Form-making Without Form Making

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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 experimentations, 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.

In discussing form-making without form making, this paper addresses a number of performative issues as factors responsible for tectonic expression driven by parameter-based definitions. When considering light, materiality, or physical forces such as gravity, with proper software we can immediately define these qualities with physically based parameters. For example, light would be
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quantitative design thinking. This allows for parametric
definition of design, but more importantly, provides
parametric output that can be also used for design
validation.

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.

**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)
Figure 4. Results achieved with Finite Element Analysis (FEA) simulation software.

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

Figure 5. Dynamics-based cloth simulations. (a) parametrically controlled material properties result in distinct catenary forms, (b) when applied forces exceed strength limits, integrity of a cloth element gets compromised and results in a progressive tear, (c) cloth object parameter controls.
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 to 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: TreeMaker¹ or Origamizer² 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.

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

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.

References


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