AC 2009-2385: DIGITAL SIMULATIONS OF ARCHITECTURAL STRUCTURES WITH THE USE OF PHYSICALLY BASED DYNAMICS

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Digital Simulations of Architectural Structures with the use of Physically Based Dynamics

Recent developments in digital design have brought new tectonic freedom into architecture. These emerging tectonic trends, combined with research into new material and fabrication technologies, make it possible to purse imaginative and unique designs that were not possible a decade ago. While digital tools allow for a broader architectural reading, resulting in innovative designs and new expectations towards space and form, these emerging designs often exist exclusively as visual propositions, deprived of a deeper structural, constructional or functional logic.

Similarly, the proliferation of structural analysis software has helped engineers to calculate sophisticated structural models. However, this ability seldom translates back into an architectural form or empowers the design process. Consequently, these two parallel developments, while promising in their individual capabilities, fall short in the synergizing of an architectural form. While attempts are made to mitigate this separation with the use of BIM software, these solutions still operate within classical, architectural-versus-structural paradigms and do not address the visual thinking dimension of buildings' simulations as well as design evaluation thinking.

Design Processes Implications

The emerging design approach that recognizes mentioned dichotomy, but also acknowledges the opportunities of an integrated design process, fuels a renewed interest in building performance simulations and analysis. It creates a new relationship between building technology education and architectural design studio teaching through computational form finding approaches. This is particularly exciting direction in the relationship to architectural generative processes where a form not only can be evaluated based on the performance criteria, but also derived through the very process of simulation. This paper focuses on the strategies for generative design validation with the use of digital simulations, particularly dynamics-based modeling tools.

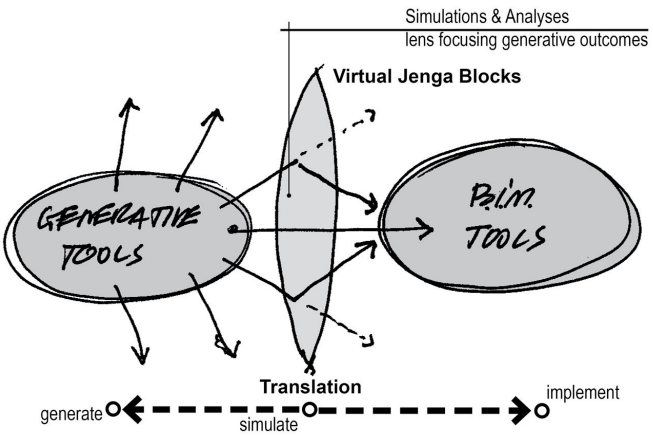


Figure 1 Simulation and analysis tools as a translation layer between generative design and B.I.M.

The phrase "design process" underlines its two formative components: generative and implement-ive. The first component—generative--'wants' to be creative, unrestrained by the current state of knowledge and is occasionally provocative. The other component is systematic and hierarchical with reasoning based on critical thinking. However, these two distinct and polarized ways of thinking: hierarchical or generative, didactic or inductive, have to occur together since neither

one alone is sufficient in the facilitation of the creative process.

In such a definition of the design process, a performance simulation component can function as a lens, both focusing and validating generative designs. Performance-based simulations can function as semi-intelligent, self-optimizing agents that pre-select promising generative scenarios, and then later channel them through a hierarchical portion of the design production. [fig.1] Genetic Algorithm (GA) and Evolutionary Algorithm (EA) are strategies that integrate structural analysis with architectural design as seen in work by Schein and Tessmann[1]. In this particular case, Schein and Tessmann develop a procedure for the space truss optimization based on a collision detection analysis.

New old things; physical models reinvented

Architectural models and mock-ups have always been one of the modes of structural simulation and experimentation. Antonio Gaudi's catenary models [fig.2] and Frei Otto's soap bubble exploration[2] are good examples of this tradition. From a broader perspective, using simulations and building on precedence defines the very nature of progress in architecture. This was true with the transition from Romanesque to, subsequent, Gothic style architecture. It was facilitated by an evolving structural understanding of load transferring and optimizing on the compressive strength of construction materials used at that time. This transition was characterized by iterative improvements in structural knowledge, experimenting with ever larger spans and efficient material use. The pursuit of limits and efficiencies was possible through the correction of previously made mistakes and building upon the achievements of structural successes. An iterative nature, involved in architectural design, is often seen in the past buildings, which served as prototypes and learning precedence for subsequent designs. This is how an architect's experience is accumulated and verified. This formation of experience is critical to the profession and can be partially substituted and expedited by virtual substitutions. In this sense, historical progression is analogous to the simulation approach used today with computer structural modeling. Both, past gradual developments and contemporary simulations purse the same question: What can be learned from an existing precedence in order to predict behavior of slightly different and more daring structures? In this particular case, the term "existing" encompasses both physical/actual and virtual existences.

This precedence based approach was common in other historical periods, as it was with Brunelleschi studying Rome's Pantheon in order to extrapolate its structural knowledge to build an even larger dome in Florence. This can also be true with today's structures. Furthermore, this comparative learning can be as effective with virtual as with actual buildings. This conviction is based not only on my own empirical research, but also on my experience as an educator working with students, who are developing their sensitivities and building their knowledge through the use of digital environments.

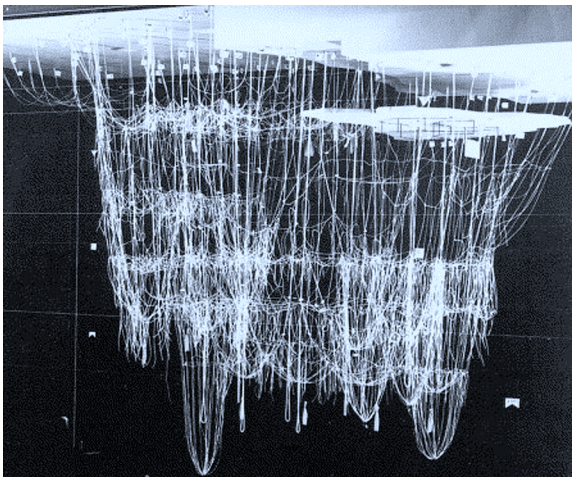


Figure 2 Reconstruction of Gaudí's hanging model

Difficulty with physical models

While the use of simulations was always present in architectural practice and construction[3], the use of computers affords unique possibilities in integrating design by bringing together of multiple expertise into the conceptual stages of the design process. Furthermore, digital based models can overcome certain limitations of physical models. By their very nature, physical models (also mock-ups), are either scaled down, or are partial or simplified versions of overall designs. As such, they bring some level of un-resolvability into physically based simulations. This is due to the inability of certain properties to be directly and linearly scalable. The same objects at different scales would perform differently based on the material characteristics not being scalable. This is evident in the example of a fly walking on the surface of water, while larger animals cannot. Furthermore, physical properties such as mass, when scaled, grow faster than other properties associated with the cross-section areas or linear spans. This causes ratio based formulas to change values and manifest different behaviors. While this still can be incorporated into calculations with today's level of knowledge, the complexity of the scale translation computations grows quickly and becomes prohibitive. This limitation of physical models was already realized by Vitruvius[4] and continued through the much of architectural history. King Ross discussing Brunelleschi's work points out: *"In the Middle Ages and Renaissance, proportionally identical models behaved differently depending on their respective sizes, and scale models were generally misleadingly strong."* [5] Outside architecture, this relationship between a physical size and performance was also researched by evolutionary biologists studying evolutionary trends in the respect of phenotypic characteristics based on environmental influences. These studies looked at ways nature (evolution) optimizes dimensional characteristics (size and muscle amount) versus the weight of individual species based on their environment and survival context.[6]

Why digital? The next good thing

Digital simulation tools can successfully address limitations of physical models because they exist in real units, even though, these units are virtual. In addition, digital simulations can process large amounts of data in a relatively short time. This raises the expectation of digital models

Figure 3 Sunlight studies throughout a day

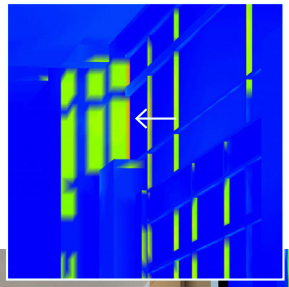


Figure 4 A detail of the illumination analysis showing the change in sunlight intensity when passing through the curtain wall glass

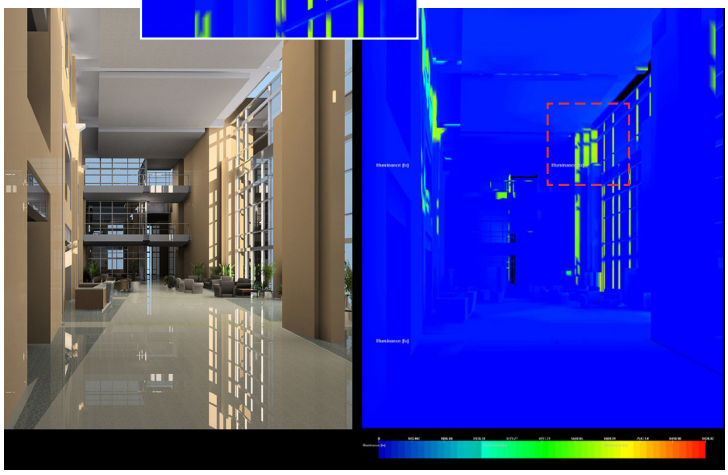


Figure 5 Sunlight illumination analysis module

to account for the technical aspects of architecture and drive design innovations. This performance based design approach and interests in sustainability lead to the emergence of Building Information Modeling software (BIM) that extends the application of digital models throughout significant parts of the design process and into post-occupancy of buildings.

While digital models bring great promise to design simulations, the value of these simulations not only lays in the ability to predict what the structural, thermal or illumination [fig.3-5] performance of a space would be, but also the ability to feed the results of the simulation back into the design equation and proceed with the design accordingly with newly-gained knowledge. The following section will discuss three levels of performance simulations and their integration with architectural design.

Three degrees of digital simulations

Performance-based design is an approach where building performance becomes a formative factor in defining its overall design. While examples I will be showing refer to structural simulations, these points also apply to other aspect of building performance such as thermal, acoustic or light analysis. Furthermore, performance-based design is a broad definition that encompasses a number of approaches that represent different degrees of form determination or generation.[7] There are a number of contemporary practices that incorporate performance simulations to various degrees in the design process. I will be using them to illustrate these approaches.

There are three levels of digital simulation involvement in defining of an architectural form. Performance-based design selection, a traditional approach, is a basic way to integrate simulation into architectural design. While it is a useful first level of optimization, this approach does not involve any form generation. It is critical to separate these two formative approaches, form alteration and form generation, to develop better strategies in dealing with performance-based design.

In the traditional approach, computer simulations are used to size structural members without any change to the original tectonics. This approach is exemplified in Gehry's work [fig.6] where

structure plays a subordinate role to an overall architectural expression. Performance simulations and analysis is limited to the structural rationalization of complex architectural forms. This approach looks at ways to optimize structural performance and efficiencies, without any changes to the original architectural form.

Figure 6 Stata Center, Cambridge, MA

Optimization approach.

In contrast to the previous example, where building performance simulation does not inform tectonic design, the optimization approach allows changes within a set range of values. This optimization approach, also known as the Genetic Algorithm (GA), was used by Isozaki in the Florence Train Station design proposal.[8] The original design was analyzed through an iterative process of progressive structural refinements with individual structural members being repositioned and optimized to maximize the overall structural design. [9]

Form generation approach

In the form generation approach, the integration of architectural and engineering performance criteria is being considered at the very outset of the design process. While various aspects may temporarily be treated with a different level of importance, all critical design drives would be considered in the final solution. In this approach, building performance becomes the driver for a building's tectonics. Building performance is a primary determinant and method for the evaluation and generation of an architectural form. In some rare cases, physical/structural performance of a material can be the only determinant of an architectural form. While this is still a novel approach with little realized work, there are instances where this method can be easily implemented. These are usually situations which rely on a single, often structural, optimization criterion. Tensile structures, in general and fabric structures in particular, are good examples that follow this model. For this reason, the tensile dynamics associated with cloth behavior, was a key component in my students' explorations of simulation-based generative designs. [Fig.7-8]

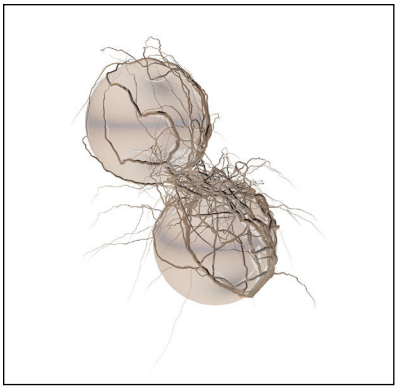
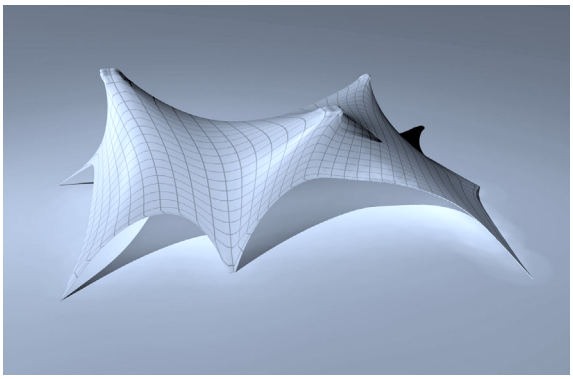


Figure 7,8 Generative form finding. Figure above shows a semi-autonomous of "vine" negotiation its growth in the relationship to surfaces of the spheres.

Self-organizing maps (SOM) or neural networks[10] are evolutionary design strategies that extend a form generation approach by analogous ideas from the field of Artificial Intelligence. They bring a valuable insight from other disciplines into architecture and design. The common denominator, of these and other approaches, is the focus on self-formation of patterns in natural and artificial environ-

ments[11].These pattern formations can be analyzed in a formal as well as a material-based context.[12] This combination of formal studies (spatial configuration of forms) and physical characteristics of a particular material allows for comprehensive analysis of hypothetical designs that was not possible before, even with the methodologies used by Gaudi or Otto.

Figure 9 Cloth simulation example



Independent of how one defines the BIM, the critical aspect of any informational model, is an ability to dynamically model design based on a set of criteria, ability to evaluate and re-formulate the design form and possibly even objectives, and finally, to continue the integrity of the design model throughout all design phases and even into post-occupancy.

Class Focus

In our class, we focused on design methodologies relating to the third approach and decided to use dynamics based tools. We looked at the design methods that incorporated optimization and form generation mechanisms. Specifically, mechanisms that openly consider form, but also interact with simulations in a bi-directional manner. This bi-directionality becomes a vital component in the form generation feedback loop. It resembles the "chicken and the egg" problem: one needs an idea of a form to run a simulation, and in turn, one uses simulations to derive a form. Furthermore, as Kristina Shea observed, "generating new forms while also having instantaneous feedback on their performance from different perspectives (space usage, structural, thermal, lighting, fabrication, etc.) would not only spark the imagination in terms of deriving new forms, but guide it towards forms that reflect rather than contradict real design constraints." [13]

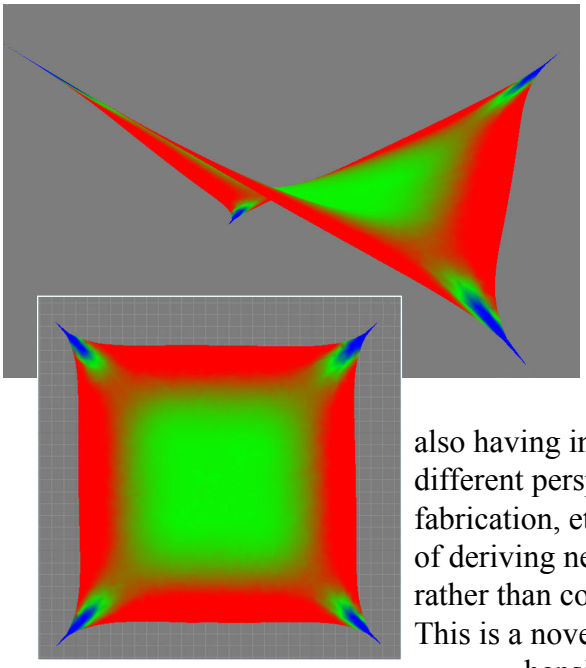
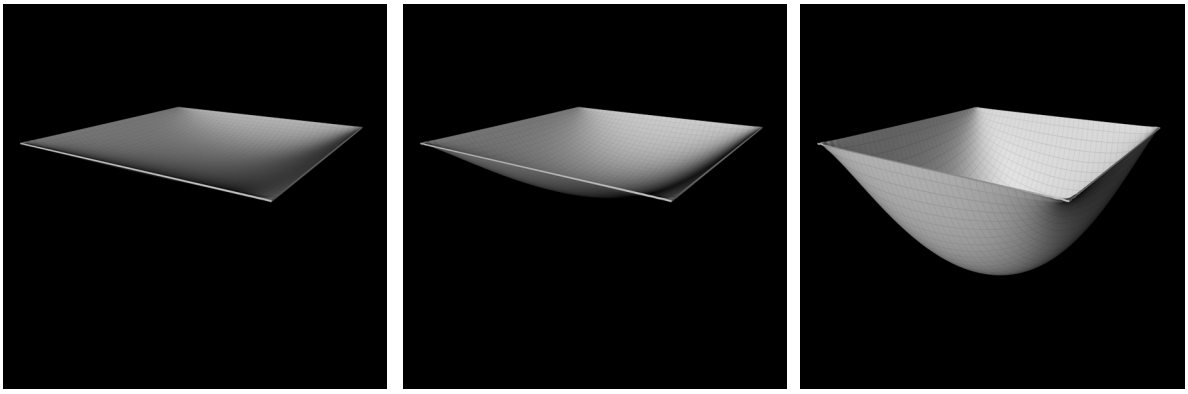


Figure 10,11 Cloth tension maps, red color indicates fabric in tension and blue color indicates areas of compression.

This is a novel approach with little precedence and no comprehensive tools to utilize. My decision was to employ dynamics simulation tools that are used in other industries, specifically, for the creation of special effects. While this may seem as stepping outside a scientifically defined education, these tools were readily available and were well integrated within a small number of software packages. Since we had to rely on the set of software that students felt comfortable with, as well as the need to cover a number of different simulations, I opted for the 3D Max/Maya approach with some data portability to other structural analysis software. Specifically, 3D Max/Maya were used in their generative aspects, and Revit and Robot Structural Analysis in their performance analysis capacity. This helped students to reduce the learning curve and opti-

Figure 12 Variations in material properties result in a different catenary shape.



mize the software knowledge they currently held.

Cloth behavior exemplifies generative properties of performance-based simulations.[Fig.9] Cloth simulations, by the very nature of this material, follow the stress flow exactly and visualize the logic of a form.[Fig10,11] For these reasons, students were asked to develop a number of cloth simulations that would mimic a fabric-based architectural structure and purse material and geometric limits. Software packages provide a wide range of material properties such as weight, flexion, stiffness or friction. [Fig.12] They also consider physical forces including wind and gravity. In result, one not only can model a spatial configuration of the cloth object as a response to acting forces, but also include material properties allowing for tearing limits and fractures. [Fig.13]

Cloth dynamics-based simulations are analogous to rigid and soft body dynamics in its 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 designed object, cloth becomes a dynamic skin that repositions itself based on the changed geometry of the collider framework.

Particle systems bring yet another simulation opportunity into design. In my course, students used them to evaluate aerodynamic properties of an architectural form. Other possibilities for particle system applications include aerodynamic simulations of urban spaces as well as smoke and fire spread in buildings.

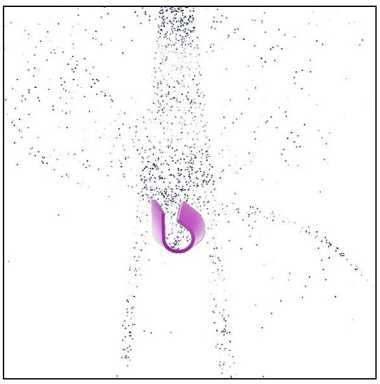


Figure 14 Particle inter-collisions

Figure 13 Cloth tearing simulations-foced applied by an external element exceeds cloth tearing limit.

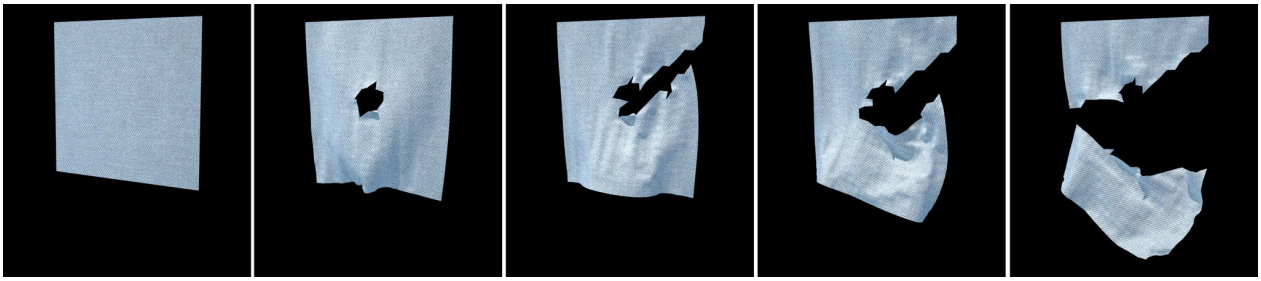
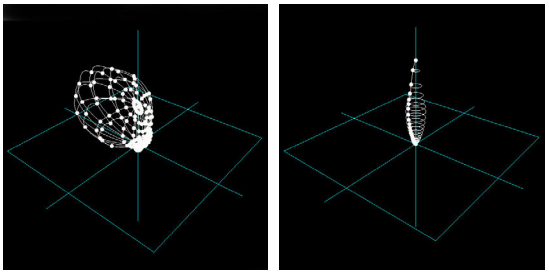
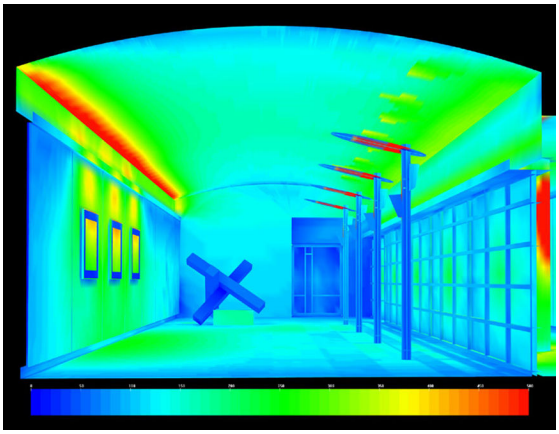


Figure 15, 16 Photorealistic rendering and the Illuminance map (right) with IES light definition webs (below)





The most interesting characteristics of a particle system are particles physically driven parameters. Particles can be designed to interact with other objects in a dynamic way, as well as to interact among each other. These inter-particle collisions not only allow modeling a particle system as a comprehensive force, such as wind, interacting with a building, but also within itself due to its volumetric properties. Figure14 shows an illustration of aerodynamic simulation that takes an advantage of the inter-particle collisions.

In an academic environment, my primary concern is empowering students with tools and methodologies to generate creative propositions and to later evaluate them. From my experience, whenever I had introduced aspects of simulations into studio design, I notice a great deal of enthusiasm coming from students. This enthusiasm went beyond the collecting of an edgy portfolio piece and often addressed students' insecurity about the extent and applicability of their knowledge. Specifically, while doing light studies, students were often enthusiastic about visual outcomes and were ready to use them in their designs. However, these light studies often worked as yet another way to present or is some cases "sell" the project and did not necessarily help them to understand or make more informed decisions about designs. This mindset became to change once students were introduced into physically based light analysis. Students were asked to choose lights based on the light manufacturer catalogs and the use provided by a light manufacture company photometric data (IES files) as light definitions. [Fig.15, 16] Furthermore, students were asked to render a number of views, including floor plan projection with tabulated illumination numbers in lux or foot-candle units. This also became an opportunity to discuss various associated design issues such as levels of illumination. We went as far as discussing the color bleeding phenomenon and ways to account for it in design.

As already mentioned before, students felt empowered not only by broadening their conceptual design framework with concepts of building performance, but also, or perhaps primarily, by its scientific and tangible dimension underwritten by physically based values and behaviors.
This pedagogic approach builds on the notion postulated by Eduardo Torroja in 'Philosophy of Structures', where he emphasized the priority of qualitative over quantitative structural thinking. *"We must disregard extraneous details—and especially eliminate mathematical procedures*

and numerical values—to concentrate on the problems rather from a more general and qualitative point of view. It is absurd to enter into quantitative concretion without the assurance that there will be a definite connection with ideas already being established."[14] Later he adds: *"The present–day student has to learn so many facts that his thought processes have little opportunity for development. (...) Attention must be directed to the basic structural concept before the mathematical process of calculation is undertaken."*[15] Even though Torroja published his words in 1950s, they still hold true and certainly gained a new relevance with the introduction of computational simulation techniques. Computationally-based digital structural simulations address Torroja' postulate of qualitative structural thinking. They do it in a way that emphasizes a structural model with calculations being a critical determinant, but not primary visual communication component. Consequently, computer-based simulations can become a core element of structural design education by forming *"connections with ideas"* and creating opportunities for students' educational development.

Two critical benefits emerge from the use of digital simulations:

1.) The development of an intuitive knowledge that may to some extent compensate for a lack of experience. In this meaning, intuitive (or primary process knowledge--we all have sensations before the verbalization or organization of a thought) knowledge is an unprocessed comprehension of an idea or a process that can be relied upon in preliminary decision making. This pedagogical approach responds to Michael Polanyi's *"Theory of Personal Knowledge"* where the author observes that knowing is an art form in which the knower understands significantly more than he or she can articulate. This comprehension of external facts without being aware of them specifically, called 'tacit knowledge', accounts for human ability to function in the world. "… tacit knowledge forms an indispensible part of all knowledge[16],' and this is this part of knowledge, which allows us to process meaning and reach goals beyond our verbalized or processed thinking. Confidentially, what we often call experience is closely related to, such defined, tacit knowledge. This connection suggests that experience can be reinforced or partially substituted by other forms of learning. Simulations can be one of those.

2.) An ability to ground a student in a physically based knowledge of architecture. In this sense, digitally based simulations relate to the teaching of materials and methods or building technology, since they bring physical properties and dimensionality to abstract designs.

The meaning of it all

On occasion, it is useful to question the validity and appropriateness of different tools or methodologies. I will follow the same approach in the following paragraph. I will discuss why it is important to use digital simulations not only for professional practice, but also for teaching.

When architectural design is informed or generated by building performance and analysis processes, design starts responding to outside formative factors. It emerges from the intuitive or subjective qualifications and is framed by explicit criteria. This does not mean that architecture can no longer be defined in terms of unquantifiable or ephemeral categories. It means that many

aspects of design once relied on descriptive characteristics, can now be better understood and defined through their parametric representations. This broadened approach does not limit, but rather broadens a definition of what architecture can be.

Figure 17 Brick project; first, freshman studio assignment by Maurice McDonald

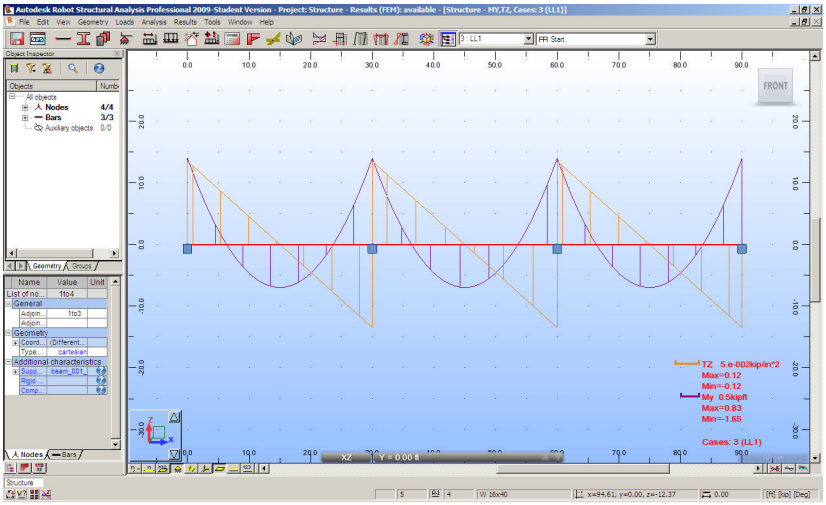
The process of simulation integration with design is analogous to that performed by an experienced designer in a conventional practice. However, it is more unequivocal since it relies less on the intuitive, unprocessed experience of a designer. With computational, performance-based simulations, judging criteria become explicit, albeit their weight and priorities would still be subject to individual choices.

Through simulation based modeling, often tacit knowledge (design thinking) becomes revealed, and consequently, solidified into tangible design criteria. As such, design thinking can be scrutinized and validated with more objective criteria. With the introduction of computational tools, we create an opportunity for individuals with less experience to navigate intuitively through design problems with more confidence. Technology, in this case, enables the democratization of specialized and complex knowledge by bringing computationally intensive tasks into a visually accessible working interface. While this might create a false confidence in some individuals, leading to design errors, the 'democratic' quality of digital simulation tools is beneficial to students and young professionals. It helps advance their knowledge, as well as helping them to experiment with design problems that would normally be outside their competence or areas of expertise.

This process of simulation and optimization of structural performance is common throughout architectural education. An example is a brick project where first year students create space frame structures to support a brick. [fig.17] Even though this model is not easily transferable into a full size, or a real life structure as discussed earlier, it still carries an educational purpose and meaning. In analogous ways, using computers to experiment with more complex structural or other performance problems extends the same rationale that grounds the educational value of the brick project.

Structural performance and simulations are often achieved with graphics modes. For example, when we teach the concept of the moment equilibrium, we usually use diagrams to explain to students mathematical relationships (formulas) in a visually understandable way, instead numeric values. We not only describe structural behavior in a visual way, but we also relate a shear with a moment diagram to discuss their interdependency (zero shear and maximum moment). We do this because; the use of diagrams makes these relationships explicit and easy to comprehend, which would not be the case with purely numeric data. With each new mode of presenting data, a new way to interpret this data emerges, potentially resulting in new idea formations and discoveries. This example is not limited to structural visualizations or architecture, and is evident in most disciplines. An analogous conceptual shift occurred in late middle ages with the introduction of algebraic symbols and transcriptions. In this instance, algebraic definitions allowed for a

Figure 18 Examples of both types of beams simulated with Robot Structures



new set of operations that were not possible with a previous descriptive approach. An introduction of algebraic ways of presenting data helped in resolving many mathematical problems, among them was the solution to the quadratic equation.[17] Similarly, digital, visually-based simulation can open creative, problem-solving, venues for architects and designers.

The use of simulation techniques does not replace but complements the current design and educational approach. There are number of area where digital simulations could have a direct impact on the quality of teaching. The visualization of numeric data such as shear, flexural moment or deflection, which display interconnected characteristics (calculus connection), directly relates to a beam's behavior. Shear values define a position of a maximum moment value, whereas, a point of inflection indicated a change in positive versus negative moment characteristics.

Furthermore, digital simulations allow students to look at more complex structural systems and to better understand their behavior. Specifically, educators can extend structural teaching models into interdependent structural systems that consider vertical and horizontal loads of an entire structure. While structural calculations, in class context, usually stop with statically determinate structures, digital simulations can easily be extended into statically indeterminate systems such as continuous beams, at the minimum. [Fig.18] This is an important distinction between traditional and computer assisted teaching methodologies. Traditional structural education would focus calculation-based learning on individual structural components such as a beam or a column. It would focus on integrated systems or complex framing in a descriptive, not computational way. Students would be told what a system would behave like, but would not be able to see it by themselves. Coincidentally, these complex systems need to be visualized most often because their behavior is less common-sensual to students as compared to simpler models. Unlike the flexion of a beam or a column, of which a student might have had observed a similar phenomenon on his or her own in the past, complex and integrated systems typically lie beyond our immediate experience. As a result, we often calculate and experiment most with structural examples that are the easiest to experiment with, but also the least educational since they often are already intuitively understood by students. This realization is not proposing an elimination of simple model simulations, but rather argues for extending those simple models to understand them as components of a broader interdependent system. I would argue that presently, digital simulation tools are the best medium for experimentation and education, albeit these tools are still in development and need of further development.

This simplified approach to structural calculation in the teaching of structures was dictated by prohibitively complex calculation required by more intricate structural systems. This complexity was often too difficult to calculate even for structural engineers, as it was the case with suspension fabric structures. Much of the calculations in those cases were done on the comparative models of soap bubbles.[18]

Reversing an Equation

In parametric-driven design, relationships between objects are defined explicitly. A parametric definition is an underlying structure—lingua franca—of both generative design and simulation based design evaluation. The parametric treatment of design allows for the quantification of input values and the interactive design modifications. The relationships once established can be easily transferred to other objects or manipulated by accessing their numeric attributes. Different parameter values could generate model variations while preserving essential topological characteristics. Since parametric controls are discrete and numeric, these characteristics are explicit and allow for the rearrangement of form defining parameters.

Form generation based on a performance simulation would not be possible without the parametric definition of digital models. Parametric controls allow for quick design reconfigurations that not only can optimize design, but also allow the deriving of new forms based on performance simulations. Furthermore, parametric design not only has the ability to define discrete tectonic states, but also allows for the interrelation of input and output values of simulations. This means that these values can be traced back, modified and reverse-engineered. The simulation derived form can be seen as a parametric equation, where both input and output values can be treated as variable.

Since generative digital design can be a product of a parametric formula, we 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 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

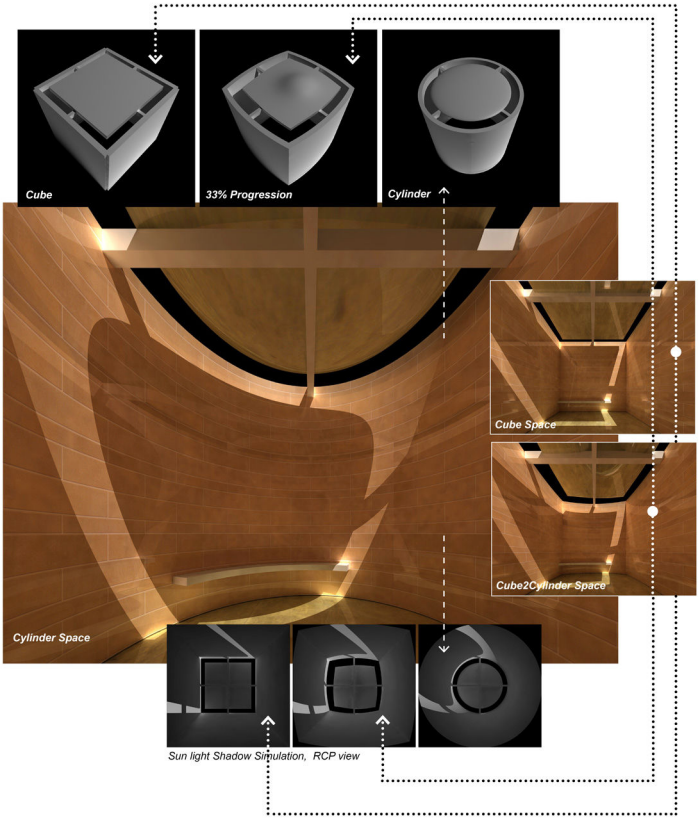


Figure 19 Animating a building envelope allows for an in-depth lighting analysis

based on final delivery criteria. For example, instead of studying sunlight within a space throughout a day, one could study the form as a morphing continuum 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? [fig.19] This effectively repositions 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.

The ability to reverse a design equation and derive a component that is usually considered as unchangeable or constant allows for imaginative leaps. This brings a feedback mechanism into design simulation and allows for a two-directional design process, where the final design can be tested against initial assumptions. Vice versa, a class of possible final designs can be used to verify the integrity of the initial assumptions. Furthermore, this approach promotes creative, non-hierarchical thinking by questioning and testing initial assumptions, which consequently help in overcoming design stereotypes and the inertia of past ideas.

Possible impediments and misuses

While I see great potential in digital simulation and analysis technologies, in general, and dynamics based tools in particular, we also need to see these tools for what they are. It is important that we use them to our benefit, not as a way of outsourcing creative thinking, design attention, or innovations. To become an empowering aid, not a crutch, which gives us an excuse to lower the expectations we set for ourselves or our students. In a similar way as was satirically yet accurately characterized in the movie "Wall-E."

There is a fine but critical line between chasing the 'newest and coolest,' and developing an understanding of its creative use and possibilities. I notice while some students go through the motions of using a tool, they do not really understand the tool's design implications nor benefit their designs from its use. Both in academia and in profession, we see more attention being given to sustainability or performance-based design issues. Unfortunately, this is often done without a due diligence, leaving the design discussion primarily within a sphere of good intensions or wishes, not a direct and focused action. The danger is that students, and professionals alike, may look like they address the performance criteria by using imagery and data that illustrates, for example photometric lighting analysis, but this does not have to implicate its actual relevance to design. This resembles situations with early CAD drawings, in which case, a neatly plotted drawing would project a sense of professionalism and completeness independent of the actual architectural abilities of a person who created them. This was a significant shift from the traditional modes of an architectural production, where the quality of drawings was associated with amount of drafting experience, which usually, but not always, correlated with architectural design and technical expertise of a designer.

Closing thoughts

This paper discusses the integration of tectonic architectural studies with structural analyses and

building performance simulations from an academic perspective, where the conceptual or visceral understanding of structures—a general and qualitative point of view—is more important than quantitative and numeric. The ability to visualize structural performance—stress, tension, sheer—and interactively study the impact of these forces on an architectural form, results in an integrated design process. Furthermore, these interactive simulations translate into a visually inspired, virtual hands-on experience for students and young practitioners by helping them to develop an intuitive knowledge of architecture.

This simulation based interactive approach shifts the student's focus from the visualization of buildings or data to the visualization of physical processes and behaviors. To bring the visual component of material and structural behaviors, I will be discussing the use of special effects software that focus on the realistic portrayal of physical processes like fluid dynamics, cloth or particle interactions. While these software packages were originally developed for creating special effects in cinematography, their visual and perceptual accurateness can be used to inform architectural design.

Since the primary focus of the special effects software is to convince the viewer not to calculate the numeric value, these software, while physically based, may not be as correct as the specifically designed engineering software. However, the question of good-enough or close-enough is relevant in terms of the overall design intention. Their use and purpose is to give designers a good-enough approximation of a model's behavior, as well as to set an overall design context and parameters. In the design process, particularly in the early formative stages, "good-enough" precision is satisfactory. The focus is on the usability of simulated data, the capacity to interactively model changes and the ability to reverse a "design equation" to derive the necessary formal suggestions.

Consequently, through the use of dynamics based software a new and promising direction of generative architectural designs emerges. An architectural form not only can be analyzed based on its structural performance, but also derived through the process of structural simulations. This method of form generation brings the promise of greater design integrity within new creative horizons.

The fundamental question that needs to be further investigated is how we should relate a generative design system with performance simulations and analysis. The common-sense approach would be to combine both in the performance based generative system, not unlike discussed example of soft dynamics--cloth simulations. While it is highly desirable to create forms that immediately respond to design criteria, there may be also limitations of introducing too much reality too quickly. After all, any generative system flourishes when it is not overly prescribed with initial conditions. Perhaps, this hesitation, on my part, would disappear when multiple criteria were considered moving design predictability form the deterministic into probabilistic sphere again.

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