same time become more intricate and difficult to manage efficiently. On the other, as the design develops and decisions are made, there seems to be less need for flexibility and more for interconnectivity among the geometrical components of the model.
In general a parametric model if used for a specific purpose it should be tailored to suit that purpose. This calls for a redefinition of a parametric model as a universal container of all geometrical components with multiple layers of relations that can control all aspects of the model, geometrical or not.

References


Interior climate optimization by volumetric adjustment

Daniel Hillukka
North Dakota State University (NDSU)
Graduate Student

Abstract

This research focuses primarily on the functionality of software, specifically Rhinoceros (McNeel & Assoc.) and a few associated Plug Ins (Grasshopper, Rhino Assembly), to create and control a model of a building to study the environmental effects of modulation of space.

Has technology been completely utilized in addressing comfort maintenance within a dwelling space? For example, animals have similarities based upon their surface to volume relationship, yet they are able to adjust the ratios based on a reaction to their environmental circumstances. For example, when cold, they are able to “fluff” their fur in order to minimize their surface area in comparison to an increasing “interior” volume. Historically, abilities to influence temperature change within a space have been relegated to passive air exchange systems and more recently completely active air exchange means of control. Technological advances have raised significant questions towards methods and means for this control.
Interior climate optimization by volumetric adjustment

Daniel Hillukka¹

¹North Dakota State University (NDSU) Graduate Student

Abstract

This research focuses primarily on the functionality of software, specifically Rhinoceros (McNeel & Assoc.) and a few associated PlugIns (Grasshopper, Rhino Assembly), to create and control a model of a building to study the environmental effects of modulation of space. Has technology been completely utilized in addressing comfort maintenance within a dwelling space? For example, animals have a similarities based upon their surface to volume relationship, yet they are able to adjust the ratios based on a reaction to their environmental circumstances. For example, when cold, they are able to “fluff” their fur in order to minimize their surface area in comparison to an increasing “interior” volume. Historically, abilities to influence temperature change within a space have been relegated to passive air exchange systems and more recently completely active air exchange means of control. Technological advances have raised significant questions towards methods and means for this control.
Through use of 3D models and simulations, the topic of climate maintenance in spatial conditions was addressed using environmental controls. Thus modulation of the interior climate as well as the space could simultaneously occur to create a radically different space of habitation. The preparation and writing of this abstract addressed various areas of the SPC requirements, which become apparent during the digestion of the paper.

**keywords:** Rhinoceros, Grasshopper, Rhino-Assembly, volume, operable architecture, parametric components, climate optimization, dynamic constructs

### Introduction

With much of today's life involving highly dynamic and interactive objects, which process much information, one can say that architecture is lacking in its exploration of information processing buildings. A majority of buildings today can be described as static objects. Buildings from the beginning of time have always possessed information, but rarely processed it. Structure, for example, has one job; to maintain its given place in space based on the information it receives from fasteners. An important job albeit, allowing people to dwell in these spaces. These unchanging spaces have become the focus for this research, concentrating primarily on how a space could react to environmental influences, which affect the climate of the interior space resulting in a highly charged dynamic dwelling space.

### Research Background

The research began with discussions centered on an animal's surface to volume ratio. It has been shown through studies that an animal's skin surface to body volume ratio, follows a particular curve in relation to the type of climate they inhabit. (Schmidt-Nielsen 1984) Yet these animals all have an ability to change this association somewhat through the adaptation of their skin, namely in shivering, or sweating. Where shivering tends to fluff the fur or cape of the animals it minimizes their surface area in relation to their volume, and helps to bring their interior volume up, in cold temperatures. Warm temperatures invoke the process of sweating which allows the cooling of body temperature through evaporation, although it does not change the surface area of the animal. The winter fur compared to the summer fur is definitely different in terms of thickness. Even natural responses show our adaptation to temperatures, as we grow cold we tend to curl significantly to reduce our surface area, this changes the ratio of our surface to volume area of our bodies. One of the exceptions are elephants, whose body mass is so great compared to their skin surface that heating or cooling via conduction through their skin surface tended to be negligible in altering their internal temperature. (Schmidt-Nielsen 1984)

In relation, a sky scraper is one building type which parallels an elephant's internal temperature mass. A sky scraper is a building type which needs cooling year round even during the cold winters of Minneapolis and Winnipeg. Historical means of dealing with climatic influences have ranged from passive solutions, such as allowing breezes to cool buildings in tropical climates, while in colder climates introduction of heat into the space allowed the space to maintain a degree of comfort. With the advent of air-conditioning, buildings were able to use cooling to maintain comfort levels through the summer months. These concepts evolved to induced heating and cooling year round for buildings.

A building's interior space has a certain amount of BTU present in that space, and it changes based on energy being introduced into that space from humans, machinery, and environmental influences from outside the space. Energy is conducted, from outside, to the interior space via the boundary surfaces, this leads to changes in the space's climactic energy content/BTU. Geometry forms needed to be studied to find out how they influence spatial BTU maintenance. Spheres are the most efficient in terms of surface to volume ratio with a ratio of 3, meaning there is...
3 units of surface to every 1 unit of volume. (Wikipedia) While a tetrahedron, or a triangular shaped figure, tends to be the least efficient, a 7.21, in terms of amount of surface compared to interior volume. (Wikipedia)

Also, recent technological advances such as 3D modeling, simulations, and various components which respond to sensory influences begin to raise questions surrounding typical ways of approaching architectural design. With the understanding of how a shape’s relation between surface and volume affects each other, new possibilities revolving around 3D parametric modeling and simulations, the decision was made to refine the design of a project through the use of an appropriate surface to volume ratio, and the new computing technology. (Figure 1)

Figure 1: The process model which directed the development of the project design.

Discussion of Procedure

Initially, much discussion revolved around the psychometric chart and the relationships on which it concentrates. (Stein, Reynolds, Grondzik and Kwok 2006) The most interesting relationship within the psychometric chart was the intertwining volume, entropy or BTU and temperature relations. Since those three factors were interrelated, theoretically one could be adjusted affecting the others. This realization began to further direct the development of the project. (Figure 2)

Since architecture is highly centric around the design of space, a procedure involving the use of volume manipulations to alter climate conditions within a space would result in a highly interesting space, a rationally developed project based on environmental influences. The factors which are most crucial in maintaining a spatial climate began to surface as important toward facilitating any such actions involving climate maintenance by volume manipulation. (Figure 3)

The U-factor, or insulated barrier, volume, and the temperature difference from inside a space to outside the space are the critical factors surrounding controlling a climatic space. It was found that the U factor when plotted next to the volume and temperature difference had the most impact on maintaining a climate at a comfortable level. (Figure 3)

Although the U-factor of a typical wall requires much attention in relation to maintenance of
climatic conditions of a space, the ability to control a space’s BTU level through means of operable boundary planes required attention to how a space might be affected. The experience of differing, or changing spaces could become an unsavory experience if designed incorrectly, the decision to alter primarily two planes from each side of the structure became the focal point. The roofs of each side become operable, with one side able to extend its length, and the other to both change the angle of attachment to the dividing wall as well as changing its covering length as well. The two long exterior walls also were allowed to change their angle of relation to the floor while simultaneously being able to extend their height as well. (Figure 4)

This allowed for the expansion and contraction of the enclosure volume to be changed as well as the spatial countenance of the interior spaces to be changed also. The restrictions of the angles and lengths of the boundary planes are based on the volume needed to accompany the extreme environmental conditions of the project, so the maximum low and high temperatures of the climate. An in-depth look at how and whether it could be possible to maintain a comfort level in a space through volume control or modulation, brought physics and thermodynamics into the discussion. The examination of thermodynamic formulas proved that air could be manipulated with pressure and volumetric changes, not simply through induced heating and cooling. (http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html) An example is airplanes, they become pressurized and maintain their volume to a certain size, this aids in the requirement of less heating of the fuselage during high altitude flying. The metal of the skin and structure conducts the cold from outside to the interior of the plane which is why there is a need for induced heat. If planes were able to alter their volumes, an answer for the infiltration of energy through the boundary plane could be to adjust the volume to anticipate for the conducted temperature change, therefore creating a negligible amount of energy to transfer into the space. A set of formulas derived with the aid of a professor began to illustrate how a building might adjust to temperature gains via adjustment of boundary surfaces. (Figure 5)

Early, during the development phase of the project, the goal was to have a completely modeled design which reacts in response to temperature differences and changes from the surrounding environment. A design was developed within Rhinoceros and modeled as a process model. This allowed the designer to select various parts of the process model in the Grasshopper program and adjust them based on what the designer decided it should do. The model was developed to the point at which it was fully functioning and displaying real-time volume, surface area and surface to volume ratios as a slider was manipulated to change the
model. (Figure 6)

Yet the realization was made that tolerances did not aid in the production of components for the architectural design, rather the lack of lifelike tolerances led to the lack of development of components.

![Figure 6: The control panel in Grasshopper showing the changing volume, surface area, and correlating ratio.](image)

This lead to the search for a Plug-in or modeling aid for Rhinoceros which allows a model to function as it would during lifelike and realistic constraints. Rhino-Assembly was found and with all considerations in mind found to be satisfactory for the purposes required. A model was then developed in a more satisfactory manner being able to model building constructs and details to become a fully operable structure within the program. (Figure 7)

With the ability to design constructs, or pieces of architecture, while allowing the desired initial conceptual design to be seen during the process, allowed for simultaneous development of two models. One a physical model, which simulates how a building may respond and change to information with different, yet compatible parts working together and the second a model which “reads” data and performs analytical calculations revealing the differing changes a building would progress through as the data changes. The next step would be to integrate it with a real time temperature and set the model “free” to visualize how would change over a day, season or year based on the temperature data obtained. This was completed through use of the Rhino Plug-in Grasshopper and a visualization of a simulated building and volume change was viewed through the integration of the model paired with select month’s worth of temperature data.

![Figure 7: A close up of the model beginning to show the implementation of architectural components designed for the project.](image)
Results

Figure 8: A spreadsheet showing the calculations showing how a particular volume will change in response to the temperature difference with the formulas used.

Through the use of the derived formulas it was found that as the temperature changed, the building would adjust to the temperature being conducted in, via the adjustment of the boundary surfaces. The calculations show how a project might produce a space of varying and seasonal change. (Figure 8) As the change in surface area was affecting the conducted temperature via the adjustment of the boundary materials, this then affected the inside climate and caused the building to adjust once again. Sensory activated components would sense the change in BTU and activate the envelope to adjust to accommodate this environmental influence. Thus a building becomes a processor of information, which addresses two types of information; climatic information, as well as spatial volume information. Other results included the formation of a physical tolerance restraint model which illustrates the difficulties in developing a fully functioning model. (Figure 9)

The development of a model which simulates a building constructed of components, evolving and changing over time becomes conducive towards believability. The importance of the implications in developing a functioning model is important regarding many aspects. During the development of the functional model many physical, lifelike conditions caused the conditions of the components to change due to restrictions imposed by the developing design, and the desire by the designer to stay true to the design intent. This resulted in the creation of new dynamic architectural components, which would not have been realized without this project.

Conclusion

The calculation loop results show the reaction of a building which responds to energy conducted into the interior climate. The result shows the building volume stabilizing at a volume in which the incoming energy is offset by the sheer amount of BTU available within the space already. In essence the calculations show a building which
finds a stabilization point, or creating the same scenario that an elephant's surface to volume ratio has created for their body temperature control, interior BTU being so great that conduction of energy via their skin does little to offset and change their body temperature.

To incorporate a changing and more accurate U factor in reflection of the changing boundary planes of the model would result in more accurate and conclusive results. Yet the simulations done through the research and the path to achieve the results, show promise in the results displayed. Influences on the spatial climate not accounted for, range from human body heat, appliances such as refrigerators, computers, and other such machines with heat as a byproduct. It is this type of inclusion in future advancements, paired with a cost analysis of a proposed design in operation to compare energy costs over use of an adaptable space to a conventionally controlled climatic space.

Although this project is shown being applied to a residential type project, this process of rationalization is not limited to a certain typology, climate zone or building system. In reality the computations formulated show the generality of application. The design was developed independent of the computations, but with the holistic understanding of developing the project towards an adaptable structure. As the project concluded the realization was made that application of modulated components tend to filter in naturally towards the end of the design process. This led to the understanding of integration of rationalization within the realm of design. Design becomes the restraint and intent of the project, while the rationalization of components into the design began to reveal the symbiotic birth of new constructs of architecture which were not thought of during the initial design stages of the project. Developing new constructs or components designed specifically for this project allows the visualization of a process incorporating far more than simply design, but the incorporation of the practical side of the discipline as well.

Implications for Practice and Advancement of Research

The research has left many avenues of pursuit open in regards to rationalization of a space in response to environmental influences. Climate is one of many such areas of investigation which look to be very promising. The control of natural light into a space, or correspondingly reducing artificial light, and creating a lighting condition based on the programmatic requirements of the space is another direction available. Light and energy, are just a few areas where the rationalization of space could be investigated and researched more.

The sense that a design has been rationalized, due to the environmental conditions imposed on it, yet allows a designer the freedom to develop a design is important. The thought of using rationalization to structure or hinder design implies unimaginative design. Rather the implications of this particular research are thought to expand the vocabulary of both architects and the field of design. A spatial composition varying in its size and enclosure is the threshold of a new era of performance buildings. The use of computers to simulate a combination of constructs to create a spatial boundary, one which evolves over time, shows the importance of tooling in the field of architecture.

The ability for architects to model designs in whole, or completeness would address many issues in the practical side of the discipline. A most important ideal would be one which would address the implications of using a 3D model as a “construction document” instead of a using plans, sections and elevations as architects primarily use today. The ability to produce complete information with by use of sections and plans creates more issues than simply submission of a 3D model which has vastly far more information at hand. The simple layering of different components of the building can allow builders to see firsthand how exactly a certain detail will work in all phases not simply in section and plan. A 3D model for builders would be much more informative than pages of drawings that reference each other over and over, and require much insight and the ability to foresee how one aspect might affect and connect with another. As more easily understood information for builders would
a 3D model be, even more evocative for dwellers would be a space which modulates and reacts to the environment. This creates a dynamic space which is constantly changing, creating new views, new views of the form, and highlighting the sensory input for the users. A building which processes information, highly reflective of our culture, yet responds to the simple influx of information of its environment.

Acknowledgements

I would like to thank North Dakota State University professor Dr. Ganapathy Mahalingam for his devoted attention to this research, for without him this paper would not have been possible.

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Figure 4: Spreadsheet of Calculations Created by: Daniel Hillukka (OpenOffice Calc)

Figure 5: Model Control Panel, Created by: Daniel Hillukka (Grasshopper3D, Rhinoceros)

Figure 6: Grasshopper Mesh Overlay of Rhino Process Model, Created By: Daniel Hillukka (Rhinoceros, Grasshopper3D)

Figure 7: Evolving Model, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)

Figure 8: Model Close Up, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)

Figure 9: Evolving Model Second View, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)
Parametric Form-Based Codes: Incorporation of land-use regulations into Building Information Models

Jong Bum Kim\textsuperscript{1}, Mark J. Clayton\textsuperscript{2}, Wei Yan\textsuperscript{3}

Texas A&M University

This project describes investigations into whether parametric modeling using a Building Information Modeling (BIM) platform can represent the provisions and constraints of Form-Based Codes (FBCs). BIM software environments couple 3D modeling with parametric form generation and rich semantics. Further capabilities of an Application Programming Interface that supports Object-Oriented Programming (OOP) results in a very powerful environment for expressing planning and design concepts. While these capabilities were developed under the intention of supporting building design, we hypothesize that they can support planning rules and regulations that are found in FBCs. If our approach is successful, future planning departments will be able to provide architects and urban designers with a FBC that is implemented as a BIM software toolkit, better integrating the planning phase of a project into the building design phase.
FBCs and Transect Zoning

FBCs were created as an alternative to conventional zoning and land use regulations by addressing the public realm and urban form (Ben-Joseph 2005). FBCs deal with the typology of block, street, open space, and building façade, whereas conventional land use regulations focus on the building use and the development capacity.

Transect zoning is an urban planning model that defines the hierarchical development scale from sparse suburban to dense urban cores (Forsyth 2003; Hascic 2006; Ligmann-Zielinska 2008; Stephenson 2002). The character of each transect zone is defined by the degree of density, open space, and urban form. Transect zoning provides a map, Transect Codes for each property, and requirements for each Transect Codes, but users need to locate all constraints and requirements from those documents. FBCs are an example of transect zoning ordinance, and follow the same structure. The main components of FBCs are the Regulating Plan with Transect Codes, Public Space standards, and Building standards, and users need to locate all requirements from those components (Parolek 2008). The general steps of using FBCs and Transect Zoning Ordinance are:

1. Define the public space type and the building type from the Regulating Plan
2. Define the allowed building locations and parking locations from the Regulating Plan
3. Obtain requirements for the public space from the Public Space Standards
4. Obtain requirements of materials and building configurations from the Building Standards
5. Overlay collected information to the Regulating Plan

FBCs users should overlay all components to understand what the consequence of FBCs is, but this overlay process is not always obvious (Figure 1). In all components of FBCs, various parameters are used to control urban geometry, and many of them are associated with other parametric values. For example, the principle building and the parking structure area are correlated with each other. If more floor area is planned, then a larger parking area would be required. As the parking area increases in the ground floor, the available first floor area of the building decreases. However, the allowed locations and heights of building and parking buildings are also defined, so these associations among constraints make the overlay process complex.

In addition, when we apply given FBCs standards to properties that have atypical morphology, the property geometry affects many parameters such as front façade locations, floor plan dimensions, and building volumes (Kim and Clayton 2010). Thus, this complex interaction among parameters and constraints can delay changes and analysis not only as users overlay FBCs components, but also as creators make decisions regarding FBCs provisions. The use of “what if” scenarios could lead to decisions that result in better codes.

Figure 1: Overlay Process of FBCs. Main components of FBCs are the Regulating Plan, Transect Codes, Standards of building and street. Users of FBCs need to overlay all components of FBCs, which delay a real-time analysis and interpretation of FBCs.
The Parametric Approach in Existing Urban Design Tools

Computer-based urban modeling allows designers and planners to describe existing and future cities, in large part replacing the traditional use of physical urban models. These tools have been shown to lead to better decisions in developing urban planning regulations and specific urban designs (Al-Douri 2006).

CityCAD was developed by Holistic City, which can report a variety of design analysis data (Holistic City Software 2011). CityCAD provides a user-friendly interface and built-in object libraries, but the function mainly focuses on the building façades design. The built-in objects are based on parametric techniques, but users can access limited parameters of the site information and urban typologies. In addition, this tool does not offer programming interfaces that allow its extension (Jorge Gil et al. 2010).

CityEngine was initially developed by ETH Zurich, and then commercialized by Procedural Inc. in Switzerland. CityEngine is a 3D modeling application for urban environments, which focuses on visualization aspects of realistic cityscapes for the movie and video game industries (Procedural, Inc. 2011). This tool also provides a limited interface for editing the regulation parameters without any analysis features.

Project Galileo, created by Autodesk, is a planning tool for creating 3D city models with civil, geospatial, and building data. For now only a test version is available (Autodesk, Inc. 2011). This tool has an interface for the energy consumption analysis of urban developments. Project Galileo models can be presented with rendering images and movies also. Various file formats can be imported and exported for ArcGIS, AutoCAD Civil 3D, Revit, Project Vasari, and etc., but further research on the parametric modeling features and the programming interface are required.

In sum, the above programs have a limited feature for the parametric modeling and programming interface. The feature for responding to the planning regulations is also limited in these programs, whereas they provide for robust and quick visualization (Jorge Gil et al. 2010); therefore, there is a significant need for the new urban design platform that would enables policy makers to analyze regulations’ consequences and users to interpret regulations more easily.

The Capability of Parametric Modeling in BIM

Parametric modeling is one of the main features of BIM that has been widely used in AEC industry, and has a potential to support implementation of FBCs. With the parametric modeling approach, objects can express geometry through formulas. By storing the object information as parameters, elements of objects may be regenerated according to any parametric values (Eastman et al. 2008; Smith 2009). As such, parametric modeling offers a degree of flexibility that is constantly responsive to change. Whenever users control any parameters of an object, they can test multiple scenarios, check the building geometry and urban morphology, and analyze the results of each scenario. These capabilities of parametric modeling can ease the complexity of the urban design process. We applied parametric modeling to FBCs components and tested its’ capability to express aspects of the FBC. To do so, we used Revit Architecture (Autodesk, 2010) and the Application Programming Interface (API) of Revit to incorporate Object-Oriented Programming in C#.

Test Case: FBCs of Farmers Branch

We conducted a test case of the FBCs of Farmers Branch, which is located north of Dallas, Texas. Since the extension plan of the Dallas Area Rapid Transit (DART) included a station in Farmers Branch, the city has created the conceptual master plan, land use, and the FBCs. The FBCs focus on the physical form to produce safe and attractive station areas. Most of the FBCs regulations define the geometry and design style of buildings and open space around the DART station.

The city provides two different Regulating Plans, which
allow a wider range of design options. However, the components and standards follow the typical structure of other FBCs. The components in the Farmers Branch FBCs are as follows (The City of Farmers Branch, 2007):

- **The Regulating Plan**: Identify a project boundary and allowed building envelope and streetscape standards
- **Streetscape Standards**: Identify typical configuration for streets for both vehicle lane and pedestrians.
- **Building Envelope Standards**: Govern public and private space through three dimensional building placement and building elements, such as storefronts, balconies, and street walls.
- **Architectural Standards**: Govern coherent architectural character for the locality, such as materials, configurations, and construction types.
- **Administration**: Describe intention of Codes and set forth the provisions.
- **Definitions**: Describe specific meaning of terms in the FBC

### Process and Findings

Before proceeding with BIM and parametric modeling, we needed to define the required parameters from FBCs standards, and identify the association among parameters. The Farmers Branch FBCs have two Regulating Plans, five Street types, and six types of Building Envelope Standards. Table 1 is a part of standards. Most of the parameters that deal with three dimensional building geometries are defined in the Building Envelope Standards.

We analyzed all FBCs components to locate the association among parameters. As shown in Table 1, the parking structure height is related with the principal building height. The Open Area ratio is defined by the Total Buildable Area. Our concern was how to access all associated parameters within differing FBCs components, and how to control dispersed parameters together.

To do so, we tested the parametric modeling capability in BIM. We created Revit family models for Building Envelope Standards and Streetscape Standards, and then made a Revit project for the Regulating Plan. Figure 2 and 3 show the test case that shows two different Building Standards. In family models, type parameters for number, length, area, and ratio are added. As we discussed, the associated parameters are linked by using formulas.

Also we investigated methods to overlay all components to the Regulating Plan. We selected a block near the DART station that has two properties. The topological information was obtained after we simplified unnecessary segments to reduce the number of lines and nodes. Based on GIS parcel data and the Regulating Map, we built a base plan that shows property lines, setback lines, the Required Building Line (RBL), and the First Ground Required Building Line (FGRBL).

The selected two properties have two Building Envelope Standards, so two families were imported after we changed parametric values in the family edit interface. Once family models are inserted in the project file, we could add floors that show total floor area and ground floor area (Figure 3). In addition, we could insert building components including walls, windows, doors, and roofs, which have a potential for supporting the Architectural Standards.

Our major finding is that parametric modeling in BIM can be used to support some aspects of FBCs. Our BIM model and applications enable users to access regulation database, modify parametric values in FBCs standards, overlay these standards to each property, and analyze developable capacity immediately. These features of parametric modeling can assist decision making processes for both planners and designers.

This project demonstrates a part of FBCs that deals with geometrical requirements. However, Architectural and Urban Design standards of Farmers Branch include many other requirements that deal with the local tradition, design style, and place making. With only urban geometries and building typologies, the quality of the public realm cannot be accomplished, so further research is required for the new parametric regulating modeling that holds both geometrical and non-geometrical information.
We create Revit family models for Building making a Revit project for the Regulating Plan. To do so, we tested the parametric modeling capability in and how to control dispersed parameters together. Associated parameters within differing FBCs components, Total Buildable Area. Our concern was how to access all Envelope Standards and Streetscape Standards, and then building height. The Open Area ratio is defined by the parking structure height is related with the principal character for the locality, such as materials, urban design standards of Farmers Branch include many geometrical requirements. However, Architectural and other requirements that deal with the local tradition, for both planners and designers.

Before proceeding with BIM and parametric modeling, we analyzed all FBCs components to locate the development capacity immediately. These features of parametric modeling can assist decision making processes and findings. As shown in Table 1, the association among parameters. As shown in Table 1, the association among parameters.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Height</td>
<td>Principal Building</td>
<td>4 stories (min) 10 stories (max)</td>
</tr>
<tr>
<td></td>
<td>Parking Structure</td>
<td>Lower than principal building’s eave or parapet height</td>
</tr>
<tr>
<td></td>
<td>Ground Story</td>
<td>25 ft. (max)</td>
</tr>
<tr>
<td></td>
<td>Ground Story Interior</td>
<td>15 ft. (min)</td>
</tr>
<tr>
<td></td>
<td>Upper Story</td>
<td>14 ft. (max)</td>
</tr>
<tr>
<td></td>
<td>Mezzanines</td>
<td>13 ft. (min)</td>
</tr>
<tr>
<td></td>
<td>Street Wall</td>
<td>Locate GFRBL if wall height is between 6 and 18 ft.</td>
</tr>
<tr>
<td>Siting</td>
<td>Regulating Building Line (RBL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Required Building Line Ground</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Floor Façade (GFRBL)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Building Front Façade on RBL / or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ground Story Unit Frontage Widths</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rear Lot Line Setback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side Lot Setback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parking Setback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buildable Area</td>
<td>Within RBL, GFRBL, and setbacks.</td>
</tr>
<tr>
<td></td>
<td>Open Area</td>
<td>15% of the total Buildable Area (min)</td>
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<tr>
<td></td>
<td>Garage Entries / Driveways</td>
<td>75 ft. from corner or other garage entry (min)</td>
</tr>
<tr>
<td></td>
<td>Garage Entries Height</td>
<td>Height 16 ft. (max), width 24 ft. (max)</td>
</tr>
<tr>
<td></td>
<td>Vehicle Parking Areas</td>
<td>Behind the Parking Setback Line</td>
</tr>
<tr>
<td></td>
<td>Vehicle Parking Areas</td>
<td>Behind the Parking Setback Line</td>
</tr>
<tr>
<td>Elements</td>
<td>Fenestration Area (Ground Floor)</td>
<td>60% (min) 90% (max)</td>
</tr>
<tr>
<td></td>
<td>Fenestration Area (Upper Story)</td>
<td>30% (min) 70% (max)</td>
</tr>
<tr>
<td></td>
<td>Building Projections</td>
<td>Beyond RBL (except overhanging eaves, balconies, bay windows, and awnings)</td>
</tr>
<tr>
<td></td>
<td>Entry Door Intervals along Ground</td>
<td>60 ft. (max)</td>
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<tr>
<td></td>
<td>Story Facades</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colonnades Clear Height</td>
<td>15 ft. (min) from interior floor to ceiling</td>
</tr>
<tr>
<td></td>
<td>Colonnades Opening Height</td>
<td>13 ft. (min) from ground to beam</td>
</tr>
<tr>
<td>Street Types</td>
<td>Street space (width)</td>
<td>88 ft. (min) 120 ft. (max)</td>
</tr>
<tr>
<td></td>
<td>Sidewalks</td>
<td>6 ft. (min)</td>
</tr>
<tr>
<td></td>
<td>Median &amp; Tree Planting Strip</td>
<td>14 ft.</td>
</tr>
<tr>
<td></td>
<td>Travel Lanes</td>
<td>4 x 11 ft.</td>
</tr>
<tr>
<td></td>
<td>Dedicated Parking Lanes</td>
<td>11 ft.</td>
</tr>
<tr>
<td></td>
<td>Pedestrian Crossing Distance</td>
<td>63 ft.</td>
</tr>
</tbody>
</table>

*Table 1. Parameters of the Building Envelope and the Street Type Standards. A summary of Shopfront Colonnade Site and Colonnade Street adapted from the Farmers Branch FBCs*
Conclusion

This project shows the potential to facilitate the integration of parametric techniques and FBCs. We project that in the future people can use parametric modeling to condense complex FBCs information into the solutions, conduct real-time data analysis, and represent highly differentiated urban patterns in accordance with regulation alternatives. As a decision-support tool, the parametric FBCs enable stakeholders to overlay each component, interpret regulations, as well as analyze and determine the consequences of alternatives. As a data exchange model, the parametric FBCs enable the invention of an urban design platform. The optimized data exchange platform can allow stakeholders to communicate each other in the BIM environment, which can change the traditional and chronological work flow in urban design domain. By using the same platform as the architects and engineers will use in later stages of the design process, an FBC expressed through BIM may be better integrated into the life cycle of the building.

Reference


Figure 1. (above) The Parametric FBCs model includes two family models for representing two Building Envelope Standards.

Figure 3. (below) In the BIM environment, parameters can be added and the associated parameters can be linked with formulas. In addition, total floor area or buildable area can be obtained.


Parametric Modeling of Informal Settlements

Duygu Yenerim, Mark J. Clayton, Glen Mills

Texas A&M University (TAMU), Texas A&M University South Africa (TAMU)

Informal settlements consisting of substandard housing that lack adequate infrastructure, sanitation, living space and security, are one of the major challenges for developing cities in terms of their unpredictable growth. The colonias are informal settlements that originated in substandard housing development in the U.S. along the Mexico border. As informal settlements grow and transform into formal communities, their potential impacts upon energy consumption and economic development can be very high. This study proposes a method by using Building Information Modeling (BIM) parametric tool to develop a database of informal houses in the colonias that would assist the planning of development and upgrades.

This report describes initial efforts in modeling buildings in informal settlements and our explorations in how to use the models to support improved development by providing four analyses through BIM: (1) solar, (2) energy use, (3) cost, and (4) total cost of ownership. Our results suggest that BIM tools can enable rapid creation of extensive models of informal settlements, aiding in the calculation of energy use, carbon footprints, and economic value of communities. Engagement of students in modeling informal communities helps address NAAB Student Performance Criteria (SPC) “Sustainability” (B.3.), “Financial Considerations” (B.7.) and “Community and Social Responsibility” (C.9.).
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Duygu Yenerim1, Mark J. Clayton1, Glen Mills2

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1. Introduction: Challenges in the *Colonias* Informal Houses

Informal settlements, defined as substandard housing that lack adequate infrastructure, sanitation, living space and security, are one of the major challenges for developing cities in terms of their unpredictable growth according to the United Nations Human Settlements Programme (UN-Habitat 2003). The *colonias* are informal settlements that originated in substandard housing development north of the U.S.-Mexico border. The term “*colonia*” is originally a Spanish word which refers to “a community or neighborhood” (Texas Secretary of State [SOS] 2011) and to “any identifiable community” along the border (United States Department of Housing and Urban Development [HUD] 2003).¹ Colonia residents often suffer from unhealthy living conditions. We chose to study the *colonias* because they share many of the same characteristics as informal settlements in other nations, but, as they are in the United States, the political climate is stable. Thus our focus can be more purely on architectural issues. In addition, our college has an involvement of nearly twenty years providing service and conducting research in the *colonias*.

The shared characteristics of *colonia* houses in Texas are listed below:

- “Unincorporated and fall within the domain of county government; only a few are incorporated towns and cities” (Donelson and Esparza 2010),
- Located on larger lots with a low population,
- Mixture of trailer and self-built houses,
- Built using improper and “non-permanent” materials without insulation (UN-Habitat 2003; HUD 2003),
- Lacking access to services such as running water, sewage system, public safety, and a proper electricity installation, along with poverty of residents,
- Attached water tanks on many units,

These are concerns not only for the residents, but for city service providers, government organizations or philanthropes who wish to improve the often deplorable living conditions. Figure 1 illustrates the many factors that make up the context for informal settlements. Poverty, migration, and lack of access to legal, adequate, affordable housing lead people to choose informal settlements. Economic pressures, legal and political

![Figure 1: Complexity map of informal settlement development and upgrading interventions.](image-url)
neglect, often environmental degradation and the creation of equity by the inhabitants contribute to the continuation of informal settlements. Government responses to colonias have tended to be neglect that leads to continued growth of the informal settlements; clearance and displacement of the inhabitants; or the more enlightened approach of aids to self-help and formalization.

This research assumes that residents of informal settlements should participate in upgrading interventions in an active way. Therefore, we accept and hope to facilitate a participatory self-help upgrading approach to improve the housing and living conditions in the colonias. This approach embraces the collaboration among settlement stakeholders: city and county officials, service providers, sponsors, architects, planners, engineers, sociologists, health and human scientists, and informal settlement residents.

![Figure 2: A Matrix of Information provided by GIS and BIM.](image)

Lack of information on individual houses limits the ability to form a meaningful collaboration among these diverse stakeholders (HUD 2003). The available data on the colonias is limited to Geographical Information Systems (GIS) maps. The Colonias Monitoring Program developed a GIS map that accommodates several data layers: “[1] transportation routes, [2] digital orthophoto quadrangles, [3] digital raster graphics of Landsat imagery, [4] colonia boundaries, [5] hydrography, [6] demographics, and [7] geographic names” (HUD 2003). However, the available information through GIS covers social, economic and physical data on a broader scale and this database is used for broad-decision-making regarding the intervention (Abbott 2002a; 2002b; Lo and Yeung 2007; McCall 2003; Olowu 2003; Sliuzas 2003). The challenge is the lack of comprehensive information on design patterns, materials, construction, and parameters of individual informal houses (Figure 2).

The second challenge is that as informal settlements grow and transform into formal communities, the potential impacts upon energy consumption and economic development can be enormous. In communities that currently have no water, sewage, or power systems, the carbon footprint is very small. As these communities are brought up to cultural norms of habitation, the carbon footprint will necessarily increase greatly.

To address these issues, we used Building Information Modeling (BIM) to document buildings in informal settlements. The BIM provides us with quantity surveys, energy audits, and other models of performance that can help us gain a better understanding of both the individual houses and the wider community.

To sum up, the objective of this study is to create a method to develop a database of houses in the colonias that would assist the community planning, and design of upgrades. The database focuses on four kinds of information: (1) solar, (2) energy uses, (3) cost, and (4) total cost of ownership. Our two research questions are:

1. Can the use of BIM speed the modeling of houses so that it is practical to model entire communities?
2. Can BIM’s of the houses support these kinds of analyses?

The significance of developing such a database is (a) to assess the current energy and solar performance of houses, and the cost and value of each individual houses, (b) to establish a ground for improved design assistance in the formal community building process, and (c) to manage collaboration by relevant stakeholders to improve the communities.
2. The Possible Contributions of BIM Parametric Modeling in Informal Settlements

The exploration of application of BIM tools in the informal settlement upgrading process is important in three ways. It allows architects (1) to document and collect large amounts of data on both existing and newly designed individual buildings and share that data with stakeholders, (2) to make decisions through integrating accessibility, sustainability, site design, security, environmental systems and structural systems, and (3) to communicate with each other by using the database of BIM (Figure 3).

Figure 3: Upgrading Implementation Process.

First, using BIM is an accurate way of documenting and collecting large amounts of data on individual informal houses to relevant stakeholders. BIM is defined as “an instance of populated data model of buildings that contains multi-disciplinary data specific to a particular building [through its lifecycle.]” (Bazjanac 2007). The National Building Information Modeling Simulation (NBIMS) committee configures BIM as embedded eight data sets: (1) designer data, (2) legal data, (3) geospatial data, (4) financial data, (5) specifier data, (6) environmentalist data, (7) sustainers data, and (8) owner/occupier data (Eastman et. al 2008). Therefore, 3D information models in BIM would constitute extensive information on each building that is currently lacking for informal settlements.

Second, since a 3D building information model can include detailed information on design patterns, elements, construction, costs and carbon emission of buildings, it enables project stakeholders to better comprehend the development process and communicate with each other (Eastman et. al 2008; Krygiel and Nies 2008). Therefore, established communication between stakeholders allows for more intelligent decision making for design improvements as informal houses are transformed into formal ones.

BIM software also provides unprecedented tools for speeding the documentation process. Parametricism is a recent advanced technique in architectural design and implementation. The idea of parametric design is to use constraints and systematic variations to explore design ideas and seek solutions with higher performance. In our application, we can use parametric design not only to model options for remodeling a particular house, but also to model very quickly many existing houses of similar type. Furthermore, BIM allows us to develop a specific library of components to the colonia houses (floors, walls, ceilings, windows, doors, and roofs) that can be reused when modeling additional houses. Our use of parametric modeling techniques provided by BIM software enables us rapidly to create 3D digital models of many houses within entire community.

Using BIM tool in informal settlements can be recognized as an important catalyst for triggering comprehensive thinking in architecture through integrating several design concerns such as: accessibility, sustainability, energy efficiency, site design, environmental systems and structural systems, improving quality of life and upgrading houses. Furthermore, this particular application in informal settlements will address NAAB Student Performance Criteria (SPC) “C.9. Community and Social Responsibility” and “B.7. Financial Considerations” as well as the more obvious impact upon “B.3. Sustainability” (NAAB 2010).

3. Methodology: BIM Parametric Modeling of Four Houses

Our aim was to develop a method that could be used to quickly model individual houses and provide information on energy performance and cost. We used Autodesk Revit 2011; we developed a library consisting of the materials frequently used in the colonia houses, and added cost parameters to each component (Figure 4).
4. Four Data Analysis Methods

The aim of performing ‘solar analysis’ is to provide information to stakeholders who take a part in upgrading interventions. The solar analysis can advise colonia residents on how to design their houses in a more efficient way due to the climate in Laredo. After the solar analyses of four houses, residents would have an understanding on the proper orientation of the houses and the location and number of windows and doors on the façade.

‘Energy analysis’ is one of the major factors in sustainability. Using energy simulation, we assess the current situation and explore the situation after transforming these substandard homes into houses that meet standards. We performed energy analysis for the four houses by using Home Energy Efficient Design (HEED) which refers to Standard 90.1 document of ASHRAE. HEED provides information on savings in energy, carbon emission, and money according to the change in design of houses, materials, and orientation. Basically, by running HEED for each house, we calculated the energy consumption of (a) the existing house, (b) what if it improved to barely meet the Energy Code (Option 01), and (c) what if it were designed more energy efficiently (Option 02).

In colonias, along with other informal settlements, ‘cost’ of houses can inform residents of the equity of their investments, and also inform the municipal government, city service providers, state and federal agencies, lenders, and insurance companies. To address this need, we developed a method which not only makes the ‘total cost of ownership’ available, but also underlines the cost of specific components of the houses. We created ten schedules by referring to the Building Information Model as expressed in Revit for each house: (1) foundation, (2) site, (4) floor, (5) interior/exterior walls (including the frame), (6) windows, (7) doors, (8) ceilings, (9) roofs (including the frame), (8) mechanical appliance, (9) electrical appliance, and (10) specialties. We referred to the construction and material information, plans and several aerial images of these four houses in colonias.
(Reimers-Arias 2009). Cost per square feet and cost per unit of materials were obtained from the most quoted and recent source entitled “RSMeans Residential Cost Data”(2011).

5. Findings and Discussion

(1) Solar analysis by using BIM began with establishing the location of the houses which is Laredo, Texas and BIM provided the actual latitude and longitude of the houses according to the determined date.

![Figure 5](image)

*Figure 5: Rotation of the House No.4 model according to the declination angle from the magnetic north.*

In order to calculate the declination from the magnetic north, we referred to the National Geophysical Data Center (NGDC 2011). Declination angle Laredo, Texas is around 5° 30’ degrees east of south (NGDC 2011). We rotated our models up to 5° 30’ (Figure 5).

This is an important concern while not only constructing new houses, but also adding rooms and openings. For each of the houses, solar analysis was performed according to winter (December 21st, 2010) and summer (June 21st, 2010) solstice (Figure 6).

The results for solar analyses show that windows in smaller sizes are mostly preferred in all four houses In House No. 1 and 3, the longer sides of houses are oriented on East-West direction whereas House No.4 is on North-South axis. House No. 1 has smaller window openings on the East façade and none on the West façade. House No. 3 which has a one storey rectangular form, has fewer openings on South and North façade as House No. 4. However, House No.2 which has a square form, has similar number and sizes of openings on each façade.

![Figure 6](image)

*Figure 6: Shadows according to winter (left) and summer solstice (right).*

Shading devices appear poorly considered on all houses. In this hot climate, shading the windows from direct sun is a key energy efficiency feature.

As a result of solar analysis, it is possible to provide recommendations on location and size of openings, and appropriate orientation of the houses according to their building forms. As additions and modifications are constructed, owners can use this knowledge to make better choices.

(2) The results for energy analysis for each house show...
explicitly the impact of factors such as material choice, orientation, housing layout and number of storeys, and area of houses on the energy consumption and carbon emission (Table 1 and Figure 7).

**Table 1:** Energy analyses for each existing houses and their design options 1, and 2.

An important assumption in the analysis is that the houses would be air conditioned. This may not be true, as energy supplies in the *colonias* may not allow for air conditioning. If the houses are not air conditioned, energy consumption could be much lower than calculated but the uncomfortable time period could be much greater.

**Figure 7:** Energy analyses for each existing houses and their design options 1, and 2.

The reason for the observed difference in saving ratio is due to the choice of wall material, orientation, and the location of openings. According to Table 1 and Figure 7, House No. 1 is indisputably the most energy efficient whereas House No. 4 is the least energy efficient one.

The most recognizable difference between House No. 1 and 4 is the choice of wall material and the orientation since they are both in linear shape and have two storeys (Figure 8).

**Figure 8:** The orientation of Houses No 1 and 4.
In House No. 1, 2 and 3, wood studs were used as the wall frame and plaster board in interior; the only difference is the exterior covering which affects the energy consumption rates. Houses No. 2 and 3 were coated by wood siding whereas House No. 1 was covered by stucco. However, in House No. 4, concrete block was used as the wall material on the first floor whereas on the second floor wood studs were used as the wall frame.

We concluded that if these houses were upgraded to barely meet Energy Code, in some cases, they may save energy, carbon emission and money but in some others, they may not. Therefore, it is important to develop a database that allows us to compare two or more design options on what their energy consumption would be. The database would allow stakeholders to perform a better implementation.

(3) By referring to the capability of BIM which is to count each component according to area or materials, we could perform cost estimation. The cost of each component separately was calculated (Table 2).

Table 2: Cost Analyses of four houses.

(4) In total cost ownership analysis, since we do not have information about the cost of land and who owns the land, we only calculated the total cost of the buildings (Table 3). Residents can use this information while applying for mortgage financing. Costs should not be used as precise amounts. They are intended to be rough.
estimates that serve as the basis for comparison among the various houses.

### Table 3: Total Cost Ownership Analyses of four houses

<table>
<thead>
<tr>
<th>HOUSE NO.1</th>
<th>Material</th>
<th>Cost per sqt/each</th>
<th>Total Cost</th>
<th>Material</th>
<th>Cost per sqt/each</th>
<th>Total Cost</th>
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The experience modeling four houses provided a sense of how long it would take a moderately skilled user to model a single house. We estimate that it would take an average of two hours to model each house and perform simulation analyses.

### 6. Conclusion

This paper describes our motives and tests our method by modeling four colonia houses. Using BIM, we analyzed the housing forms, orientations, materials, and energy systems of houses and generated a database. The models of the houses are easy to understand and accessible to the various stakeholders. Furthermore, the process has been routinized so that it is quick and easy to perform. We believe that an entire community could be modeled with a modest amount of effort.

The outcomes of this study are the BIM parametric models of four houses in the colonias, Texas and their solar, energy use, and cost analysis. Solar analysis and energy use analysis are complementary to each other.

The contribution to knowledge of the study comes from development of a database on individual houses as opposed to the existing databases provided by GIS. The main difference comes from our use of a BIM tool that brings comprehensive information on design patterns, materials, construction, energy efficiency and parameters of individual informal houses. We have shown that modeling houses in informal settlements using BIM can collect and document large amounts of information, and furthermore be used for useful analyses.

Our future scope is to build a database of selected houses from different colonias in South Texas. Not only this database would pave the way for the upgrading implementations of the existing houses in the colonias, but it would guide residents on how to build properly for their new constructions. Furthermore the database would allow stakeholders to collaborate in the decisions. For policy makers, the database could allow development of estimations of energy use, replacement cost, and value for entire communities, both at the present and in the future as these communities grow and change.

### Endnotes

1 There are different definitions for the term colonia. According to Texas Secretary of State (2011), the variety in definition reflects the characteristics of colonia in terms of their type of agency and government code. Moreover, there are five different definitions for a “Border County” (SOS 2011).

2 Additionally, government agencies, state organizations and other sources provided knowledge on the Colonias informal settlements and settlers: U.S. Department of Housing and Urban Development (HUD), U.S. Department of Agriculture-Rural Development (USDA-RD), U.S. Environmental Protection Agency (EPA), Texas Water Development Board (TWDB), Economically Distressed Areas Program (EPAD), Texas Department of Housing and Community Affairs and also Texas A&M University Center for Housing and Urban Development (CHUD).

3 We will use Vasari instead of HEED in our future studies for heat analysis.
References


Modeling Building Information in a Parametric Environment

Kene Meniru

1Community College of Baltimore County (CCBC), ilom.org.

The building design stage starts with an early effort by the architect to create a sketch which embodies the fundamental building knowledge that forms the basis for all later work. This knowledge is mostly lost in current building design practice procedures where the sketch is reduced to individual building components such as walls, floors, etc. By the time the building is constructed, new efforts have to be made to document information about the building necessary to control and maintain it during operation. This paper represents the next step to a Ph.D. study that describes the early building process and important features to support. It presents a sample design session from the study and based on observations from this session, it identifies and describes important digital objects that can be used to capture building knowledge in the sketch.

Introduction

Design begins at an early stage when the design problem is still unclear. Graphic symbols are used to both understand and investigate possible solutions and the symbols are often incomplete in both form and meaning. At the end of the early design stage the designer arrives at a configuration of building parts that functionally and
aesthetically satisfies the requirements of the overall building problem which is typically called a sketch.

Much building knowledge is utilized to arrive at a sketch even though certain issues cannot be fully considered that involve dimensions and other specifics. These are largely resolved in later design in which scales and more standardized symbols are used to evolve the sketch into a proposal.

In a typical design process the transition from sketch to proposal involves some loss in knowledge. For example as spaces are turned into a collection of wall components there is little knowledge of the spatial relationships that were considered in creating the spaces. By the time the building is constructed a substantial amount of such building knowledge about the building cannot be retrieved.

Background

There are some solutions that capture building knowledge at the early design stage such as (Leclercq, 2001) however the issue of using this knowledge in work beyond the design phase is not addressed. This paper draws from a Ph.D. study (Meniru, 2005), (Meniru, 2010) which provides a clear description of the early building design process and lists features that are important to be supported in a digital tool (Meniru et al, 2003). Eight designers’ early design processes were studied using the method of protocol analysis.

This paper takes the next step in this Ph.D. work by identifying objects needed in a digital environment that will capture the building knowledge created in the early design process.

Method

To put the goal of this paper in context a presentation of an early design session from the Ph.D. study is provided from where observations are drawn concerning the actions of the designer.

Based on these observations, the rest of the paper identifies and describes digital objects and features/capabilities to capture the building knowledge embedded in the design session.

Our description of support for the design process addresses SPC B.6 i.e. understanding of the interdependency between various elements of a building assembly and SPC A.2 i.e. simplification of construction coordination and opening up “What if...” speculative exploration that allow for broader questioning of design intent and possibilities.

Early Design through Protocol Analysis

The following report contains some of the designer’s descriptions using the think-aloud method. The researcher is describing the actions with references to the images. Not all of the transcribed work is provided.

The designer reads the requirements carefully underlining parts of it. The designer traces the site and marks off the setbacks in Figure 1 at A. In addition, the north-direction was determined and illustrated clearly at B. "When you design the first stage of a project the scale is very important because you have no architectural party [team ?], so you must work at a very small scale. What is very important is to work at the same time in plan as well as in elevation and section, because you are missing opportunities". Due to the site being narrow and the requirement for a two-car garage, the designer starts by establishing the dimensions for the garages as shown in Figure 2 then working with this diagram as a template established the main entrance to the right side of the site and with a few steps rising beside the garage to meet it.

This solution does not please the designer and a second option is begun (Figure 3) where alternate garage and entrance ideas are explored at F.

This time the steps are located in the middle of the garage shown in Figure 3 at A. Designer uses a center line at C to divide the design into two parts to enable the concept of a central staircase. Soon a problem is
encountered with circulation. The designer reverts to the original idea as shown in Figure 3 at G with the stair at H. Shrubs are drawn at I as a way to access the courtyard at the back of the house. The designer uses diagram at J to think about the height difference between the garage level and the entrance level.

**Figure 1.** Sheet showing site and north-direction.
Designer continues on a new sheet to resolve the upper level bedrooms when, discovering inadequate spacing, returns to the main level to adjust the area for the kitchen in Figure 3 at M.

**Figure 2.** Establishing space for the garage.
The circulation path is shaded at K. An approximate area for the dining space is shown with a bubble at L and space for the living room is created at N.

**Figure 3.** Sheet showing configuration of spaces
The wall is slanted at O to bring in more light into the kitchen area. Furniture is placed in Q which is used to establish some scale and to work out specifics in circulation. A terrace is also created at P which leads into the courtyard at the back of the house. The designer goes on to create some elevations that help to resolve the spaces in the upper level.

The designer finally retraces the spaces in all floors, combines the plans and elevations into a 3D sketch for presentation. During this procedure it is mentioned that a CAD system would preferably be used at this stage however no details will be provided more than what has already been done. Once the general idea of the sketch is accepted by the owner, the next step will include changes and more details of the building components.

**Observations from Design Session**
The building model is created using a hierarchy of containers. Only the most important information is presented or required when the container is created. For example the site is created with a North-direction and setbacks only. We present and describe this hierarchy as well as some of the type of knowledge that is captured. Embedded knowledge in the hierarchy is parametrically modeled to apply/represent building components. The
following is a list of the rest of our observations.

1. The designer begins work by getting the important information about the site. This includes establishing the maximum available footprint for the proposed building using required setbacks for the design area. The North-direction is then established to designate the orientation on the site.

2. The designer is not interested in the detail of components at this early stage. Work begins using a metric scale of 1:100.

3. The designer needs to work using more than one type of view e.g. plan and section.

4. The designer works with lines and shapes. Lines are used to show generic information such as axis, distance, emphasis, etc. Shapes are used to show building components such as spaces, stairs, walls, etc.

5. The designer “puts” necessary details in the design as opposed to drawing them such as doors, windows, furniture, etc. Only basic information is shown such as size or swing.

6. The designer cleans up the design by retracing shapes before presenting to the client (not shown). Most of the lines are left out of this final sheet except those that are part of the shape for example the direction of travel on the stairs.

7. The designer prefers to present the final sketch as a 3D model to the client because they read better than flat drawings.

The Building Model

The following sections describe the different containers required in a building model in sequence to their hierarchy level and based on the early design session presented.

1. The Building Site

At the top of the hierarchy is the site container (Figure 4). The top of which is invisible. It must contain an orientation object and setback containers. While the orientation can be shown anywhere on the site, the setbacks are confined to set distances from the sides of the site container. Parameters for both orientation and setbacks can be set by the system through the application of requirements provided at the beginning of the early design session or manually during the session.

Figure 4. Site container showing setback containers.

The Site container is automatically created once a building project is initiated with a minimum of 3 sides. The designer then moves these sides and/or adds additional sides as required.

2. The Building Level

At the second hierarchical level is the level container (Figure 5).

It allows the designer to bring together the different systems necessary to support the activities desired by the client. Examples of systems in a building are architectural, structural, mechanical, etc. Levels are typically created when needed by the designer and are stacked one on top of the other i.e. the base of a newly created Level container partially or completely rests on the top of a previously created one.

Levels maintain a connection with each other through this contact. Apart from the elevation of the base of the level container, its borders are not configured by the designer and so are invisible. Level containers assist the designer by coordinating information amongst each or all of the different systems such as in calculating total space used or structural load.
When the site container is created, a single level container is also created by default. The base of this first level container can modify the base of the site container. Likewise the top of the last level container, when created, can modify the top of the site container.

### 3. The Building Space

At the third hierarchical level is the space container (Figure 6). The Space container is the main part of the architectural system.

Much of the knowledge in the early building design stage is used to manipulate the space container. Building spaces are areas in a building that are designated or set apart for accommodating specific types of activities desired by the occupants. Most activities supported in a residential building can be accommodated using 4 types of spaces including sleeping, living, service and traffic. Additional specialization of these spaces must be provided for example a stairwell is a special type of traffic container. These different space containers have different parameters and considerations which assist the designer in the early building design process. For example the shared boundary between a sleeping space and a service space may be flagged by the system for special treatment to reduce possible noise transmission.

Such treatment can be globally or selectively addressed by the designer. Space containers can contain other spaces as well as object containers. Object containers represent typical items found in space containers such as fixtures and furniture pieces.

When created, spaces have a top and bottom boundaries and up to three side boundaries. The top and bottom boundaries are not manipulated by the designer in terms of creation and sizing. This is managed automatically by the space as the designer creates and/or manipulates the sides.

In order to provide appropriate seclusion for activities within spaces, the designer can use two types of side boundaries called solid and open boundaries. The bottom of spaces can only be of the solid type but the top and sides can be either solid or open. A solid border provides a visible barrier that can, depending on its configuration, separate the space from other adjacent spaces. An open border has an invisible barrier which increases access into the space. A third type of side boundary called a share-side (Figure 7) is also available which makes it possible to designate a boundary that is being shared by two spaces.

A share-side can only be placed on an already existing solid or open side. It establishes a communication path between the two spaces involved.

When created, all space containers must have an area
that is fully described i.e. the space must be enclosed by a combination of solid and open sides. When two spaces share a boundary, a share-side is created automatically along the common area.

The share-side also makes it possible for the part of the side facing each space to be treated appropriately to seclude the activities as required.

Other parts of a space such as openings, windows, doors, furniture, etc. are called object containers. Each embodies specific knowledge applicable to it for example a window has a sill, a lintel and a hole.

4. The Building Form

The building form is the digital component for describing the physical shape or property of the building.

Forms are containers prefilled with specific building material properties which are then used in different sizes and combinations for prebuilt components or directly by the designer in the design process.

Several form containers can be combined for example to create the solid side of space containers as wall assemblies (Figure 8). Forms can also be used to describe holes for example in an object container like a window.

Using Digital Objects in a Design Session

This section describes the use of a building information modeling tool with the capabilities described in the preceding sections in an early design session. The sequence of this description will follow the observations listed.

Early Design:
1. When the system is started the site container is created by default. The designer provides the number, length and angle of the sides. Each side has a setback container attached by default. The designer enters the distance of each setback on the corresponding side of the site container. The site container also has an orientation object by default so the designer sets the degree for the north-direction. This establishes the available footprint and orientation for the proposed building.
2. The tool uses a 1:1 scale. The zoom factor can be used to reduce the size of the drawing area.
3. All spaces are volumes. Orthographic views are available so the designer can work as desired.
4. Lines are like strokes and do not represent building components. The distance and angle a stroke represents can be shown. Different stroke sizes are available for visual impressions such as emphasis. Spaces are initially created with single lines as borders. The designer is free to add
more sides with desired changes to angle of inclination as well as length.

5. Object containers can be placed in the desired locations of the space. All objects have defaults settings so distractions are kept at a minimum. For example when placed in a space, a window object attaches itself to the nearest location on a wall and only requires the designer to establish its length.

6. All lines (strokes) can be cleaned automatically from the design when the sketch is complete as they are not part of the building. At the end of the sketch, all boundaries for spaces automatically change to reflect a default width. Share-sides automatically adjust shared boundaries accordingly showing a single width for any two touching sides from different spaces. Very little additional work is required of the designer in this step.

7. All containers are already 3D building components so no additional work is required in this step. Analysis can be performed to ascertain that the spaces are appropriate. For example sun path studies can be performed as the space containers combine inherited North-direction (site container) and size of openings (object containers in their sides).

Detail Design:
Work required in this stage is mostly focused on adjusting parameters for containers and the addition and configuration of building forms for construction documentation. For example you may have a complex combination of finishes for the side of a space container. Building forms of the required finish material may be added and sized as desired to the sides.

Construction Documentation:
Section planes are established and construction documents extracted.

Facility Management:
All knowledge accumulated so far remains available for controlling and managing the building. Materials used in the construction are those specified in the building forms. Sizes for repairs as well as maintenance due dates can be queried.

Conclusion
As a next step to a Ph.D. research, we made some observations about a designer’s actions in a sample design session which show that designers create building parts that relate hierarchically. We then identified and described four digital objects with capabilities/features that can be used to capture building knowledge from the session. Finally, we described the use of the objects in the context of the design session to show how building information can be modeled in a computer environment with the knowledge from the early design stage accessible all through the phases of AEC/FM.

References


Parametric Modeling and BIM: Innovative Design Education for Integrated Building Practices

James Haliburton, AIA LEED AP\(^1\), Mark Clayton, PhD\(^2\), Ozan Ozener, PhD\(^3\), Francisco Farias\(^4\), WoonSeong Jeong\(^5\)

\(^1\)Prairie View A&M University, \(^2\)Texas A&M University, \(^3\)Istanbul Technical University, \(^4\),\(^5\)Texas A&M University

Abstract

Parametric modeling and Building Information Modeling (BIM) present opportunities to radically change the architectural design process, which has similarly radical implications upon design education. These processes and technologies are demanding a broader knowledge base and deeper skill set. The same technologies and processes create opportunities to meet and surpass the traditional architectural knowledge base that forms the basis for design education. Outlined in this paper are the results of three studies that employed BIM and parametric modeling within the context of simulated professional project delivery and compares the results using the new process to the NAAB Student Performance Criteria. From these studies, it appears that the alternative design method that employs BIM and parametric modeling is more rigorous and effective than the traditional method of instructing students with respect to the Student Performance Criteria in Realm B: Integrated Building Practices.
Introduction

Parametric modeling and Building Information Modeling (BIM) present opportunities to radically change the architectural design process, which has similarly radical implications upon design education and the way architectural design is taught (Ambrose 2007). Parametric modeling and BIM are demanding a broader knowledge base and deeper skill set. At the same time, Parametric Modeling and BIM create opportunities to meet and surpass the traditional architectural knowledge base that forms the basis for design education (Clayton 2006). Effective use of BIM software for an architectural design requires the integration of multiple knowledge bases yet facilitates the integration of those knowledge bases. In this sense Parametric Modeling and BIM lead to a heightened, intensified design process that nevertheless addresses the essential objectives of sophisticated problem solving around integration of many functions and factors.

Recognizing the importance of the simultaneous development of multiple individual understandings and abilities, in 2009 the National Architectural Accrediting Board (NAAB) issued the Conditions for Accreditation (NAAB 2009). Included in these conditions are a distinct set of Student Performance Criteria (SPC). The SPC state that the architecture student of today is expected to clearly demonstrate both understanding and ability within multiple different aspects of architectural knowledge. Additionally, the SPC require the student to show the ability to integrate these different aspects into a comprehensive design.

This paper makes a comparison between the results of three case studies of teaching parametric modeling and BIM to design students and Realm B of the NAAB SPC. The three case studies employed a new teaching method, called Studio 21, which contrasts with conventional teaching methods in the typical design studio (Clayton, Ozener et al. 2010). The studies demonstrate that implementing Parametric Modeling and BIM in the design studio using the Studio 21 process provides opportunity to address multiple aspects of the Student Performance Criteria. It also sets the framework for establishing BIM as a tool for both fostering Ability and generating Understanding as outlined by the NAAB.

The New Criteria

Architects are required to understand and implement a wide variety of technical, artistic, historical and even societal information as part of their professional responsibility. Supporting this supposition are the 2009 NAAB Student Performance Criteria’s three realms:

Realm A: Critical Thinking and Representation
Realm B: Integrating Building Practices, Technical Skills and Knowledge
Realm C: Leadership and Practice

Under the NAAB conditions students are required to demonstrate either Understanding or Ability of different aspects within each of these three realms. The NAAB defines Understanding as “the capacity to classify, compare, summarize, explain, and/or interpret information” and Ability as “proficiency in using specific information to accomplish a task, correctly selecting the appropriate information, and accurately applying it to the solution of a specific problem, while also distinguishing the effects of its implementation”. The SPC are very broad in their coverage and a typical curriculum relies on a multitude of courses to encompass understanding and ability within all three realms. This paper deals with Realm B: Integrating Building Practices, Technical Skills and Knowledge. Taken directly from the NAAB document Realm B is expanded:

Architects are called upon to comprehend the technical aspects of design, systems, and materials, and be able to apply that comprehension to their services. Additionally they must appreciate their role in the implementation of design decisions, and impact of such decisions on the environment. Students learning aspirations should include:

Applying principles of sustainable design.

It is clear, the amount of technical things required to be incorporated by students is immense. Practitioners know that a successful design incorporates all these things on extremely detailed levels. Doing so requires creating, keeping, integrating, and evaluating large amounts of information.

Critique of Current Practice

The traditional design studio process is limited because it assumes an outdated mode of practice, reinforces hierarchical team organization, and relies heavily on tacit knowledge (Fisher 2004). This method of workflow cannot address all the technical aspects of design project simultaneously. Students are given cursory introductions to several aspects, asked to integrate them and left to ambiguous, esoteric, and rarely constructive studio critiques as the definable measure of success. The process of design studio is as equally important as the product and the jury system loses this point along the way (Koch, Schwennsen et al. 2002). Therefore, when reviewing the understanding and abilities that students are required to demonstrate to meet the conditions of the NAAB Student Performance Criteria creating a design studio pedagogy that can address all of them seems daunting. The learning tool necessary to accomplish these goals can be found in technologies coupled with new design studio processes that mirror the emerging modes of practice these technologies support.

Outlined below are the results of three Action Research Cases done as part of an investigation spanning two schools of architecture within the Texas A&M University System. The goal of the research was to investigate a new method of studio education centered around emerging modes of Architectural practice supported by technologies: Parametric Modeling, and BIM. Parametric modeling requires defining a set of rules and relations or parameters that define and object or class rather than defining the object itself and BIM is defined as “a modeling technology and associated set of processes to produce, communicate, and analyze building models” (Eastman, Teicholz et al. 2008). These new processes led to the definition of a new studio method that has been named “Studio 21” to differentiate it from 20th century studio methods. From the study, the researchers found that changing the entrenched design studio framework was not a challenge of software or learning, but one of changing an entrenched culture of design. Once that culture was altered, students embraced a new method with the vigor and enthusiasm only students can muster (Ozener 2009).

The form of the cases was that of design courses within an architecture curriculum. The first case was undertaken as a graduate seminar in the fall of 2009. It met weekly over the course of a semester. The second case was held at a different university as a lecture/seminar course. The third case was a graduate charrette project. There were a total of 27 participants in the case studies. They included nineteen M.Arch Students, one M.S. Architecture Student, four M.S. Construction Science students, and three PhD Architecture students. The M.Arch students collaborated with consultant teams made up of all other students. All three case studies began with an intensive introduction to Parametric Modeling and BIM tools. The intensive introduction was done to establish a common base among all participants. Pre-study surveys indicated a varying range of skills with regard to BIM software and as such, the intensive introduction was to get all students to the same level or at least a close as possible.

The process required students to make a “Base Case” in which a very simple solution was modeled using Autodesk Revit Architecture. This base case was used as a benchmark for performance by running it through various analytical tools to compute energy consumption, construction cost, construction schedule and other measures. The base case provided students with a starting point for their design work, allowing them to measure changes in performance with each design iteration. Because the projects were done with BIM and employed parametrically modeled components, changes could be made easily based on strong technical data from the simulations. Because the interoperability steps were worked out in the base case, each subsequent design could be analyzed quickly and accurately using the
various analytical tools. This “base case” method became central to the Studio 21 model.

In all three studies students were given the same simple design brief; a train station on the Texas A&M University Campus in College Station, Texas. The project program was simple and straightforward: 4000SF of indoor space and an 8000SF covered platform with a budget of $2 million. The other condition was a 4 month construction time limit. The students were required to provide evidence to support design decisions and alternatives in twelve different areas:

1. Schematic alternatives illustrated with plans, elevations, and perspectives
2. Preliminary and detailed construction schedule proposals
3. Construction cost estimate
4. Structural component selection and design
5. Operating cost report
6. Energy consumption report
7. Mechanical systems integration
8. Sunlight studies and daylighting performance
9. Water balance and rain water harvesting strategies
10. LEED Silver Certification
11. Conformance with Amtrak design guidelines
12. Visual analysis to indicate sensitivity to the campus setting and design aesthetics

Making the Comparison

The results of all three case studies were similar. BIM and Parametric modeling were shown to allow for a better integration of both structural and mechanical systems. Using reliable information students were able to make micro and macro level design decisions. Using parametrically modeled components changes could be integrated and students could quickly see how those decisions impacted form and spatial considerations (Ozener 2009). While the structural systems were not avant garde in their form, they were, in most cases, respective of their context. In every case the structural system met the constraints of economy and schedule (Figure 1). This clearly shows an Understanding of Structural Systems (SPC B.9) as well as being a key component in the Ability to produce a comprehensive design (SPC B.6). Canopy structures designed by the students, on the other hand, were quite interesting and innovative (Figure 2) and showed some exploration of parametric components. This shows an Understanding of materials and assemblies (SPC B.12).

Because the main design tool was a BIM program students could generate quantity surveys that supported cost estimates from the construction consultants. Students could also get 4D construction visualizations and timelines using Microsoft Project and Autodesk Navisworks (Figure 3). This allowed students to see the cost and constructability impacts of their design decisions. BIM and parametric modeling allowed students to quickly make changes affecting the budget and
construction timeline. Students were able to get cost comparisons for eccentric forms (Figure 4). This was shown to be a valuable method of addressing issues of cost and constructability as well allowing for a frontloading of project information (Ozener, Jeong et al. 2010). This aspect of the case studies shows an understanding of Financial Considerations (SPC B.7) as well as an understanding of Building Envelope Systems (SPC B. 10).

![Image](image1.png)

**Figure 3** showing 4D scheduling and construction sequence

![Image](image2.png)

**Figure 4** showing cost breakdown for eccentric canopy form

Designing for Sustainability was also a requirement in the cases. The third case involved incorporating daylighting problems. Students produced a progression of designs and evaluated each one using Autodesk Green Building Studio (Figure 5). This allowed students to see direct performance gains and losses between each scheme. Additionally students evaluated their models using Autodesk Ecotect software, giving them another dimension of performance and usable information (Figure 6) The findings showed that while students had difficulty adopting the software and mastering the associated learning curve, the BIM models coupled with analytical evaluation and rapid feedback helped students to “understand the impact of design decisions on the daylighting and sunlight performance of the design alternatives” (Ozener, Farias et al. 2010). These portions of the case study clearly show an Ability to design an energy saving system, test it, and modify it based on received data (SPC B.3). Additionally, they show students beginning to understand Environmental Systems and Service Systems (SPC B. 8 and B. 11).

![Image](image3.png)

**Figure 5** showing iterations of shading design and energy calculations

![Image](image4.png)

**Figure 6** showing different shading options evaluated in Ecotect

Overall, the case studies produced some intriguing design
solutions (Figures 7 & 8). Each solution met the constraints of economy, aesthetics, and schedule.

![Figure 7 Final design solution](image)

Figure 7 Final design solution

![Figure 8 Final design solution](image)

Figure 8 Final design solution

Conclusions

The cases demonstrate that the Studio 21 approach can be implemented in graduate settings, by more than one instructor, and at more than one school of architecture. They further show that NAAB SPC criteria can be well met in the courses that use the Studio 21 approach. In particular, requirement B.6 Comprehensive Design lists several criteria. Our experiments addressed most of these criteria at a demonstrably high level:

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<td>B.1. Pre-design</td>
<td>Yes</td>
</tr>
<tr>
<td>B.2. Accessibility</td>
<td>Yes</td>
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<tr>
<td>B.3. Sustainability</td>
<td>Yes</td>
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</tbody>
</table>

We believe that the results of all of the courses are remarkable in the quality of designs produced, and, also significantly, the demonstrated technical excellence of solutions that were supported by simulation results. The methods used in these courses may be more comprehensive, better able to convey lessons in integration, and produce better designs than conventional methods. Students stated that the course changed their views of architectural design process. They appreciated the unique and powerful design method that they learned.

Parametric Modeling and BIM have catapulted design and design pedagogy into the twenty first century. The NAAB have recognized the challenges that face future professionals and are setting requirements that will ensure the knowledge and skills of licensed designers. Studies like the one outlined show the potential of technologies like Parametric Modeling and BIM to bridge the gap and produce Understanding and Ability within students.

As with any case study initiative these investigations raised as many questions as they answered, but they did advance the argument for BIM and Parametric Modeling in the design studio. More than this these studies elucidated the massive amounts of technical and specialized knowledge that an architectural design student is required to integrate in a typical design studio. What is required of architects will not get less, therefore it is incumbent upon educators to adopt methods and technologies that can best prepare students to deliver professional design services based on explicit analytical information. The studies outlined above illustrate the
potential of Parametric Modeling and BIM technologies to directly address requirements of the Student Performance Criteria.

References


Reconfiguring Collaboration by Computational Means

TEX-FAB: A new model for collaborative engagement
TEX-FAB: A new model for collaborative engagement

Brad Bell\textsuperscript{1}, Kevin Patrick McClellan\textsuperscript{2}, Andrew Vrana\textsuperscript{3}

\textsuperscript{1}University of Texas Arlington, \textsuperscript{2}University of Texas San Antonio, \textsuperscript{3}University of Houston

Abstract

TEX-FAB is a non-profit organization founded between three universities in Texas with the primary function of connecting design professionals, academics, and manufactures interested in digital fabrication. The three co-directors established TEX-FAB as a collective action, one that attempts to combine divergent interests and capabilities, for the purpose of strengthening the regional discourse around digital fabrication and parametric design. The three primary avenues for accomplishing this goal are set out as Theoria (Lectures / Exhibitions), Poiesis (Workshops) and Praxis (Competition). We see this type of effort as a new paradigm focused on providing a network of affiliated digital fabrication resources, and a platform for education/exchange on issues of parametric modeling. It is our position that TEX-FAB engages the new and growing awareness of a regional and global hybridization. We seek to leverage the burgeoning global knowledge base to produce a more specific and contextual dialogue within the region we operate, teach, and practice.
Introduction

TEX-FAB is a non-profit organization founded between three universities in Texas with the primary function of connecting design professionals, academics, and manufacturers interested in digital fabrication. The three co-directors established TEX-FAB as a collective action, one that endeavors to combine divergent interests and capabilities, for the purpose of strengthening the regional discourse around digital fabrication and parametric design. The three primary avenues for accomplishing this goal are set out as Theoria (Lectures / Exhibitions), Poiesis (Workshops) and Praxis (Competitions / Commissions). We see this type of effort as a new paradigm focused on providing a network of affiliated digital fabrication resources, and a platform for education and exchange on issues of parametric modeling. It is our position that TEX-FAB engages the new and growing awareness of a regional and global hybridization. We seek to leverage the burgeoning global knowledge base to produce a more specific and contextual dialogue within the region we operate, teach, and practice. We assert that TEX-FAB presents a new model for collaborative engagement through the framework of our organization. Specifically, we will use the international competition entitled REPEAT that our organization recently hosted to illustrate how collaboration is a vital tenant to the success of executing a complex full-scale installation entitled Minimal Complexity.

Organizational History

TEX-FAB was formed in 2009 by Brad Bell, Kevin Patrick McClellan, and Andrew Vrana. With professors Bell, McClellan and Vrana each teaching digital fabrication curriculum at University of Texas Arlington, University of Texas San Antonio, and University of Houston respectively, there was a pre-existing mutual interest and dialogue in place. What was evident out of these conversations was a strong awareness of similarity in situation. We all shared and were cultivating relationships with fabricators, academics, and professionals in the urban centers where we lived. We were all leveraging our universities as a bridge back into the community to strengthen ties for the purpose of applied learning opportunities for our students. We were all very interested in developing digital fabrication techniques and methods that investigated substantive and material realities. Our journey to this point was not impetuous. Our educational trajectories all started back with connections at Texas A&M twenty years prior. Over the following two decades, dialogue, and at times collaborative exploration, laid a framework that facilitated the formation of TEX-FAB.

At the core of the TEX-FAB initiative is a fundamental belief that collaborative interaction within the architectural process is no longer a choice but a necessity. Even as we look back into the nascent stages of our own education, it is clear when engaging the deep computational capacity of the digital software to explore complex geometries that relinquishing some degree of authorship is already at play. What arose from the co-authorship of the digital and fabrication toolsets we employed as students, pioneering and exploring these issues while at Columbia University and the Architectural Association in London, has now been brought even more into focus as we apply this in practice. Beyond our academic affiliations, each co-founder maintains an active practice, which serves as a venue for application of issues being researched within the academic realm. For each of the co-founders of TEX-FAB position in both the academic and professional worlds is as essential to the origins of TEX-FAB and our capacity to work together as our pre-existing working relationships.

Since the very earliest stages of putting together TEX-FAB we have pursued this as an opportunity to create a vehicle for interaction and conversation between a wide-range of designers. Within Texas there is an emerging network of companies, institutions, and individuals focusing on the exploration of parametric design and the digital production of building components. Specifically, there is a growing opportunity for collaborative exchange between the academic, technical, and professional communities by leveraging the immense resources found in some of the largest metropolitan centers across the United States.
TEX-FAB 1.0 launched initially as a website in September of 2009 and served to initiate a call to interested designers in the region. On February 4th-6th TEX-FAB hosted the first round of workshops and lectures at the University of Texas Arlington. The event was completely sold-out and drew participants from throughout Texas and the 5 contiguous states. TEX-FAB 2.0 launched in the summer of 2010 as the second round of workshops, lectures, exhibition and competition. The event was hosted at the University of Houston February 10th – 13th again with a completely sold-out round of workshops and even more ambitious lecture series and exhibition component.

Three Modalities of Interaction

TEX-FAB is organized around three primary tenants that provide specific ways in which the collection, distribution, and sharing of information about digital fabrication and parametric modeling take place: Theoria (Lectures / Exhibitions), Poiesis (Workshops) and Praxis (Competitions / Commissions). These three avenues are not unique by themselves, and are certainly found collectively in other regions. However, it is when we survey our own context and examined the unique opportunities within the Texas and Southwest Region we see TEX-FAB filling a vital role in shaping the discourse.

The lecture offerings provided or co-hosted by TEX-FAB to date have attempted to provide a broad range of exploration into digital fabrication. Lecturers are from both the academic, professional, and fabrication communities, all with significant accomplishments within the field. A select list of lecturers provided by TEX-FAB includes: Scott Marble of Marble Fairbanks / Columbia GSAPP NY; Axel Paredes of Universidad Francisco Marroquín, Guatemala; L. William Zahner, Ceo & President of ZAHNER®, Patrick Hood-Daniel; and Branko Kolarevic of University of Calgary. As well exhibitions have become a central element to our TEX-FAB event 2.0 in Houston. The current exhibition features the work of the recently completed international competition hosted by TEX-FAB entitled REPEAT. This exhibition will become a travel to a variety of locations within the region in 2011 & 2012. This will provide greater opportunity for stimulating dialogue around the issues of digital fabrication and parametric modeling.

Workshops are currently the primary avenue for education and direct interaction between academics, professionals, industry partners, students and professionals. TEX-FAB maintains a policy of reserving half of all available seats for students and at the same time aggressively pursues participants from a wide range of architecture and affiliated design offices through out the region. Workshops are two-day events led by internationally recognized instructors within the field of parametric modeling and provide a robust opportunity for participants to be exposed to the highest level of concentrated learning possible. A select list of workshop instructors and courses offered include: Rajaa Issa of McNeel & Associates: Architectural Geometry and Algorithmic Design; Andy Payne of Lift Architects: Grasshopper; Marc Fornes of theverymany: Scripted Design; Chris Lasch of Aranda / Lasch: Algorithmic Design; Gil Akos and Ronnie Parsons of Studio Mode: Parametric Design.

Competitions are the third and most far reaching of the three TEX-FAB tenants. The competition is a platform for a very diverse set of designers to explore the potential of parametric modeling. Unique to our mission however is a desire to see competitions result in a built commission – regardless of scale. So to that end, TEX-FAB sees the process of fabrication coming out of the competition to be one that can leverage the TEX-FAB network and utilize it’s inherent values to provide a robust support system for fabrication, installation, and construction. In the summer of 2010 TEX-FAB took on the ambitious task of hosting an international design competition.

REPEAT Competition

In June of 2010 the REPEAT competition launched with the explicit intent of promoting the role of digital fabrication and parametric design within the Texas region. With the organization and development of the competition brief, context and goals beginning March
2010 and the final installation planned for February of 2011, the competition cycle – start to finish – was to be one year. The deadline of October 31st, 2010 was established and promotional materials where distributed to over 200 Universities internationally and online within digital fabrication and parametric design communities. A total 95 teams of 1-4 designers from 19 states in the US, 18 countries and 5 continents registered, ultimately receiving 73 submissions.

![Figure 1. Geography of REPEAT Competition participants.](image)

The REPEAT brief asked entrants to look first at the connection and then, through repetition define of the whole. By reevaluating the design process and looking at it from the connection, what might emerge? We encouraged the generation of cutting edge design proposals for a structure with the only caveats being it be generated and conceived digitally, incorporate repetitive elements, be optimized for relocation and transportation and be produced through fabrication technologies available within Houston, Texas. These three ‘programmatic’ parameters served to be very open ended and broad, while another constraint was included that served to delimit the work, a budget. No more than $10,000 could be used in the competition proposal’s production costs. The role of Houston as context was also significant and provided the perfect backdrop for the objective put forth by the competition, as it is within cities with atomized light manufacturing capabilities like Houston, there exists a potential for designers to engage fabrication via direct communication with machines. Harnessing the network of fabricators already affiliated with TEX-FAB we established the means and methods of production for the winning entry and ensured the production and costs were fixed.

To further define the potential and enlist greater interest in REPEAT we invited five leading figures in the world of digital fabrication and parametric design to jury the competition: Patrik Schumacher (Jury Head), an internationally recognized educator, acclaimed theorist and Design Director at Zaha Hadid Architects; Marc Fornes, founder of the influential design practice *theverymany*; Lisa Iwamoto of Iwamoto + Scott, architect and author of the seminal work *Digital Fabrications: Architectural and Material Techniques*; Chris Lasch partner of the renowned experimental research studio Aranda \ Lasch; and Blair Satterfield, an educator, award-winning inventor and founder of the design collaborative Houminn.

Submitted to the competition was a rich and varied collection of proposals that explored and intently challenged preconceived notions of form, use and assembly. It can be argued that production and design have become two distinct processes in architecture since the advent of the formalized design document. It is evident within the numerous competition entries that this method is being questioned. Previously wherein the conception and production of drawings have occurred months and sometimes years before anything was realized physically, the digitally conceived work proposed in many cases was produced simultaneously along side small-scale tests and models that not merely represented the work, but instantiated it as a version - an iteration. These projects were on-the-one-hand speculations and reflections on the potential of digital fabrication and parametric design, while on-the-other hand realizations of that potential.

The success of the competition was evident in the winning entry designed by Vlad Tenu, a young Romanian architect practicing in London. His ongoing research focuses on the integration of computation, science and technology in the architectural design process, involving generative computational methods,
digital fabrication techniques and interactive design. He studied architecture in Lasi, Lisbon and in London at the Bartlett, UCL, where he was awarded a MSC. in Adaptive Architecture & Computation and a Certificate in Advanced Architectural Research.

The jury selected Minimal Complexity for the aesthetic beauty, technical superiority and elegance of detailing. It employed structural robustness, material efficiency and an inherent logic of assembly embodying the principals of the competition brief to the highest degree. While a great many of the submissions showed real promise the jury focused on a selection that was feasible by adhering to the context and budget. In keeping with the spirit of the competition intent the jury enumerated four Runners-Up and another seven Honorable Mentions that embraced the brief as is reflected in the comments by Chris Lasch for one of the Runners Up, “it uses a low tech solution to leverage high tech design thinking and does it through a clear assembly logic that seeks to combine the abstract logics of geometrical assembly with the fine grain affordances of their chosen material.”

**Minimal Complexity – Optimization and Construction**

With Minimal Complexity selected the optimization process was initiated between TEX-FAB and Vlad Tenu. One of the primary interests for the Directors of TEX-FAB in generating REPEAT was to find a collaborative partnership with a designer or design team and work through the spectrum of issues needing resolution in order to bring the design to realization. In this manner, TEX-FAB would not just serve fabrication consultant, but work closely with the winner to resolve a wide range of issues resulting ultimately in our constructing the piece.

Stage one in the optimization came though weekly teleconferences between Vlad and TEX-FAB and email communication. We also made use of an online communication and work coordination system to provide a central location for the exchange of ideas, files, technical information, scheduling, etc. This stage took approximately three weeks to complete and was an essential part of establishing a collaborative dialogue with Vlad Tenu as well as resolving issues needing clarification prior to starting fabrication. Stage two of the optimization process was to construct a ½ scale version of Minimal Complexity at the University of Texas Arlington. The goal for this phase was to understand the intricacies of the piece as well as discovering fabrication issues. Because Vlad had already constructed the scheme at a smaller scale and with range of materials, we were able to start with a very developed understanding of what was required in working with the design as proposed.

Over the course of eight days the University of Texas Arlington team was able to successfully fabricate and assemble the seven foot scaled version of Minimal Complexity (Figure 3.) With this in place the TEX-FAB
This was an invaluable step in the collaborative process because it raised a series of issues that required collective resolution. Issues like part numbering, templates for sub assemblies, bolt length and type, workflow studies, and special installation equipment needs were all resolved during this optimization process.

**Minimal Complexity – Final Construction**

After the optimization phase operations moved to Houston where final fabrication and installation would take place. The competition was predicated on the ability to utilize resource for materials and fabrication partners in the greater Houston area. To that end, very early on in the process of developing the project for construction, Crow Corporations who is a digital fabrication partner with TEX-FAB and metal fabrication company located in Houston, was brought in to help resolve technical issues for laser cutting aluminum. Once TEX-FAB, Vlad Tenu, and Crow Corporations established that 14-gauge aluminum was the desired thickness for the several thousand pieces needing to be cut the next step was to check for structural soundness of the design, material properties and connection detail. For this the Buro Happold New York office was enlisted to coordinate a detailed structural analysis (Figure 4.)

A Finite Element Analysis models was run on the geometry as both a shell and beam structure. The Global Shell Model, using iso-parametric finite shell elements, revealed to be very sound under the dead load of the piece overall.
The final structure is composed of 148 basic quad sections of the Schwarz’s P Surface with each section being made out of 16 parts resulting in 2368 total pieces. The true strength of the design is found in the simplicity of repeating the same 16 parts through out the entire surface. When each of the basic quad regions is set up for assembly, the curvature of the surface is introduced through the alignment of the 16 parts.

Based on the optimization model, the FEA analysis and the consultation with Crow and the direct communication with Vlad, TEX-FAB initiated a 2-week assembly process. Because of the limited number of unique parts, the process of assembling the basic quad regions was highly repetitive. It was determined by that creating sub assemblies out of the 16 part quads would allow for easier installation (Figure 7.) This size and division of the sub assemblies was based on how two people might be able to handle the part for installation in terms of both weight and size. Once all the sub assemblies were constructed final installation began.

TEX-FAB took control of the means and methods of final assembly by employing a series of templates, base plates, ballasts, shoring, scaffolds and hoists to manage the vertical development of this self-organizing structure. The process of building up the system up into 16 part quads led the planning and construction of larger subassemblies or sections of the structure that could be built on the ground and then positioned correctly and bolted in. The choice of 14 gauge laser cut aluminum with ¼” holes proved to be ideal for workability and joining with a variety of fasteners that served to align the parts progressively.

A pattern of tightening and loosening the fasteners at adjacent components was learned by the assembly team in order to allow for hole alignment before final bolting was accomplished. The structure’s progressive rigidity as the fasteners became fully engaged was further proof of the designer’s concept, the engineer’s FEA analysis and TEX-FAB’s expertise as fabrication and logistical
consultants. The main assembly took approximately 20 hours with a team of 3-4 members who were new to the system.

Regional and Global Coalescence

In the course of the 20 months since the establishment of the TEX-FAB and the incorporation of the *Digital Fabrication Alliance, the three outlined avenues: Theoria (Lectures / Exhibitions), Poiesis (Workshops) and Praxis (Competitions / Commissions), have all been tested and proved successful. Our growing network of collaborators within the region is reinforced to a greater degree as needs arise – creating a dynamical relationship adaptive to specific challenges. Additionally the local intelligence of our structure is extended and enhanced by a link to a broader, global, affiliation that we can call upon to a greater degree for material and technique specialization.

In the case of the REPEAT Competition, our local network partners in manufacturing, such as the Crow Corporation, enabled the completion of Minimal Complexity economically.
We foresee the inclusion and expansion of our network as an array of fabricators located in each of the urban centers that we currently operate. These fabrication partners enable our endeavor in the illustration and implementation of parametric design and digital fabrication in other cities in the state and serve as a model for how the local and regional might work together for production and fabrication purposes.

The extension beyond the Texas region into New York for the structural engineering, and ultimately the inclusion of Vlad Tenu, in London, as a catalyst for a project, in effect reinforces the porous nature of TEX-FAB. Additionally, our own tri-city base of operations for TEX-FAB joined with affiliation to three different academic institutions, provide a layer of collaborative and interconnected opportunities for the advancement of digital fabrication issues. As a platform for education and exchange, and a collaborative partner in the production of projects, TEX-FAB serves as a unique and new model for advancing issues that will only continue to transform the way we design and produce architecture.
The aim of this paper is to understand the outcomes of parametric methods in beginning design projects and their impact on rethinking digital technology in current design education. In order to realize comprehensive results, in this paper i) conceptual and formative projects are presented to describe specifications of a parametric design at OSU School of Architecture; ii) for OSU SOA, we plot pedagogical objectives and evaluate how we have interpreted and applied novel digital technology into the design process; and iii) cultivate parametric design as systemic and organizational design. Along with unit-based, component design, expand the use of digital tools to become the discipline and domain of the creative culture. How digital tools are integrated into early design education through a collaborative studio project will be the focus of the study. Through the experimental exercises, we can begin to explore how the digital process can be integrated at a fundamental level.

Initiation of Parametric Thinking in Formative Studios

As technology is constantly evolving around us, we have a unique opportunity to educate students in novel design processes. Parametric Design is transforming the design process, as a means of translating ideas between the human and the digital. In the article Design by Anne Balsamo (2009), Design as a verb refers to a set of actions: Imagining, Creating, Representing, Negotiating, Prototyping, Fabricating, Building, Evaluating.
Parametric Translations

Seung Ra¹

¹Oklahoma State University (OSU)

Abstract

The aim of this paper is to understand the outcomes of parametric methods in beginning design projects and their impact on rethinking digital technology in current design education. In order to realize comprehensive results, in this paper i) conceptual and formative projects are presented to describe specifications of a parametric design at OSU School of Architecture; ii) for OSU SOA, we plot pedagogical objectives and evaluate how we have interpreted and applied novel digital technology into the design process; and iii) Cultivate parametric design as systemic and organizational design. Along with unit-based, component design, expand the use of digital tools to become the discipline and domain of the creative culture. How digital tools are integrated into early design education through a collaborative studio project will be the focus of the study. Through the experimental exercises, we can begin to explore how the digital process can be integrated at a fundamental level.

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Iterating. The notion of design reflects the ideas and principals of the parametric thinking process. What is the specific contribution of Parametric Design in the process of making beyond the ability to simply make expressive and complex forms? The discussion continues to be challenged by the idea of digital design as a visual communication skill.

This paper positions how the perception of digital media is changed by tools like parametric modeling. In the current realm of digital technology, Parametric Design Language has become a dominant geometric expression tool as well as an efficient project delivery solution (Ceccato, 2010). It is crucial to introduce new design procedures like parametric modeling to schools which maintain a traditional approach, using the computer as little more than a drafting tool (Monedero, 2000). The National Architectural Accrediting Board (NAAB) still refers to digital design as a graphic skill:

“Realm A: Critical Thinking and Representation

A. 3. Visual Communication Skills: Ability to use appropriate representational media, such as traditional graphic and digital technology skills, to convey essential formal elements at each stage of the programming and design process (NAAB’s Student Performance Criteria).”

How can we go beyond satisfying these criteria - using digital technology as a representational tool- and begin to integrate it within the design process? The idea of parametrics lends itself to one pathway of developing ‘digital thought’ processes. Parametric, as a word, describes a boundary or variable in a functional relationship set forth to describe something. It derives from the word parameter, which in mathematics is a constant or variable term in a function that determines the specific form of the function but not its general nature, as \( a \) in \( f(x) = ax \), where \( a \) determines only the slope of the line described by \( f(x) \). With this concept of variables coming together to describe an object, we set out to investigate how this idea of variables could be multiplied to define one larger object, utilizing both digital and analog processes.

In OSU’s Introduction to Computers course, two projects were given in a series as a part of this beginning exploration: Abstract Machine (AM) and Exoskeleton Barricade (EB). This class is a required course for both Architecture and Architectural Engineering pathways, and gives students an introduction to digital tools and processes. As an introductory course, students were learning to use the digital tools while exploring the digital design process within these projects (Figure 1.).

![Figure 1. Abstract Machine_1: Using the paneling tool in Rhino, students created semi-parametric objects, based on a cube.](image)

**Pedagogical Objectives**

With the Abstract Machine (AM), we used parametric methods in somewhat different terms. Instead of declaring the parameters to generate a form, the form constructed the constraints. Within these parameters, intentionally, students were given immense freedom to generate form and fabricate the form into the physical models while they are learning Rhino as a modeling tool.
for the first time. Using Rhino, students generated variations of forms. Using repetition, transformation, datum, rhythm, symmetry, void, volume, thickness and so forth, students explored creation of tower forms. The given spatial limit was a volume of 6”x6”x24”(Figure 2.).

This initial project became a beginning to investigate the parametric thinking process in simple terms. Each student’s work was produced as a series of variations by using the same procedures but varying the parameters. This parametric modeling exercise produced variations of forms which show the design process as an improvement of designed artifacts (Barrios, 2005).

The final class project, Exoskeleton Barricade (EB), was a collaborative project, building on the ideas explored in the first project (Figure 3.). Because of the introductory nature of the course, students were provided with a 3D model of a curvature structure which constrains how each form is generated by students. Students each chose one of the grid components to design & construct. Each design represented a variation of the overall design. Based on the geometry they chose, students designed a complex form while maintaining the shape and scale of their grid component. The forms were volumetric, with each form having at least one complete opening to allow light to pass through. Each form was fabricated into a physical model for use in the larger structure. Students explored how changing the parameters of their forms and openings impacted the quality of light, and the collaborative nature of the project required students to study the impact of their designs on the neighboring forms. Students are constantly asked to be flexible with their designs for the universe of possible solutions within a given time. This is the iterative search process of variations of a design idea (Barrios, 2005).

Students were required to illustrate their component design to explain the process of how each component was designed and assembled. They used the laser cutter to fabricate their designs, and then assembled their components. For the final part of the project, accuracy was the critical element. After constructing each individual component, they assembled the cubes together. The precise fit of the pieces required students to confirm their construction accuracy with adjacent components (Figure 4.).

Beyond Form Making

Using the parameters given, students were able to go beyond working within the variables of one project to
explore the impact of decision making and formal expression on a broader scale. In parametric design, it is the parameters of a particular design that are declared, not its shape. By assigning different values to the parameters, different objects or configurations can be created (Kolarevic, 2003).

Working together with analog mock-ups, students explored the relationship between their variations and those of their neighbors in the grid. They used digital tools to manipulate their forms to respond to the changing shapes around them. Using digital tools to mold complex geometries became an efficient vehicle for students to explore expressive form. The complex forms fabricated with Bristol board using a laser cutter also challenged us to adapt the thought process of hand making. Integrating parametric thought into architectural thought supports a design process which can grow with technological innovations.

Using the Design procedure by Carlos Barrios (2005), the process illustrates the same dependency relationship between EB and tessellation of surface. The initial shape was a quadrilateral geometry which consisted of convex quadrilaterals: parallelograms. These shapes were produced by parametric modeling tools: Rhino and Grasshopper, which allowed a multiplicity of quadrilateral forms.

Constructing the parametric design through a physical model was also a valuable part of the exercise. Going through the steps of making a large scale model allowed the students to recognize constructability issues and the value of collaboration (Figure 5.). Pedagogically, the design process and accomplishment of each step demonstrated the realization of digital design through physically built form. Both analog and digital media embrace the idea of repetitive process of making within projects done by a group. The connection between physical and computational modeling is a critical element of the course because exploration through modeling allows for an intuitive spatial development (Szalapaj, 2001).

These projects serve as a platform for further study and initiation of use of parametric modeling methods. While time and logistical constraints did not allow for more parametric exploration of larger surfaces in EB, the next planned step in this progression will be to introduce a group project where perhaps the parameters of each grid
component surface could be altered.

The Future: Cultivating SPC with Variation

“Computerization is about automation, mechanization, digitization, and conversion. Generally, it involves the digitization of entities or processes that are preconceived, predetermined and well defined. In contrast computation is about the exploration of indeterminate, vague, unclear and ill-defined processes; because of its exploratory nature, computation aims at emulating or extending the human intellect (Terzidis, 2006).”

How will parametric design affect the end result of each design and ultimately the future of design? Parametrics are transforming the design process, facilitating quicker, more efficient explorations. They are allowing for the integration of design process components into a more fluid approach to creating. As a communication vehicle, parametric design will allow for group exploration of project variables, on a small or large scale. The possibilities for collaborative design are endless (Figure 6.).

References


This paper describes a recently concluded graduate seminar which tested how form-generative design tactics of algorithmic work could be productively brought to bear on the conceptual analysis of existing buildings. The seminar did not seek to optimize performance or aesthetic value but simply to query the mechanics and consequences of translation as an act. Seminar participants mined existing buildings as sources for parametric rule-sets which were subsequently applied to varying media fields (e.g., physical materials, text, and graphics). This application revealed that specific media resist certain kinds of translation. This peculiar resistance suggested that characteristics of architecture exist which might broadly be called untranslatable.

Introduction

Two distinct trajectories are discernible in contemporary architectural pedagogy and research concerning the use of algorithms: that is, finite rule-sets or procedures. I call these trajectories the analytical and the form-generative.

Within the analytical trajectory, researchers rely on algorithmic formulations to analyze existing architectural form as a means of disclosing spatial, structural, or material patterns typical of a body of built work, or of deriving “design principles” specific to a body of work (Asojo, 2001; Gomez de Silva Garza and Maher, 2001). In related efforts, researchers use algorithms to analyze the
Parametric Variation
Revealing Architectural
Untranslatability

Mike Christenson¹

¹North Dakota State University

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performance (e. g., structural behavior, or energy performance) of a building (Clarke, 2001). Within the form-generative trajectory, algorithms are used to derive two- or three-dimensional architectural form from given parameters (Hsu and Krawczyk, 2003), or to model naturally occurring forms and processes, in turn provoking the production of novel architectural form. Genetic algorithms, for example, are capable of instigating conceptual design, of provoking a decision-making process, or of optimizing a solution space (Besserud and Cotten, 2008; Aranda and Lasch, 2006; Renner and Ekart, 2003; Caldas and Norford, 1999; Holland, 1992).

Given this context, and assuming that architectural design and architectural analysis have a tactical identity — that they share tactics though their strategies differ (Porter, 2004; Crowe & Hurtt, 1986) — the following question arises: How could the form-generative design tactics of algorithmic work be productively brought to bear on the conceptual analysis of existing architecture? This question formed the basis for a recently conducted graduate-level seminar led by this paper’s author. The seminar staked out territory distinct from the analytical trajectory, such as those discussed by Gomez de Silva Garza and Maher, in that it did not attempt to disclose patterns specific to a designer’s intent. The seminar also differed from the form-generative trajectory, for example as discussed by Aranda and Lasch, in that it was not an overt attempt to generate novel form from observations of naturally occurring behavior or patterns. Instead, the seminar sought to hybridize aspects of the analytical and form-generative trajectories. Over the course of the seminar, existing buildings were mined as sources for parametric rule-sets. These rule-sets, specifically formulated to be portable, were translated from their sources into other media, including text, two-dimensional graphics, and sculpted material. In this way, novel form was generated not in response to naturally occurring forms or processes, but in response to architecture. At the same time, the

![Digital model of Case Study House #22. Student: Brian Glueckert.](image)

**Figure 1.** Digital model of Case Study House #22. Student: Brian Glueckert.
ACADIA Regional 2011 : Parametricism: (SPC)

The seminar did not propose to derive “rules” for replicating the original works.

The results of the seminar, which are reported here, are relevant to both the form-generative trajectory (because novel form was generated) and the analytical trajectory (because the original works were brought into comparison in a novel way), but more importantly within a new trajectory, one which I call the translation-limitation trajectory: that is, a realm of architectural research and pedagogy in which algorithmic procedures are capable of disclosing the resistance of specific media to certain kinds of translation. This peculiar resistance is in turn suggestive of unique characteristics of architecture which, when considered in totality, might broadly be called untranslatable.

Construction of base models

To begin the seminar, each student was directed to construct a digital solid model of a house assigned by the instructor (Figure 1). This initial assignment included no limitations on the choice of software application, except that the chosen software should allow the students to quickly and efficiently model the formal properties of their assigned houses, avoiding excessive detail whenever possible. These directions prompted most of the students to choose Sketchup for the assignment, simply because it was the most familiar of the various software applications available to the students during the seminar.

Assigning houses

The instructor selected a group of existing houses, based on the criteria that the houses should be small, reasonably well-documented, and not likely to be familiar to the students. The selected houses were as follows:

- The Koehler House (2001), in New Brunswick, Canada, designed by Julie Snow;
- E.1027 (1929), in Roquebrune, France, designed by Eileen Gray;
- Case Study House #22 (1960), in Los Angeles, California, designed by Pierre Koenig;
- Casa Gaspar (1991) in Zahora, Spain, designed by Alberto Campo Baeza.

Suspension of familiar influences

To promote conditions for subsequent assignments (beginning with the generation of discrete formal sequences), the instructor proposed to challenge or subvert the students’ assumptions concerning familiar influences in the analysis and design of architecture. For example, participants were assumed to hold as an a priori assumption that a program (i.e., an expression of the proposed or actual use of spaces) and a site (i.e., a specific locus of proposed or actual construction) are necessary components of architectural design, and as such, are commonly addressed with familiar tactics such as the systematic gathering and ordering of site-specific information or the production of proximity diagrams derived from a given program. For the initial construction of digital models, students were asked to suspend or set aside these a priori assumptions and their associated tactics as far as possible, and to instead focus their attention on formal manipulation. Stated differently, the initial assignment required no attempt to associate the modeled forms with any significance whatsoever beyond their geometrically measurable, formally legible properties; in fact speculations about such significance was actively discouraged.

Concerning program, the students were directed to avoid speculation about the social significance of their modeled architecture, in particular as such significance could be inferred through assigning specific activities to spaces or areas. In most cases this was practically difficult because the existing documentation of the houses tended to identify rooms with labels (e.g., “Kitchen,” “Bedroom,” etc.). Concerning site, students were directed to avoid speculating on how the orientation of the house or its placement on the site could be architecturally significant (e.g., to inhabitation, usefulness, the internal organization of spaces, etc.), and to avoid modeling the specifics of site topography. Finally, seminar participants were asked to suspend any attempt to model materials “realistically” or to endow them with any kind of...
Parametric Variation Revealing Architectural Untranslatability

Initial formulation of parametric rule-sets

On the basis of the digital models produced in the first few weeks of the seminar, the students were asked to develop, using their selected modeling application, a sequence of parametric rules transforming a generic “cube of unit volume” into the model of the house. An example of student work resulting from this assignment is shown in Figure 2.

The seminar emphasized the topological nature of these transformations to focus attention away from any attempt to model real-world behavior of material, light, etc. Mathematically considered, it was not necessary that two subsequent steps in the parametric transformation should be limited to topologically equivalent forms, or that a specific step in the sequence be topologically legal. Thus, to undergo a “topological transformation” was not to work within a finite set of transformations as such but rather to restrict attention to only those formal properties which the software could register. The assignment was not an attempt to construct a model of the house as an analogue for the making of the house in the real, but for promoting instead precisely those kinds of manipulations and transformations which topology encourages.

Articulating and transforming the rule-sets

After modeling and illustrating a parametric transformation sequence for their assigned house, the students were asked in a series of assignments to apply the sequence against different fields. These assignments were designed to test the robustness of the sequence as it was applied to different kinds of “material” (physical and digital). By robustness here is meant the ability of a specific sequence to maintain its integrity as it is ported from one medium to another.

Into written rule-sets

First, students were asked to transform their parametric transformation sequence from digitally modeled form into written rule-sets. Students were directed to use active verbs where possible, to focus specifically on the act of transformation. Most of the students identified several steps within their own sequence which, while easily modelable, did not easily translate into written rules. Such occurrences prompted students in some case to reformulate steps within the sequence. These occurrences constituted the first appearance within the seminar of a consequence relevant to the transformation-limitation trajectory. Stated differently, when the...
students attempted to translate their sequence from a group of digital models into words and rules, unique difficulties emerged: some of the “steps” in the sequence simply did not lend themselves readily to translation into written form. At the time, several students remarked on this lack of robustness without attaching any particular architectural significance to it.

Against a generic field

Next, students were asked to apply the written rule-sets to an abstract repetitive field such as ten dots or ten lines. Figure 3 shows the result of applying a rule-set originally written for Case Study House #22 to a field of four vertical lines. The resulting diagrams, from left to right, show the transformation of an original set of ten dots (analogous to the original cube of unit volume) into a set of dots with one dot selected and expanded, and on through several more steps involving additions and shifts – each of which is analogous to a corresponding shift within the original parametric transformation sequence. Several students confronted difficulty in this assignment, in particular in those cases where the written rule-set simply proved to be far too specific to be easily translated to a coarse-grained, scaleless field of dots or lines. Again, as in the previous assignment, some of the students reacted to this apparent lack of robustness by rewriting
or simplifying steps within the rule-set.

**Against a materially specific field**

Next, students were asked to apply their parametric rule-set to a given material or object. Figures 4 and 5 illustrate examples of work in which students selected, respectively, a potato, a piece of paper, wood strips, and a rubber ball. In response to these material translations, the seminar discussion shifted decisively away from the original works of architecture and toward an engagement with material specificity. Critically, the concern was not about the material specificity of the *original buildings*, but of the new materials introduced as testing fields. In short, it was at this point in the seminar that the parametric rule-set prompted substantive discussion of the “untranslatability” of specifically *architectural* attributes.

In each of the translations from one medium to another, students faced unique difficulties of translation (i.e., a lack of robustness). For example, some students found that steps in a parametric rule-set which could be easily modeled in Sketchup were not easily described in words or drawings. Or again, a specific transformation which might be easy to suggest through the use of folded paper did not translate into wood.

**Observations**

Initially, when the students encountered difficulties from translating parametric rule-sets from one medium to another, they tended to characterize these difficulties as weaknesses of the original rule-set or as evidence of their own unfamiliarity with the material under consideration (folded paper in particular provoked unexpected difficulties in translation). In short the students tended to see these difficulties of translation as obstacles to be overcome. But as the seminar proceeded, and difficulties mounted with each new attempt at translation, more and more students came to acknowledge that what they had seen as obstacles could actually be unique opportunities to reflect on the limitations and capabilities of materials as well as on the specifically “untranslatable” aspects of architecture. Seen in this light, one important provocation which emerged from the seminar is the possibility of conducting similar exercises but on a finer scale of detail, as a means of testing the translatability of construtional logic. Allen and Rand’s work with detail patterns (Allen and Rand, 2007) and Borden’s recent book concerning material precedent (Borden, 2010) constitute important explorations of this issue, though in both cases through primarily graphic means. Another important possible trajectory for future work is the possibility of conducting similar exercises with regard to factors such as energy performance, structural behavior, or activity/program. Such factors, even if not easily or obviously expressible in formal terms such as those discussed in the seminar, may instead be expressible (for example) in written, mathematical, or geometrical terms.

**Summary**

The seminar’s purpose in generating parametric rule-sets was not to explain or prompt the generation of works of architecture but rather to map a specific structure of thinking about architecture into new fields. Each of the test fields (such as the “generic” dots and lines, or the found objects) has its own inherent properties which are themselves made *uniquely* visible through the application of each rule-set. Ultimately, the purpose of the seminar was not necessarily to achieve insight into the intent of the original architects, nor to arrive at new architecture. Instead, its purpose was to understand the specific limitations inherent in *translation as an act*, which when considered generally, is rich in potential to disclose otherwise latent attributes in both existing architecture and material and digital fields.

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As we increase the complexity and correlations of variables that are critical to the design of a project, we are becoming increasingly aware of the possibilities emerging from a computer integrated design process. There is such great opportunity to use these tools to manage and analyze multi variable design information, yet there is still much criticism of the design solutions created from computational design. These design solutions have been said to be "lacking any character, cultural influence, human engagement, or communication" and that "most of our contemporary architecture has forsaken this dimension of architectural discourse and it's potential for exceptional spaces." The current focus of computational investigation is primarily limited to building performance and optimization. Buildings that are designed from a purely optimizational construct without acknowledging the users desires and needs are falling short in creating "places". Optimization can be the end result, but the constructs that are being optimized must be broadened to address all facets of a project. Computational design has emerged because it has the capacity to resolve multiple constraints and deal with extreme complexity of variables. By optimizing a more holistic set of constraints, computational architecture can truly provide comprehensive design solutions.
Humanizing Parametricism

Devan Castellano

Doctoral Student, University of Wisconsin Madison, School of Human Ecology, Design Studies.

As we increase the complexity and correlations of variables that are critical to the design of a project, we are becoming increasingly aware of the possibilities emerging from a computer integrated design process. There is such great opportunity to use these tools to manage and analyze multi variable design information, yet there is still much criticism of the design solutions created from computational design. These design solutions have been said to be “lacking any character, cultural influence, human engagement, or communication” and that “most of our contemporary architecture has forsaken this dimension of architectural discourse and it’s potential for exceptional spaces.” The current focus of computational investigation is primarily limited to building performance and optimization. Buildings that are designed from a purely optimizational construct without acknowledging the users desires and needs are falling short in creating “places”. Optimization can be the end result, but the constructs that are being optimized must be broadened to address all facets of a project. Computational design has emerged because it has the capacity to resolve multiple constraints and deal with extreme complexity of variables. By optimizing a more holistic set of constraints, computational architecture can truly provide comprehensive design solutions.
“Parametricism aims to organize and articulate the increasing diversity and complexity of social institutions and life processes within the most advanced centre of post-Fordist network society. It aims to establish a complex variegated spatial order, using scripting to differentiate and correlate all elements and subsystems of a design. The goal is to intensify the internal interdependencies within an architectural design, as well as the external affiliations and continuities within complex, urban contexts.” Manifestos such as this by Patrik Schumaker address the power and beneficial attributes of computational design and have excited the architectural community with the potential and transformative nature brought on through its use. Unfortunately, there is little work that successfully applies all of these principals. While it may take time to fully embrace this change and develop the technology to successful apply these ideas, it should be acknowledged that some critical aspects of projects are not being addressed. Shumakers states, “It aims to establish a complex variegated spatial order, using scripting to differentiate and correlate all elements and subsystems of a design”, but in practice not all elements are being addressed. This lack of humanism in computational design has led to debate.

**Missing Variables**

There has been much criticism of the paradigm shift to computational architecture. Neil Spiller addresses this deficiency in his article Surrealistic Exuberance – Dark Matters. He critiques parametric design as lacking any character, cultural influence, human engagement, or communication. Because of this, he states that these projects are devoid of interest and mystery. “It is also to point out that most of our contemporary architecture has forsaken this dimension of architectural discourse and its potential for exceptional spaces.... some contemporary architects have sought to collapse ‘theory’ and ‘practice’ in new ‘algorithmic’ processes of design that avoid subjective ‘judgment’ and produce novelty through instrumental mathematical operations. Made possible by powerful computers and ingenious software, the new algorithmic magic creates novelty without love, resulting in short-lived seduction, typically without concern for embodied cultural experience, character, and appropriateness.” Like any critique and iterative design process, there is room for revision. Humanism needs to be brought back into the architectural equation. Instead of disregarding computational design as a methodology, priorities should be reset and emphasis should be placed on creating more comprehensive design solutions.

Designers that have embraced parametricism as a method of optimization are on the right track of inquiry, but they have left out some very significant puzzle pieces. Buildings and places that are designed from a purely optimizational construct without acknowledging the users desires and needs are falling in a similar fashion to those that are using the computational design strictly for ornamentation. They are selling short the potential of computational design. Optimization can be the end result, but the constructs that are being optimized must be broadened. Building performance is not the only component of a project. Optimization must be addressed in all facets of the project. While it may be difficult at this stage to expect the computer to resolve all of the design decisions, they need to be addressed.

The built environment should address the user’s psychological, informational, and social needs as well as the functional and programmatic requirements, environmental concerns, and optimization. All of these values define the success of a project. (Figure 1).

![Figure 1. “Supportive Environment”](image-url)
Integrating Qualitative Research

Architects and engineers have gotten very good at using the computer for optimization, but it is critical that the tools now address the qualitative building performance as well. These design components are often overlooked in current practice, and this area does not seem to be addressed in computational design. It seems since there are so many parameters that influence a design project, many of the qualitative measures of the design have been left out. Instead, the focus should be to figure out how to embrace the number of parameters needing to be that are addressed in parametric design strategies and create a more holistic and more valid design response. If there cannot be a singular system that addresses all of the needs of a building or design, then a system must be developed where all parameters are examined and possible individual studies of each can then inform the design process.

This is important to architectural discourse because in an age where builders, engineers, and even computers have the ability to create buildings, and efficient ones at that, there is a reason and importance for the architectural profession to understand the complexity of not only the building performance, but the social and contextual issues. Architects are distinct in that they have the advantage and knowledge if applied to create “places”. It is unfortunate that these are the areas that are lacking attention within computational design, but by introducing the human construct back into computational architecture we are drawing closer to inspiring those manifestos.

While architects are trained to ensure the environment is suited to the physiological needs of the user, the informational and social needs of the user are often overlooked. This is not new and has been studied rigorously in the films, “The Social Life of Small Urban Spaces” and Kevin Lynch’s, “Imageability.” Attributes of the city are often part of curriculum in architecture programs, but there is little attention paid to the mounting research and evidence of how humans perceive and learn through environmental interactions, as well as how this changes significantly from children to the elderly. Wouldn’t designers be able to create better design of housing and facilities for the elderly knowing the implications of sensory and cognitive changes of the elderly when designing? Isn’t it important to understand the limitations of young children in spatial cognition in the design of educational institutions?

The quality of the built environment and the implication of design decisions have been studied by various disciplines including environmental psychologists, environment and behavior researchers, and even design professionals. To define a quality environment, EBS researchers use the term “supportive environment,” one in which the physiological, informational, and social needs of the users are supported by the physical environment. While it would make sense to most design professionals that this should be evident in all projects, it is often not the case.

With the collaboration and research in the fields of Neuroscience and Architecture, Environment and Behavioral Studies, Environmental Psychology, and more cross disciplinary research; we now have a large amount of empirical data that can greatly contribute to the success and performance of the built environment. Evidence based design is now mainstream and the data produced seems to be a good match for setting constraints in computational design.
While there are not many projects incorporating this research into computational design, there is no reason to view these qualitative design constraints any differently than other variables used in a computational framework. There is great potential in investigative measures infusing this knowledge in the current body of work, but there needs to be further investigation into how to address the informational and social needs of the user and the most appropriate method of defining and setting those design constraints.

This study should begin by looking at some of the existing research and findings as a starting point. There has been much research in understanding the perceptio-cognitive system: how humans perceive their environment, how the cognitive system interprets that perception and creates mental images that allow us as humans to store information, create route knowledge and spatial understanding of the environment. Spatial understanding is critical to any design and since this legibility is linked to human preference, it can be used as a predictor of user satisfaction.

Gestalt theory in psychology has been applied to EBS to deconstruct how humans perceive the built environment. “Gestaltists proposed that the nervous system is predisposed to group incoming sensory elements by certain rules: Proximity, simplicity, closure, continuity and similarity,” the research has then translated these Gestalt laws to design applications. Design applications of these Gestalt laws have already been broken down into defined variables that determine how well a space is understood. These application variables include: figures, patterns, form and space. Creating “imageable” spaces are significant and necessary to create and store spatial information. Imageability attributes have been defined by Appleyard as environmental features that affect attention and memory including imageability, distinctiveness, visibility and significance. These are all rules that can apply to design elements and set constraints on how we order and create visual elements in design.

Within the application of architecture, the cognitive process is crucial to the success of a project. Hunt defines legibility as the ability to organize environmental elements and orient oneself. The attributes that contribute to this understanding include perceptual access, architectural differentiation and plan configuration. Within this research it has also been determined that structured variety must be evident to aid in this spatial understanding. Legibility and wayfinding greatly contributes to the satisfaction and emotional security of the user. According to Hunt, an individual’s wayfinding ability “affects their capacity to enjoy and appreciate the surrounding environment and encourages exploration and interaction”. The inability to understand ones environment can be a safety issue as well as cause confusion, stress and anger which, as is well documented in healthcare design, indirectly affects health and well-
being. Agent based simulations are beginning to address some of these concerns, and there is great potential for investigative modeling to be used to determine how to optimize spatial cognition to enable a person to formulate a mental image with optimal organizational structure as quickly and efficiency as possible.

Human preference is influenced by both informational needs and social needs, and has been thoroughly researched. While the findings are somewhat instinctive to many designers, it is important to test and validate these conclusions through practice. Preference process qualities such as flexibility and content qualities such as views, environmental features, and the golden proportion are all variables that could be addressed through computational means. Perhaps more critical than optimizing human preferences would be to avoid undesirable human conditions. Visual overload could be combatted by setting limits, then automatic clustering as that limit. Spaces that reach a size limit would be forced to be subdivided into conceptual spaces, and visual escapes could be varied into the equation all in an effort to avoid the feeling of crowding.

Social needs of users are often addressed in current architectural design, but in many cases designs are unsuccessful or not used as the designer intended. There are many variables that can be addressed by computational design to predict the success of those spaces. The significance of clustering and home range has been studied to predict the success of spaces. Technology could contribute to this success by setting constraints and running simulations that would ensure social spaces would fall within the home range of the users. Designing sociopetal spaces and using proxemics are all design variables that would be addressed by computational architecture to create more supportive environments.

Buildings that are designed from a purely optimization construct without acknowledging the users desires and needs are falling short in creating “places”. Optimization can be the end result, but the constructs that are being optimized must be broadened. Building performance is not the only component of a project. Optimization must be addressed in all facets of the project. Computational design has emerged because it has the capacity to resolve multiple constraints and deal with extreme complexity of variables. By optimizing a more holistic set of constraints, computational architecture will be difficult to contend with. The fusion of human understanding and technology enables designers to revolutionize the practice of architecture, revalidate the significance of the profession and create extraordinary “places”.

References


Paper Sessions
Above: Kyle Miller from UK CoD
Below: Investigations in Digital Curricula
Workshops
GIS Mapping Introduction | Geographic Information System
Dr. Zhenghong Tang | Assistant Professor in UNL’s Community and Regional Planning

Dr. Tang is also a courtesy professor in the School of Natural Resources; a faculty fellow in both the Water and the Advanced Land Management Information Technology centers at UNL; a research fellow in the Environmental Planning and Sustainability Research Unit in the Hazard Reduction and Recovery Centers at Texas A&M where he received his Ph.D. in Urban and Regional Science.

Parametric Modeling | McNeel’s Grasshopper
Nathan Howe | Assistant Professor at Kansas State University (workshop not pictured)

Nathan is a graduate of Kansas State University and holds a Masters of Architecture from the University of Texas at Austin. Nathan has also taught at the University of Nebraska as assisted design studios at the University of Texas. Nathan’s research interests examine how emergent technologies and techniques of digital fabrication can transform the architectural design process.
Energy Modeling | Autodesk’s Ecotect
Nancy Clark Brown, AIA | Senior Manager for Autodesk Education Programs in the Americas

Nancy Clark Brown, AIA is Senior Manager for Autodesk Education Programs in the Americas. Nancy directs programs and services that focus on integrating technology into the education of architects, engineers, designers, and digital artists in both academic and professional environments. As a former tenured associate professor, Nancy has practiced the teaching of technology in the educational environment for over 14 years. Nancy has a Master of Science in Advanced Architectural Design from Columbia University and a Bachelor of Architecture from Washington State University. She is a licensed architect in the State of Washington and is a member of the American Institute of Architects.

Intermediate NURBS Modeling | McNeel’s Rhinoceros
Brian James | Industrial Designer and Adjunct Professor at the Rhode Island School of Design (workshop not pictured)

Brian James is a Boston based industrial designer working as a Rhino specialist and trainer with Robert McNeel & Associates. He is currently also an adjunct professor at the Rhode Island School of Design. Here he teaches a course in concept development and photorealistic rendering using mainly Rhino and a variety of plug-ins. Visit www.McNeel.com/user/BrianJames for free HDRI environments and Rhino video tutorials.
Parametric Design I | McNeel’s Grasshopper
Nathan Miller  l  Associate and Designer at NBBJ

Nathan is interested in creating systems for performance-driven architectural solutions using advanced design computation and 3D parametric modeling technology. Over the past three years, Nathan has been leading NBBJ in the development and implementation of advanced digital tools for engaging complex problems of geometry, program, and user experience. Most recently, Nathan’s leadership and expertise were essential for the successful design and execution of the Hangzhou Olympic Sports Center in China, a landmark stadium and recreation project in to be completed in 2013. Nathan holds a Master of Architecture degree from the University of Nebraska - Lincoln and has previously worked for design firms Randy Brown Architects and Graft. Nathan’s has participated in work which has been recognized by the AIA and has been published in Architecture Record, ACADIA, Interior Design Magazine, A+U, Plus Magazine, ArcCA, and PanStadia.

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Above: Andrzej Zarzycki (center) speaks with Tim Hemsath and Mike Christenson (foreground).
Below: Reception Dinner
Above: Tom Verebes (right) chats with Roly Hudson (foreground), James Halliburton and Nate Holland (background).
Above: Jeff Day (left) and Mark Hoistad (right).
Below: Reception Announcements. Nancy Clark Brown, from Autodesk, at the podium.
Above: (front to back) David R. Scheer, Tom Verebes, Kyle Miller. Reception Dinner.
Above & Below: Session lunches in Architecture Hall ‘link’.
**Keynote Speakers**

**Jeff Day**
Jeffrey L. Day, AIA the Omaha based principal of Min | Day, graduated magna cum laude from Harvard College in 1988, with an AB in Visual and Environmental Studies. He went on to receive a Master of Architecture from U.C. Berkeley in 1995. Before founding Min | Day, Jeff’s work experience included an extended period with Fernau & Hartman Architects in Berkeley. He is NCARB certified and a licensed architect in both California and Nebraska. Jeff is an Associate Professor of Architecture at the University of Nebraska-Lincoln, where he runs our allied practice, FACT (Fabrication And Construction Team), an academic / professional collaborative design lab that offers students a forum for exploring the complex relationships between thinking and making. A frequent collaborator with Min | Day, FACT engages design intensive projects and creative clients in collaborations that bridge the gap between design and construction.

**Tom Verebes**

Tom Verebes is currently Associate Professor in the Faculty of Architecture at the University of Hong Kong. Formerly Co-Director of the AA Design Research Lab (DRL) at the Architectural Association in London, where he had taught design studio and seminars in the post-professional MArch course from 1997-2009, as well as a former Guest/Visiting Professor at ABK Stuttgart. Tom is also the founder and Creative Director of OCEAN.CN, a consultancy network of specialist design consultants based in Hong Kong, with links to Beijing, Shanghai, Jakarta and London, working on urban and architectural projects in China and the Asian region. As the team leader of an integrated, multi-disciplinary team, including architects, urbanists, engineers, experts in computational design, manufacturing, visualization and information communication, OCEAN.CN strives for innovation across a range of scales and types of design projects, from urban master planning to architectural interiors. Tom has written, published, exhibited and lectured extensively in Europe, North America, Asia and the Middle East.

**Nate Miller**

Nathan Miller is an associate and designer at NBBJ. As a design professional, Nathan is interested in creating systems for performance-driven architectural solutions using advanced design computation and 3D parametric modeling technology. Over the past three years, Nathan has been leading NBBJ in the development and implementation of advanced digital tools for engaging complex problems of geometry, program, and user experience. Most recently, Nathan’s leadership and expertise were essential for the successful design and execution of the Hangzhou Olympic Sports Center in China, a landmark stadium and recreation project in to be completed in 2013. Nathan holds a Master of Architecture degree from the University of Nebraska - Lincoln and has previously worked for design firms Randy Brown Architects and Graft. Nathan's has participated in work which has been recognized by the AIA and has been published in Architecture Record, Interior Design Magazine, A+U, Plus Magazine, ArcCA, and PanStadia.1988
Roly Hudson (left) presented the ACADIA Best Paper Award for, *Race track modeler. Developing an Iterative Design Workflow Combining a Game Engine and Parametric Design* by the conference co-chairs, (left to right) Tim Hemsath, Jangwhan Cheon, and Steve(n) Hardy. Authors: Roly Hudson, Drew MacDonald (not pictured), and Mark Humphreys not pictured.)
Ergun Akleman
ergun.akleman@gmail.com

I am a professional cartoonist, illustrator and caricaturist who has published more than 500 cartoons, illustrations and caricatures. I am also a computer graphics researcher who has a background in Electronic and Computer Engineering. I received my PhD in Electrical and Computer Engineering from Georgia Institute of Technology in 1992. I am a professor in Department of Visualization at Texas A&M University since 1995. In the Visualization Sciences program, I teach a wide variety of topics in covering both artistic and scientific aspects of computer graphics. All my courses are interdisciplinary by nature. I combine a studio approach with lectures. In my art and design courses, students also learn mathematics. In my technical computer graphics courses that are usually heavy in computer science and mathematics, students also learn aesthetics aspects of the subject. My research work is also interdisciplinary, usually motivated by aesthetic concerns. I have published extensively in the areas of shape modeling, image synthesis, artistic depiction, image based lighting, texture and tiles, computer aided caricature, electrical engineering and computer aided architecture.

Carlos Barrios, PhD
Assistant Professor, The Catholic University of America; Partner, Planetary ONE
barrios@cua.edu / carlos@planetaryone.com

Dr. Barrios comes from a rigorous and diverse background having studied architecture, engineering, computer science, aviation, music, film and fine arts. He is a recognized scholar in the field of Parametric Design and Morphology with published research in national and international forums. Dr. Barrios received a PhD in Design and Computation from the Massachusetts Institute of Technology researching in parametric models for complex geometry and focused on twisted tall buildings. At MIT he co-founded the Digital Design Fabrication Group and created the seminal work for research projects in that area. He has collaborated in research and educational endeavors with recognized practices that include SOM, KPF, Gehry and Partners, Foster and Partners, Nicholas Grimshaw, and Arup. At MIT, he was awarded the Thomas Upham Fellowship for his research in Parametric and Morphogenetic Design. Dr. Barrios seeks to understand the morphological principles in natural systems to generate creative solutions for design problems through parametric modeling. He is Design Partner and Director of the Design LAB at Planetary ONE where he leads research in morphogenetic computational design. He also is an avid sculptor, mountain climber, a martial arts expert, and a glider pilot.

Brad Bell
Assistant Professor, University of Texas Arlington; Director, bradbell studio
brad@tex-fab.net

Brad Bell is the founder and director of bradbell studio – a design practice focused on the application of innovative digital technologies to produce highly crafted objects, branded environments, and architectural spaces. Specifically within residential architecture, bradbell studio has worked to expand the application of new and contemporary design solutions to contextual and regional construction methodologies. bradbell studio has completed projects in Colorado, Texas, Louisiana, & Oklahoma. As a professor of architecture for over a decade, Brad is an Assistant Professor of Architecture at the University of Texas Arlington where he teaches undergraduate and graduate courses on the integration of digital fabrication technologies into the architectural design process. He has lectured, taught, and written on the uses of such technologies and has been an invited critic at schools of architecture throughout the United States. Brad received his Master of Architecture Degree from Columbia University in 1998 and his Bachelor of Environmental Design Degree from Texas A&M in 1993. In 2009 Brad became one of the founders and co-directors of TEX-FAB. TEX-FAB is a collaborative network of
affiliated Texas designers focused on providing a platform for the exchange and exploration of issues related to parametric design and digital fabrication.

**Erin Carraher**  
Visiting Assistant Professor, Virginia Tech; Project Manager, OnSite  
erin.carraher@gmail.com

After graduating from Virginia Tech with a Bachelor of Architecture, Erin Carraher went on to receive a Master of Architecture from Yale University where she received the Gene Lewis Book award and was nominated for the H.I. Feldman Prize. She subsequently served as co-editor for the book Layered Urbanisms, which presents critical discussions and illustrations of urban research and design analysis as carried out in the advanced studios at Yale. She returned to Virginia Tech for the 2004-2005 academic year where she taught a first-year studio before moving to New York City to practice architecture. In New York, she worked for BKSK Architects where she focused on sustainable, large-scale institutional projects including public libraries and educational facilities. In addition, she was a volunteer for the non-profit organization, Housing Works, and is working to redesign the cafe in their Soho bookstore. Erin currently divides her time between teaching a first-year studio at Virginia Tech and practicing as part of the award-winning firm OnSite. Erin is a registered architect in New York and Virginia and is LEED certified.

**Devan Castellano**  
Doctoral Student, University of Wisconsin Madison, School of Human Ecology  
dcastellano@wisc.edu

I am currently a Ph.D. student in Design Studies in the School of Human Ecology at the University of Wisconsin-Madison with a concentration in Environment and Behavior Studies. My research interests lie in the relationship of humans and their physical environment and how research is utilized in design practice. My dissertation will investigate how “biophilic design” can enhance the cognitive, social and emotional development of children in educational institutions. In the Design Studies department I am receiving funding through a Digital Media Teaching Assistantship.

After receiving a BA in Architectural Studies at the University of Illinois Chicago and a Masters of Architecture from Illinois Institute of Technology, I worked in several Chicago architectural firms and taught at Harrington College of Design. Along with teaching I worked on developing the sustainability and digital technology curriculum for the interior design program at the bachelors and masters level. Professionally, I have worked with the Lost Boys Rebuilding Southern Sudan (LBRSS) organization to design an educational compound. After completing my doctoral research, I hope to be active in the architectural community in both design research and practice.

**Mark J. Clayton**  
Liz and Nelson Mitchell Professor of Residential Design, Texas A&M University  
Email: mark-clayton@tamu.edu

Dr. Clayton has extensive and varied experience in research, education, design, and administration. He served as the Interim Head of the Department of Architecture from 2006-2008 and was previously the Executive Associate Dean of the College of Architecture for five years. During twenty years of experience in architectural computing and education, Dr. Clayton developed early expert systems in climate responsive design in the 1980’s, helped pioneer computer-aided design education at Cal Poly in the late 1980’s, and developed early Building Information Modeling techniques in the 1990’s. Since 1995 he has introduced innovations at Texas A&M in areas such as electronic design studios, telecommunications supported design education, wire-
less networks, facility information systems, digital fabrication, integrated practice, and Building Information Modeling. Dr. Clayton has contributed to the association for Computer Aided Design in Architecture (ACADIA) since 1990, having served as Steering Committee Member, Conference Technical Chair, Newsletter Editor, Vice President, and President. Dr. Clayton earned a Bachelor of Architecture from Virginia Tech, a Master of Architecture from UCLA, and a PhD in Civil and Environmental Engineering from Stanford University.

Mike Christenson
Assistant Professor of Architecture, North Dakota State University
mike.christenson@ndsu.edu

Mike Christenson, AIA, NCARB, is a registered architect (Minnesota) and an Assistant Professor of Architecture at North Dakota State University in Fargo. Christenson’s research examines the means through which architects make their ideas visible (physical and digital representation). The research is grounded in the assumption that a tactical identity exists between architectural analysis and architectural design. Despite their strategic aims being different, the tactics of analysis and design are identical, consisting of the persistent, iterative production of mediating artifacts such as drawings, text, photographs, and models. Christenson’s research is thus aimed at developing media-based strategies and tools suited for both analytic and design-generative purposes. Christenson has published his research nationally and internationally. He is a member of several national organizations, including the Association for Computer-Aided Design in Architecture, of which he is an elected member of the Steering Committee. He serves on the Editorial Board of the International Journal of Architectural Computing. At NDSU, Christenson teaches design studio, architectural representation, and contemporary architectural theory.

Ryan Collier
Architectural Intern, Corgan Associates, Inc.; Teacher, Cistercian Academy
Ryan.r.collier@gmail.com

Ryan Collier currently practices architecture at Corgan Associates in Dallas, Texas, and teaches History of Architecture at Cistercian Academy. His primary pedagogical interests are in asemic geometry, weaving methods, and digital fabrication. He holds a Masters of Architecture from Texas A&M University and is a AIA Henry Adams award recipient. Current professional work includes corporate and educational facility design and documentation. In addition to ACADIA, he has also published work through the MIT journal Thresholds, the Bridges conference in the University of Coimbra, and maintains the blog the pliancy experiment.

Anna H. Dyson
Associate Professor, Rensselaer Polytechnic Institute; Director, Center for Architecture Science and Ecology (CASE)
dysona@rpi.edu

Anna Dyson teaches design, technology, and theory at the School of Architecture at Rensselaer. She is the director of The Center for Architecture, Science and Ecology (CASE) which hosts the Graduate Program in Architectural Sciences, concentration is Built Ecologies. She has worked as a design architect and product designer in several offices in Canada, Europe, and the United States. Her work has been exhibited in the MoMA Young Architects Series, and was a finalist in the international Next Generation Design Competition. Dyson holds multiple international patents for building systems inventions and is currently directing interdisciplinary research sponsored to develop new systems for on-site energy generation. Dyson received a Baccalauréat Général from Université Laval and a Master of Architecture from Yale University.
Gabriel Esquivel was born and educated as an architect in Mexico City with a degree from the National University and received his Master’s Degree in Architecture from The Ohio State University. Gabriel Esquivel teaches architecture at the College of Architecture at Texas A&M University. He previously taught Architecture and Design at the Ohio State University.
He has worked on different collaborative projects by himself and with Kivi Sotamaa, concentrating on developing a diversity of High Design projects, concentrating on the importance of affect, sensation and atmospheres. Gabriel just started a new office in Texas called “Spy and the Apparatus”, working on some projects like “La Riviera restaurant”. Gabriel has a blog called” Theoremas “which is a forum for new ideas in architecture.
His earlier professional experience comes from working in large corporate offices like NBBJ and completed projects in New York, Los Angeles, Santiago, Istanbul, Taipei, Beijing, Mexico City and Buenos Aires. His projects include healthcare, commercial, retail and residential developments.
His focus of attention has always been surfaces and their different possibilities using digital modeling techniques, the importance of rapid prototyping and fabrication using CNC milling as well as other techniques. Consequently Gabriel Esquivel has taught several studios that dealt with these issues providing the background for architecture education to be at the top of the cutting edge technology.

Francisco Farias is an architect graduated at Facultad de Arquitectura y Urbanismo, Universidad de Chile, in 2000. He worked as a practitioner for 7 years with several firms in Chile, with experience developing different projects such as residential buildings, educational buildings, train stations, banks, office buildings, museums, parking facilities, wineries, and interior design. He is currently a Ph.D. candidate at Texas A&M University, and his areas of interest are sustainable design, Building Information Modeling, daylighting, energy simulation, Integrated Project Delivery, parametric modeling and design methods.

Jason Griffiths gained his professional qualification at the Bartlett UK and is a partner of Gino Griffiths Architects in collaboration with Alex Gino. He began teaching in 1994 at the Bartlett (M.Arch) and then went on to teach at Oxford Brookes and University of Westminster as a senior lecturer. Jason’s teaching career is paralleled with competition work winning prizes in eleven competitions including first prize in both the AA FAB 2009, Temple of Laughter, Millennium Café competitions. Other competition prizes include Future Visions of Kyoto, Aomori Housing, Shinkenchiku Residential Design (three times) and the Oklahoma Memorial. In 2003 Jason and Alex came to the US to conduct a Sabbath research/lecture tour of North American Suburbs. Prior to joining ASU he worked in Texas, Nebraska and Iowa. His teaching explores the design build studio as a vehicle for research interests in both digital fabrication and contemporary iconography. Completed works in this field include Arts Pavilion for Iowa State, Sioux City Bus Stops and ASU Dining Pavilion. He is currently building a house in Mojave Desert in collaboration with Alex Gino. Jason has been published in many academic and professional journals including the Journal of Architecture, Architecture, Sunday Times, World Architecture, Building Design and AJ. He has lectured in Spain, Italy, Mexico and the USA for institutions that include ESTAM, In-Arch, UNAM, Rice, Sci-Arch, the AA and the Bartlett.
James Haliburton AIA, LEED AP
Visiting Assistant Professor, School of Architecture, Prairie View A&M University, Prairie View, TX
jthaliburton@pvamu.edu

James Haliburton is a practicing architect, researcher, and educator. His experience ranges from teaching and research to design and construction. James is currently a visiting professor at Prairie View A&M University while he completes his dissertation on Small Firm BIM Adoption at Texas A&M University. He brings valuable experience from industry to research and teaching. James became a registered architect in 2008 and began studying under Mark Clayton, PhD shortly before finishing his registration process. Recognizing the importance of computing in architecture and design James is committed to researching how to improve professional practice and professional education through the applications of technology. James has a Bachelor of Environmental Design and a Master of Architecture from Texas A&M University.

Daniel Hillukka
Graduate Student, North Dakota State University
deimhillukka@hotmail.com

Currently completing the final requirements in pursuit of a Masters Degree in Architecture at North Dakota State University in Fargo, North Dakota.

Nate Holland
MArch + MBA Graduate Student University of Nebraska Lincoln
nholland@huskers.unl.edu

Nate Holland is a 6th year graduate student at the University of Nebraska - Lincoln. He is currently working towards a Masters degree in Architecture and a Masters degree in Business. His interests are in generative design, digital design and manufacturing, and real estate development. As an intern he has worked for Holland Basham Architects, TRex Architex, The Weitz Company, and HDR Architecture. He also teaches architectural design software in the Architecture College at UNL.

Nathan J Howe
Assistant Professor, Kansas State University
nhowe@ksu.edu

Nathan is a graduate of Kansas State University and holds a Masters of Architecture from the University of Texas at Austin, where he studied under Michael Benedikt. Nathan is currently teaching at Kansas State University after stints of teaching at the University of Nebraska and assisting in design studios at the University of Texas. Nathan’s research interests examine how emergent technologies and techniques of digital fabrication can transform the architecture design process, both in academia and practice, from its conception in algorithmic form-making through the fabricating device which manufactures the idea. Nathan’s current home is as much a shop as a home, as a CNC router claims a room just off the main living space, and provides him a personal lab from which to create.

Dr Roly Hudson
Dalhousie University; r.hudson@dal.ca

Roly Hudson received his Phd in 2010 from the University of Bath where he worked with The Centre for Advanced Studies in Architecture (CASA). His research was based on practical experience of applied parametric design. Working with Populous and Buro Happold he developed a bespoke shared parametric definition for
the development and project delivery of the Aviva stadium in Dublin which controlled the building envelope and associated it with the structural systems. Current research interests involve developing fully integrated design, production and construction processes in collaboration with local design offices and contractors. He has been actively involved with the SmartGeometry group since 2005 and given workshops in parametric design at over 20 European Academic institutions. In the past 3 years he has published and presented in leading architectural computing journals and conferences.

Mark Humphreys
IT Systems manager, Populous

WoonSeong Jeong
Ph.D. Student, Texas A&M University;
Email: wsjeong@neo.tamu.edu

WoonSeong Jeong (1977~) was born in Republic of Korea. He finished his B.A. in Architecture Engineering at Chungbuk National University in Republic of Korea. During the study, he learned the skills and knowledge about Architectural design and engineering from basic architecture theory to complex engineering method. He continued his study at the KyungHee University in Korea for a year as master’s level of study. He was more focused on studying Product Model and Building Information Models (BIM). After a year and half, he pursued his new master’s degree at University of Illinois at Urbana-Champaign (UIUC). Through two years of study at UIUC, he focused on how to support progress monitoring, using BIM. He ended his master work by writing the thesis; Evaluation of IFC2X3’s Capabilities to Support Cost-Based Construction Progress Monitoring. After graduate his master degree at UIUC, he has been pursuing his Ph.D. program at Texas A&M in Architecture Department since Fall semester, 2008 focusing on how to integrate BIM and Energy Simulation Model to support sustainable design.

David Karle
Adjunct Professor, University of Nebraska Lincoln
Email: dkarle2@unl.edu

David Karle is an Adjunct Professor in Architecture at the University of Nebraska-Lincoln where he teaches undergraduate courses in design studio and urbanism. David has also taught architecture courses at the University of Michigan. He has worked professionally throughout the United States, in Australia, and at Mack Scogin Merrill Elam Architects on the Yale Health Service Center Project. David has received national and international awards for his design work including; Green Lung: Toronto Canada and Digital Fog: Detroit, Michigan.

David’s research focuses on the formerly forgotten territory of the commercial roof and the implications of its vast scale that disconnects the interior from the exterior.

Brian M. Kelly, RA
Assistant Professor, University of Nebraska Lincoln
Email: bkelly2@unl.edu

Brian M. Kelly, RA is an Assistant Professor of Architecture at the University of Nebraska at Lincoln College of Architecture. His previous teaching experience includes Drury University’s Hammons School of Architecture in Springfield, MO and California Polytechnic State University at San Luis Obispo. Prior to joining the faculty at UNL, Brian served as lead designer in the office of Randy Brown Architects, designing several award-winning projects of various types and scales. In addition to teaching, he has also recently started his own office.

ACADIA Regional 2011: Parametricism: (SPC)
focusing on smaller scale architectural projects, objects, and graphics. His student work has been featured in academic journals and his professional work has been published internationally. Serving as the coordinator of the beginning architectural design program, Brian’s teaching and research focus is in the areas of beginning design, architectural representation theory, and the craft of making occurring at the threshold between marking and making. Recently, Brian was selected as the University of Nebraska Douglass Professor with his proposal to design and develop a speculative project called “perfor(M)ations”.

Elizabeth A. Krietemeyer  
Ph.D. Candidate, Rensselaer Polytechnic Institute, Center for Architecture Science and Ecology (CASE)  
kriete@rpi.edu

Elizabeth Krietemeyer is a Ph.D. candidate at Rensselaer Polytechnic Institute whose work focuses on the experimental engagement of display technology within the public realm and surrounding infrastructure. She is interested in information display systems for dynamic solar responsive building envelopes that improve the quality and control of interior environments through optimized daylight exposure while decreasing the energy profile of buildings. Understanding the ways in which humans interact with their social and built environment, specifically relating to the temporal nature of information and light, is critical to her research. Krietemeyer received her B.S. degree in Architecture and her M.S. degree in Architectural Sciences from Rensselaer Polytechnic Institute.

Jong Bum Kim  
Ph.D. student, Texas A&M University  
Email: Jongbum.kim.coa@gmail.com

Jong Bum Kim is currently pursuing a PhD degree on the subject of Computational Urban Design at Texas A&M University. He holds professional degrees in architectural engineering and urban design. Prior to this engagement, he received an urban design master degree from the University of Texas at Austin and an architectural master degree from Yonsei University, Korea. He has practiced in architectural firms in Korea and the U.S. on mixed-use, high-rise residential, and community developments. His current research focus addresses urban computing, parametric modeling, decision making, and design communication platforms for sustainable community developments.

Chad Kraus  
Assistant Professor, University of Kansas  
ckraus@ku.edu

After receiving a professional degree in architecture from Kansas State University, Chad moved to New York to join the studio of Shigeru Ban Architects from 2003 through 2008. While at SBA, he had the opportunity to work on a wide variety of published and award-winning projects such as the Nomadic Museum in New York, Furniture House 5 in Sagaponack, Furniture House 6 in New Orleans, and the Metal Shutter Houses in New York. In 2009, he received a post-professional degree from the History and Theory of Architecture program at McGill University, studying under Alberto Perez-Gomez, where he cultivated his interests in Phenomenology. Currently in his 2nd year at the University of Kansas, Chad has taught courses on the history of Modern architecture, architectural theory, 4th-year architectural design studios, and a grad-level accelerated design studio.

Dave Lee  
Assistant Professor, Clemson University; Co-Founder, quixotic  
dlee2@clemson.edu

Dave Lee is the founding principal of quixotic, a transdisciplinary design practice focusing on engaging perception, human occupancy and interaction through computational design strategies. He is also a Professor
Brian Leounis  
Co-Founder, studioCLAD  
bleounis@gmail.com  

Brian is a freelance designer and co-founder of studioCLAD based in Charleston SC. Originally from upstate NY he studied architecture at the University of Buffalo and completed his education graduating Master of Architecture from Clemson University. Brian has worked on various projects gaining international attention including proxyFlorence featured in the 2009 SKIRA Yearbook of World Architecture, and the Upside-down House featured at Buffalo Rising. His research DigiGami, performed under the guidance of Clemson Professor David Lee, focuses on combining analog origami folding techniques with digital parametric modeling tools to create complex kinetic architectural form.

Drew MacDonald  
Track Designer and Motorsport Specialist, Populous  
email unknown  

Drew MacDonald is a Mechanical Design Engineer with over 12 years’ experience. He spent the first part of his career working as race team engineer both on and off the track. He has worked in World Championship events working closely with drivers to develop the car to rise to the challenges presented by circuits. Over the last 9 years Drew has been able to take his on track experience to develop new challenges for drivers and riders alike having worked on some 17 circuits around the globe. Using his experience, of computer analysis and simulation, to develop new racing cars he continually looks to bring a ‘motorsport’ approach, to circuit design, through simulation and mathematical analysis to design new circuits.

Troy M. Malmstrom  
Assistant Professor, Louisiana Tech University; Director, Digital_Processes  
TroyM@latech.edu  

Troy M. Malmstrom is an Assistant Professor of Architecture at Louisiana Tech University. There, he leads 2nd and 3rd year design studios, graduate-level digital craft studios, teaches computer application courses, and is Director of the Digital Fabrication and Rapid Prototyping Laboratory. Malmstrom received his Masters of Architecture from the Knowlton School of Architecture at The Ohio State University where he has also taught 2nd year studio as an Adjunct Instructor. More recently, he has worked in the Chicago office of Skidmore, Owings, & Merrill as an architectural assistant on various international competitions and projects. Malmstrom also heads up Digital_Processes, a digital design and fabrication consulting group, and is a Core Tutor of tech workshops with DesignOnTheSide.net, a collective focused on the exchange and exploration of digital design and fabrication topics.

Kevin Patrick McClellan  
Lecturer, University of Texas San Antonio; Director, A / K  
kevin@tex-fab.net  

Kevin Patrick McClellan is an artist/designer, educator and director of Architecturebureau / Kevinpatrickmcclellan. Founded in 2000 with the intent of exploring complex systems and their material effects on form, A / K has designed and built work in California, Texas and the UK ranging in scale from small conceptual objects,
furniture and installations to residential and commercial construction. Kevin’s undergraduate education is in both Painting and Installation Art from the University of Texas additional to an Environmental Design degree from Texas A&M. His post-graduate degree was taken in London at the Architectural Association School of Architecture. After receiving his Masters in Architecture and Urbanism from the AA’s Design Research Laboratory with a Project Distinction in 2005, he subsequently worked in New York for Kevin Kennon - leading the development of a penthouse addition in Tribeca. Afterward in London with Zaha Hadid, he served as Project Architect for two highly publicized temporary installations, one for the Serpentine Gallery titled Lilas and the second for Swarovski Crystal Palace exhibited in the 2008 Milan Furniture Fair. Additionally he directed the Perm Museum XXI entry that placed 3rd in an open international competition. His personal and professional work is published regionally, nationally and internationally. Since 2009 Kevin has co-directed with Brad Bell and Andrew Vrana the Digital Fabrication Alliance, a not-for-profit, working under the title TEX-FAB. DFA is a design resource intent on strengthening the role of digital design and fabrication within the architectural community in Texas. He has served as a visiting critic at the Architectural Association and the University of Houston and lectured in the US and Mexico. Currently Kevin teaches design studio at the UTSA College of Architecture.

Kene C.U. Meniru
Adjunct Professor, Community College of Baltimore County; Owner, IlloM Corporation
Kene.Meniru@illom.org

Kene Meniru has a doctorate (Ph.D.) in Building Engineering from Concordia University, Montréal, Canada with specialization in computer-aided conceptual building design. His credentials also include a master of architecture (M.Arch.) from State University of New York (SUNY) at Buffalo. His final thesis broke new ground among his peers, at the time (1995), in the use of 3-D computer models to support his early design process (sketch work) and design development (detail design) in his M.Arch. thesis. Kene currently holds an associate membership in the AIA and teaches architectural CAD/3-D modeling techniques and procedures in the Community College of Baltimore County (CCBC). After numerous years as an architectural designer, Kene continues his design practice as the owner of a new company (illom.org) that redesigns and remolds existing structures for residential use. In addition, Kene has recently started following up on his Ph.D. findings with the ultimate goal of adding to the body of knowledge that will lead to the creation of an appropriate and effective digital building design/documentation/management environment.

Joe Meppelink
Director of Applied Research/Adjunct Assistant Professor, University of Houston College of Architecture; Principal, METALAB
joe@metalabstudio.com

Metalab principal Joe Meppelink previously co-owned and operated Metalab as an architectural metal fabricating shop. This shop fabricated dozens projects in the Houston area, ranging from furniture to multi-story stair structures, and began steadily employing digital fabrication technologies in 1998. After selling the shop, Joe returned to teaching and practice in Houston. He taught design and fabrication courses at Rice University for 2 years, and then began Framework Design Studio – a residential design practice still active in Houston – in 2004 with partner Marisa Janusz. Currently, Joe is an Adjunct Assistant Professor at the University of Houston, co-teaching courses in digital fabrication with Metalab partner Andrew Vrana. Joe also serves as Director of Applied Research at the College of Architecture, where professional and academic efforts coincide in the development of Green Building components and products. Joe’s dream is to work via constructive interplay between the often disparate camps of “architecture-design-technology” and “construction-fabrication-manufacturing”. Or more simply put, the head and the hands.
Kyle Miller
Assistant Professor of Architecture, University of Kentucky; Director, eightyeight-west
kyle.miller@uky.edu

Born in Milwaukee, Wisconsin. He completed his Bachelors of Science degree in Architecture at the University of Michigan and received his Master of Architecture degree from UCLA, completing his research studio with Neil Denari. He has worked professionally since 2003 in offices located in Milwaukee, Los Angeles, and most recently for Ben van Berkel and Caroline Bos with UNStudio in Amsterdam. Kyle is currently an Assistant Professor at the University of Kentucky.

Nate Miller
Associate, NBBJ
NMiller@nbbj.com

Nathan Miller is an associate and designer at NBBJ. As a design professional, Nathan is interested in creating systems for performance-driven architectural solutions using advanced design computation and 3D parametric modeling technology. Over the past three years, Nathan has been leading NBBJ in the development and implementation of advanced digital tools for engaging complex problems of geometry, program, and user experience. Most recently, Nathan’s leadership and expertise were essential for the successful design and execution of the Hangzhou Olympic Sports Center in China, a landmark stadium and recreation project in to be completed in 2013. Nathan holds a Master of Architecture degree from the University of Nebraska - Lincoln and has previously worked for design firms Randy Brown Architects and Graft. Nathan’s has participated in work which has been recognized by the AIA and has been published in Architecture Record, Interior Design Magazine, A+U, Plus Magazine, ArcCA, and PanStadia.1988

Glen T. Mills
Adjunct Professor of Architecture, College of Architecture, Texas A&M University, USA; Centre for Applied Studies in Africa, PO Box 786918, Sandton 2146, South Africa
gmills@arch.tamu.edu

My interest is in the interplay between spatial design, technology and social function in buildings, human settlements and urban infrastructure. My research and practice includes projects and case studies in South Africa (Gauteng, Limpopo, Western Cape), and in the United States (Texas). In this work I have emphasized the integration of technology and design in pedestrian bridges, the in-situ upgrading of informal settlements, the development of appropriate housing and living environments for low-income communities, and the relationship between city form and crime. The underlying theme of this work is on the design of living environments that are socially, economically and ecologically sustainable. The aim is to consistently evolve high quality places that are affordable, safe, varied, adaptable, flexible, and desirable.
Areas of specialization: Architecture of movement patterns and social functions in cities, low-cost housing, pedestrian bridge design, and informal settlements.

Taro Narahara
Assistant Professor, New Jersey Institute of Technology (NJIT)
narahara@njit.edu

Taro Narahara holds a Doctor of Design degree from Harvard University Graduate School of Design and a Master of Science in Architecture Studies in Design and Computation from MIT. He also received a BS in Mathematics from Waseda University in Tokyo and a M.Arch from Washington University. He is currently an Assistant Professor at the College of Architecture and Design at the New Jersey Institute of Technology, where he teaches digital design studios and courses in design scripting and physical computing.
He has won the Peter Rice Prize and the Digital Design Prize at the Harvard GSD and has published and presented papers for Journals and conferences, such as IJAC and eCAADe. He is currently a member of an international VR group to promote VR technologies that visualize traffic and human behavior models using multi-agent simulations. His research focuses on generative approaches in architectural design inspired by self-organization and emergence. He is a licensed architect in New York and has worked professionally for over seven years as a project architect with Gluckman Mayner Architects and Skidmore Owings and Merrill in New York. Projects include Mori Arts Center; Hotel Puerta de America in Madrid; MoMA Store; and Kuwait Police Academy.

Ozan Onder Ozener, PhD
Assistant Professor, Istanbul Technical University
ozener@itu.edu.tr

Dr. Ozan Onder Ozener is a faculty member at the Istanbul Technical University with appointments in Architecture and Design Computing. He is currently serving in the university administration board as the director for communications and international R&D activities. His particular research interests lies in BIM applications in architectural practice and education, computational design and data visualization. He has published in various international conferences and journals including eCAADe, IJAC, and DDSS. During his graduate education he was affiliated with TAMU CRS Center and Visualization Laboratory. He was also appointed as an adjunct Professor at Prairie View A&M University in 2008-09. Dr. Ozener received his PhD degree from Texas A&M University College of Architecture (2009); M.Arch in Design Computing (2003) and BArch (2000) from Istanbul Technical University.

Troy N Peters
Assistant Professor, California Polytechnic State University
tnpeters@calpoly.edu

Troy Peters is an Assistant Professor in the Architecture Department at California Polytechnic State University. He has a Master of Architecture degree from the University of Oregon. Before teaching at Cal Poly, Troy taught Environmental Controls at Ball State University. Professionally Troy is NCARB certified and a registered architect in the state of Illinois and Wisconsin in addition to being LEED accredited. He is the founder of ArchiPhyscs, a website for distributing software and other tools for building simulation and investigation. The author of several software programs for passive solar calculations and daylighting, his academic research and software designs have focused on various aspects of thermal transfer and passive solar design. Currently, Troy is working on SolarShoeBox, a simple design tool built on EnergyPlus.

Seung Ra
Assistant Professor, Oklahoma State University
Seung.ra@okstate.edu

Seung Ra is an Assistant Professor of Architecture at Oklahoma State University School of Architecture. His current research and design practice focuses on culture, technology, and progressive approaches to the interdisciplinary study of architecture and urban design. He has presented and exhibited his research and theoretical works throughout the U.S., Germany, Singapore, China, Brazil, and Spain. Professor Ra holds a Bachelor of Architecture from Oklahoma State University and post-professional Master’s degree from Columbia University. He taught at the New York Institute of Technology and as a BIG12 Faculty Fellow, he visited at the University of Nebraska at Lincoln. Prior to his teaching and research at OSU, he worked on a wide range of projects at Studio Daniel Libeskind, Friedrich St. Florian Architects, and Kohn Pederson Fox.
Paola Sanguinetti
Associate Professor, University of Kansas
paolas@ku.edu

Paola Sanguinetti received a Bachelor of Architecture from the University of Kansas, and a MS in Advanced Architectural Design from Columbia University. She gained professional experience with internationally distinguished architectural practices including Zaha Hadid and Emilio Ambasz. She is currently a PhD candidate at Georgia Institute of Technology, with studies in high performance buildings and design computing. Her research focuses on guiding building envelope retrofit decisions by energy saving guarantees. At Georgia Tech, she is a researcher in the Digital Building Lab, working with Professor Chuck Eastman. She is cited as a contributor to the publication of “Automated Assessment of Early Concept Designs” in Architectural Design 79 2 52-57. She is also credited as co-author of one of the case studies in Eastman C, Teicholz P, Sacks R, and Liston K., 2008, BIM Handbook, A guide to Building Information Modeling (New York: Wiley) 418. She actively worked with Professor Fried Augenbroe helping prepare an EFRI-NSF research grant, “Risk conscious design and retrofit of buildings for low energy” which was awarded in fall 2010. Paola was awarded the NSF ADVANCE Program Women of Excellence Award from the College of Architecture at Georgia Institute of Technology in 2010.

David R. Scheer
Principal, Scheer & Scheer, Inc., Salt Lake City, UT
dscheer@scheerandscheer.com

David R. Scheer is the founding architectural design principal of Scheer & Scheer, Inc., an architecture and urban design firm based in Salt Lake City. The firm, founded in Cincinnati, Ohio in 1994, has won numerous awards for architecture, urban design and urban planning. The firm was also a very early pioneer in the use of building information modeling. Prior to founding the firm, Mr. Scheer taught architectural design, theory and history at the University of Cincinnati, Miami University and Arizona State University. For the past three years, Mr. Scheer has been a member of the national advisory group of the Technology in Architectural Practice Knowledge Community of the AIA. He has written and spoken widely on the impacts of technology, particularly building information modeling, on architectural thinking and practice. Mr. Scheer came to architecture by an unusual route. In 1980, having previously earned an M.S. in physics, he met Peter Eisenman who shared his interest in topology. He worked with Eisenman for a year at the Institute for Architecture and Urban Studies in New York City where met many of the most thoughtful architects active at the time. Mr. Scheer received his M. Arch. degree from the Yale School of Architecture in 1984.

Nick Senske
Assistant Professor of Architecture, University of North Carolina at Charlotte; PhD Candidate, University of Michigan, Ann Arbor
nsenske@uncc.edu

Nicholas Senske is an Assistant Professor of Architecture, specializing in computational design integration. His research draws from the fields of education and computer science and seeks to improve how architecture students learn computer software and computational thinking. He currently teaches second-year undergraduate studio, computational methods seminar, and digital representation.

Michael Tomaso
Architectural Intern, Corgan Associates, Inc.
angelotomaso@gmail.com

Michael Tomaso earned a Bachelor of Science in Visualization at Texas A&M University. He currently works at Corgan Associates, Inc. in Dallas, TX as architectural staff on projects including corporate offices, mission-crit-
Andrew Vrana
Visiting Assistant Professor, University of Houston College of Architecture; Principal Architect, METALAB
andrew@metalabstudio.com

Andrew Vrana is an Architect who has structured his practice at Metalab around design informed by advanced computation and digital fabrication as well as a working knowledge of materials and building culture. This expertise was cultivated at Columbia GSAPP (MArch '98) where he was awarded the McKim Prize upon graduation and though employment at the offices of Enric Miralles/EMBT and Renzo Piano Building Workshop. Now, through working with a network of capable fabricators at Metalab since 2007 with Joe Meppelink, the integrated delivery of design, custom building components and construction management is achievable on architecture, civic art and product design projects. They have recently added Dennis Oppenheim and Dror Benshetrit to their growing list of clients. In academia as a Visiting Assistant Professor and researcher in the College of Architecture at the University of Houston he has taught digital fabrication seminars and studios with Joe Meppelink since 2005 that have produced award winning work like the Ceiling Cloud (AAFAB Award for Interiors in 2010) and the New Harmony Grotto with Ben Nicholson. Andrew seeks to merge the formal and material possibilities of contemporary design with a localized sensibility toward craft and quality of execution. In 2009 he co-founded TEX-FAB *Digital Fabrication Alliance to expand his interests in pursuing design research through the application of digital technology within the Texas region and beyond by organizing workshops, lectures and design competitions.

Qing Xing
PhD student, Texas A&M University
qingxing@viz.tamu.edu

I am a student in the Visualization Specialization of the Architecture PhD Program at Texas A&M University. I am advised by Dr. Ergun Akleman. I received my B.S. degree from Taiyuan University of Technology. I was advised by Dr. Sung Yong Shin in the Theory of Computation Laboratory and received my M.S. degree from Korea Advanced Institute of Science and Technology. Then I worked in Imaging Media Research Center. My research interests include geometry modeling, weaving theory, and real-time rendering.

Wei Yan
Assistant Professor, Texas A&M University
Email: wyan@tamu.edu

Wei Yan’s areas of academic interest include Computer-Aided Architectural Design (CAAD), Visualization, Building Technologies, and applications of Computer Vision and Computer Graphics in Architecture. His academic interests were developed during his studies in Architecture at Tianjin University, China, in CAAD at ETH Zurich, and in Computer Science and Architecture at the University of California, Berkeley. After joining the Department of Architecture at Texas A&M University in 2005, his research has been focused on environment-behavior simulation, computer games for design education, digital imaging technologies for architectural heritage documentation, and Building Information Modeling and parametric modeling for sustainable design. He received the Best Paper Prize in the International Conference of Design Computing and Cognition (DCC) in 2006. His recent research projects are funded by the National Science Foundation (NSF), the National Endowment for the Humanities (NEH), U.S. Department of Energy (DOE), and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). Wei Yan teaches courses in the multidisciplinary areas of Architecture, Visualization Science, and Computer Science, with a focus on design computing. He was on
Duygu Yenerim
Ph.D Student at Department of Architecture, College of Architecture, Texas A&M University, USA; Research Assistant of Interior Architecture and Environmental Design, Hacettepe University, Turkey
duygualb@tamu.edu

Residential design and human settlements focusing on informal settlement (slum) upgrading methods, Building Information Modeling (BIM), sustainable and affordable design are the practice categories that I am interested in. Currently, as part of Ph.D, I am conducting research on integrating BIM into informal housing upgrading interventions while focusing on the existing settlements along the U.S.–Mexico border, the Colonias. I also performed research on the concepts of flexibility, adaptability and typological variety in multifamily residential design during my Masters education in Architecture at Middle East Technical University, as well as sustainable design principles in multifamily residential design at Delft University of Technology.

Andrzej Zarzycki
Assistant Professor, New Jersey Institute of Technology;
Andrzej.zarzycki@njit.edu

Andrzej Zarzycki is an assistant professor in the College of Architecture and Design at New Jersey Institute of Technology (NJIT)—dual appointment with the school of architecture and the school of art and design. His work as a designer and researcher focuses on media-based environments and the use of digital tools to create experiential architectural spaces. Additionally, his research focuses on validation methodologies of generative design through building performance analysis and simulation tools. Andrzej is a co-winner of SHIFTboston Ideas Competition 2009 and a co-founder of TUTS, a design initiative focusing on innovative adaptations of infrastructure into contemporary public spaces and on the integration of digital technologies into urban life. (the-tuts.org)
Janghwan Cheon
AIA

Janghwan is currently an Assistant Professor at UNL, a registered architect of Massachusetts, and AIA member of New York Chapter and LEED accredited Professional. He holds an M.Arch from Columbia University and a B.S. Engineering in Architecture from Yonsei Universit, Seoul. He founded multi-disciplinary design firm office ReduX (http://www.officeredux.com) in 2009 and his work has been widely recognized and exhibited. To date, successes include the international competition winning proposal for the Rome City Vision Competition in 2010 and honorable mention for HUB architecture competition in Charleston, SC in 2010. Before joining UNL in 2009, he has worked at Asymptote, Hanrahan Meyers Architects, Gwathmey-Siegel Architects, Stan Allen Architect and office dA leading various projects as a project architect.

Steve(n) Hardy

Steven(n) is an Associate Professor in the CoA at UNL and is the current recipient of the Killinger Professorship of Urban Design. He has taught diploma and graduate design studios with digital emphasis at the Architectural Association, UCL’s Bartlett School, the University of Westminster and London Metropolitan University. He has also previously served as Departmental co-Chair of Digital Design/IT/AV/CAD and was Course Leader of the MA in Architecture & Digital Design at LMU and was Research Curator at the Architectural Association. He has an M.Arch from UCL’s Bartlett School and a B.Arch from the University of Kansas. Steve is also a member and director in Urban Future Organization where he has lectured in Europe, the U.S. and Asia on his work with Urban Future Organization. Urban Future Organization has exhibited its work at the Venice Biennale and was one of six practices to represent the United Kingdom at the Beijing Biennale. The work of Urban Future Organization was featured by Zaha Hadid in 10X10 v. 2 as one of the most interesting contemporary international young practices. His most recent book is Environmental Tectonics: Forming Climatic Change was published by AA Publications.

Tim Hemsath
AIA, NCARB, LEED® Accredited Professional

Timothy Hemsath, is currently an Assistant Professor in the College of Architecture at UNL. He has both an M.Arch and a BSAS from the University of Nebraska Lincoln. He has over 10 years of combined industry and educational experience in the design, construction and research in energy efficiency and sustainable design. He was the architect for the ZNETH and ZNETH II energy efficient prototypes working with the College of Engineering. He has served as the PI on a $98,787 Nebraska Research Initiative funded project to build research capacity surrounding Zero-net energy research at the University of Nebraska. Currently, he serves on the UNL team, Building Energy Efficient Homes for America, composed of researchers funded by the U.S. Department of Energy’s Building America Program working with home builders and national partners. The team is eligible to receive up to $2.5 million per year in funding over the next four-and-a-half years to identify, test and validate energy efficiency measures in new and existing homes. Recent publications include, Digital CADCAM Pedagogy Model, presented at the 2009 Taiwan, 14th conference on Computer-Aided Architectural design Research in Asia (CAADRIA), Between Man and Machine held in Yunlin, Taiwan; and Recon Decon: Parametric CADCAM Deconstruction. He is a registered Architect in Pennsylvania and Nebraska. He has previously served as Adjunct-Faculty at Philadelphia University, School of Architecture teaching Digital Design.
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