Unusual Encounters: The Use of Special Effects Tools as Design Generators

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INTRODUCTION

Once new and exotic, digital tools have become a mainstream approach to design thinking and production in architecture as well as other creative disciplines. Highly specific and effective in their particular functionalities, these software packages often focus on narrow operabilities with a limited range of design outcomes.

Meanwhile, tools such as AutoCAD or Rhino have acquired such a prevalent use that they are no longer perceived as groundbreaking in the way they were seen 15 or 20 years ago. Certainly, continuous updates and releases allow for advancement of new generations of digital tools. However, meaningful creative breakthroughs often come from subverting intended software uses and pursuing guerilla-like applications. Frequently, new ideas emerge from challenging established conventions and from unorthodox uses of existing tools.

This paper investigates such "unusual encounters" and their role in questioning newly established methods and practices. These "subversions" not only keep a creative dialogue current by promoting innovative designs but also indicate possible areas of growth for future software releases, demonstrating needs and possible outcomes.

Generative design in the context of performance analysis and validation tools is a topic pursued by a number of researchers. For this purpose, most approaches use dedicated performance analysis tools that require data to be exported outside the basic modeling package. In these instances, the integrity of data is often compromised. Futhermore, often the evaluated and validated data cannot be transferred in a bidirectional way back to the original modeling package. Consequently, this lack of bidirectionality limits the portability of design models and ultimately leads to narrowing desing explorations.

This paper discusses the strategies for generative design validation using dynamics-based modeling tools that allow for the "within-the-package" simulations, and as such eliminate the need for data transfers. At the same time, this approach facilitates an increased awareness of structural perfmance issues and form-making in architecture. Case studies below look specifically at digital tools that realistically portray physical processes such as rigid/soft body dynamics, including cloth simulations, forward and inverse kinematics (FK/IK), hinge-like constraint systems, and particle interactions. Through the use of dynamics-based software, a promising direction for generative architectural designs emerges. An architectural form not only can be analyzed based on its structural performance, but also can be derived through the process of structural simulations.

The emerging design approach fuels a renewed interest in geometry, physics, and building performance simulations. It creates a new relationship between science, technology, and design through computational form finding approaches. It also sets new expectations for digitally based architectural practices: expectations for architecture that behaves like a 21st-century structure, not merely looks like one, and that fully benefits from the present state of knowledge.

PHYSICALLY BASED DIGITAL WORLD

By definition, virtual environments exist outside physically bound reality. While they are usually experientially real, they often do not directly correspond to the world outside the computer. In virtual worlds we decide on laws of physiscs or, in what is more common practice, we choose an "option" to ignore them. Criticized for being scaleless, materialless, and unrelated to the surrounding context, this form of abstraction often liberates creative thinking, resulting in innovative designs. However, this non-physical existence of virtual models does limit the applicability of creative results in the physical world, leaving these innovations in a sphere of imaginary, not-actual creations.

Consequently, new digital design directions pursue virtual environments that are conditioned by, and also can influence the way we engage, the physical reality. Performance-based simulation is emerging as a critical component of the contemporary design process [Kloft 2005][Oxman 2008], where it can function as a mechanism for the generative design validation. Performance-based simulations could facilitate creativity by interactively responding to design parameters or function as semi-intelligent, self-optimizing agents that preselect promising generative scenarios and then channel them through a hierarchical portion of the design production (BIM software). The genetic algorithm (GA) [Sasaki 2008] [Benoudjit and Coates 2008] and other evolutionary algorithms (EAs) are among the strategies that integrate structural analysis with architectural design.[Schein and Tessmann 2008] For example, Schein and Tessmann have developed a procedure for the space truss optimization based on a collision detection analysis. However, this and similar tools are still in the developmental stages and are harder to implement in a classroom context to test complex designs.

The gap between generative design tools, which are often used to pursue exclusively formal gestures, and building modeling tools (BIM) is narrowing. Generative tools start considering form's performance as well as material behaviors, while BIM tools define architecture as a parametric, spatially resolved object that can be freely manipulated and explored. This mutual convergence between generative and BIM tools is particularly effective in a scale of design components, where individual elements and properties can be parametrically interrelated. Both approaches also establish an active link between an object (component) and the entire system (whole) with an ability to manipulate individual design characteristics. While each software environment achieves this in a different way, the ability to interrelate a fragment with the entire design is common for both environments: generative dynamics and parametric BIM.

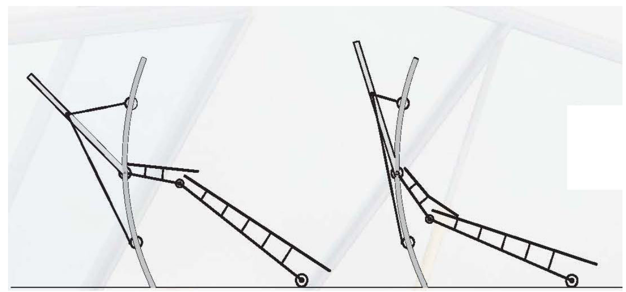

Figure 1 IK system after translation into BIM model with parametrically controlled components.

For example a rigged, IK bone system can demonstrate behavior similar to parametrically controlled composite beam-column. [fig.1] 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. Consequently, 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.

Recognizing this opportunity and testing design possibilities afforded by this approach became a central theme for a class taught by the author. Students in the class focused on traversing this 'continental divide' between generative and building modeling software with promising, yet hard earned, results. Students' work discussed later in this paper shows this convergence.

DESIGN APPLICATIONS

Special effects 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 dynamic simulation. This combination of increased accuracy and interactivity brings a new promiseof integrated thinking into digital architectural design.

Dynamics tools such as cloth, particles or IK bring a combination of interesting characteristics into design. On one hand, they are very suggestive, visually inspiring modeling tools that function well as generative tools. On the other hand, they start considering 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). [fig.2]

In class projects, we focused on design methodologies relating to the use dynamics-based tools. We looked at approaches that incorporated optimization and form generation mechanisms: specifically, mechanisms that openly consider form, but also interact with simulations in a bidirectional manner. This bidirectionality 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. While the form finding could have been achieved in various software packages, an ability to animate transformations and interactively change design parameters was seen as a crucial feature of an effective generative tool. Animation tools allow for scanning the entire spectrum of possible solutions by analyzing a class of objects rather than an individual instance.

Furthermore, animating simulations puts a particular design scenario in a wider spectrum of design performance. This approach has broader design and educational benefits as discussed by Shea: "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." [Shea 2004]

The class engaged these possibilities by employing dynamics simulation tools that are used in other industries, specifically, for the creation of special effects, gaming and character animation. [fig.3] While this may seem like 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 most comfortable with, as well as the need to cover a number of different simulations, we opted for the 3D Max/Maya approach with some data portability to other structural analysis software. This helped students to reduce the learning curve and optimize the software knowledge they currently held.

The following examples show specific applications of dynamics tools such as rigid/soft body dynamics, forward and inverse kinematics (FK/IK) and particle systems. While each of them represents a narrow aspect of design performance simulation, a combination of them quickly becomes a potent design tool.

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.[Fig.4] 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.

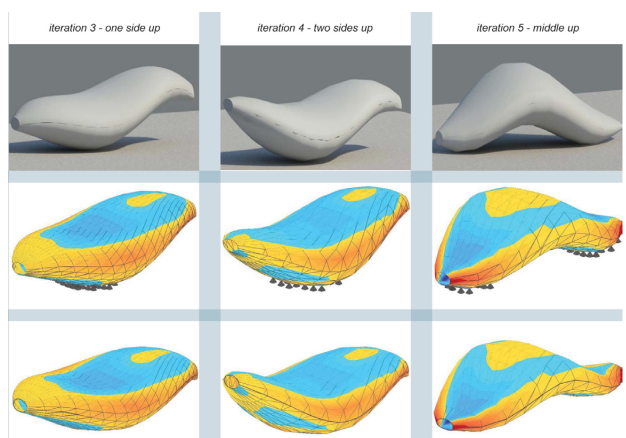

Figure 2 Similar results are usually achieved with advanced Finite Element Analysis (FEA) simulation software.

They also consider physical forces including wind and gravity. In result, one not only can model a spa-

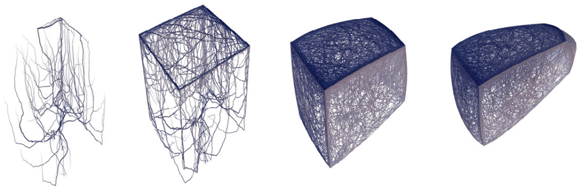

Figure 3 Generative form-finding. Figure above shows a semi-autonomous "vine" negotiating its growth in the relationship to continuously morphing form.

tial configuration of the cloth object as a response to acting forces, but also include material properties allowing for tearing limits and fractures. [Fig.5] This interdependence between performance of a form and material parameters brings 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.

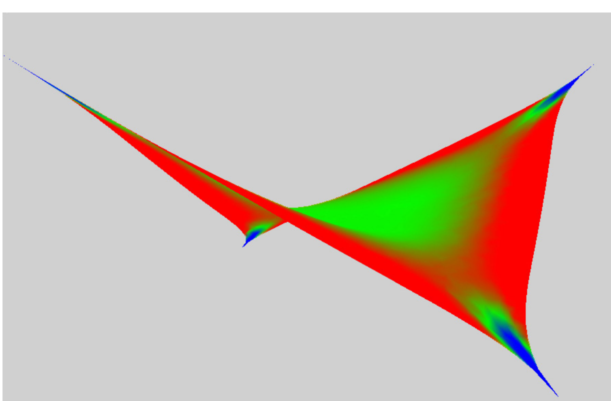

Figure 4 Cloth tension map; red color indicates fabric in tension and blue color indicates areas of compression.

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. In some cases, 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.

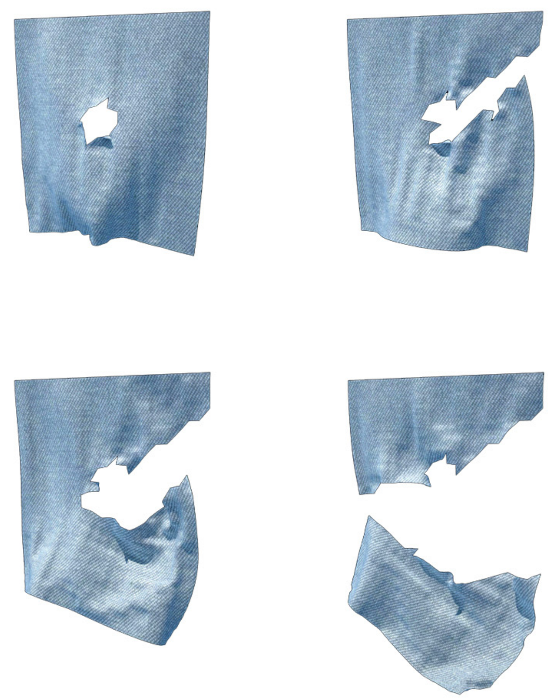

Figure 5 Cloth tearing simulation. Force applied by an external element exceeds cloth tearing limit, resulting in a progressive rip.

BONES AND SKELETAL SYSTEMS

Inverse kinematics techniques, adopted from character animation modules, were used investigate structural skeleton systems with integrated and interconnected framing members that mimicked sophisticated architectural structures. [Fig.6,7,8] The ability to rig complex bone arrangements into a hi-

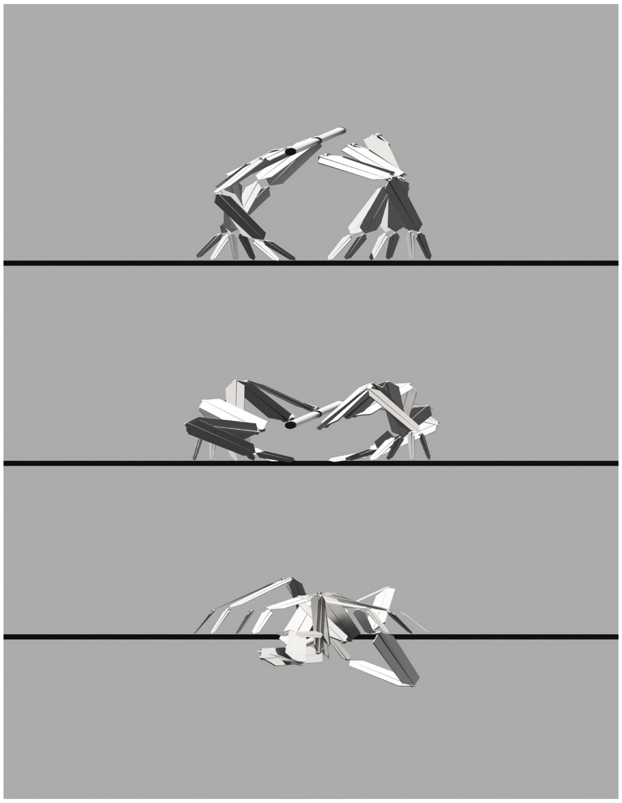

Figure 6 IK bone system helps to control structural frameworks

erarchical 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 composite design integrated cloth with bone framework and could have been 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 purse unusual and imaginary designs without need to resolve constraint requirements necessary in BIM system.

HINGES, CONSTRAINTS, AND RIGID ORIGAMI

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 can be realized with a number of software tools. Digital origami generators, such as: TreeMaker,1 Origamizer,2 and Mathematica, 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.

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. 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.

Research into rigid origami, facilitated by these unorthodox software uses, provides an effective platform for investigations into kinetic structures and adaptive buildings. 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. 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]

WHEN NUMBERS MATTER

Particle systems bring yet another simulation opportunity into design. In my course, students used them to evaluate aerodynamic properties of an architectural form. This was a narrowly defined approach dictated by a wide range of various simulations they were expected to do. Other possibilities for particle system applications include aerodynamic simulations of urban spaces as well as smoke and fire spread in buildings.

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. [Ophir 2008]

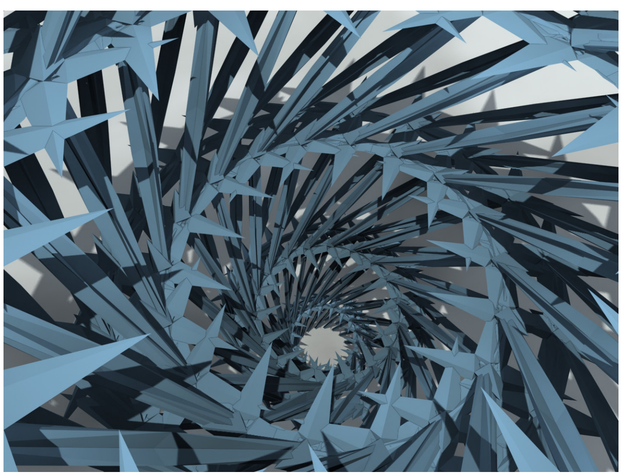

Figure 7 Interconnected frames mimicking adaptable structures.

Faktura:[3] combining form and texture

Digital sculpting software tools such as ZBrush or Mudbox allow for simultaneous three-dimensional modeling with surface sculpting and painting.

3D modeling and painting are usually separated in the traditional design process, which results in detached thinking about form as separate from material considerations. The combination of both techniques in a single toolset enables a conceptual merger of form and materiality. Each of these qualities is always considered in the context of the other in a bidirectional way. Not only can a form call for a use of a particular material, but a texture can be a driver defining a form, particularly on a micro scale. An example would be a tree bark with three-dimansional definition of its surface.

Additionally, an ability to paint texture three-dimensionally allows for a greater photorealism and efficiency in developing textured models for uses that benefit from hyper-realistic renditions, such as historical preservation, renovations, and recreation projects. This is particularly effective when considering material aging and degradation (dirt) within a scene. Finally, features such as texture baking can be used to reduce theamount of geometry in a scene and provide pixel-based details, particularly on a large, highly detailed scenes.

BRIDGING PERFORMANCE WITH DESIGN

After the initial development and simulations of generative designs, students were asked to transfer them into a BIM environment for further analysis. The path from generative to building modeling software was difficult and convoluted. Students often had to use other software packages to make transitions possible. This could have involved rebuilding a cloth surface in Rhino or recreating structural elements that behave like IK bones in Revit. While there are not direct and easy ways to go back and forth between various software, the process of 'crossing the divide' was educational and gave students a better understanding of design possibilities afforded by various software packages. Additionally, by recreating IK chains in BIM software, students became exposed to the logic of constraints and degrees of freedom.

Dynamic toolsets can define design in ways that would be difficult to arrive at with more traditional digital techniques such as NURB or solid modeling. This became particularly evident to students in the class who were attempting to recreate certain aspects of their IK models within BIM software. They quickly realized that using a constraint system of IK produced results faster than fully parameterized and initially less constrained BIM model/object.

Students learned from constraint and parametric models how to define parameters in a way that brings flexibility into a design system, but at the same time, define parametric flexibility that would not over-constrain their designs. Since each new parameter introduces a set of constraints (parameter range), a large number of parameters may result in increased constraints or inability to resolve them.

This parameter versus constraint relationship allows students to realize that creativity of solutions is achieved not by excessive "parameterization" of their design objects but rather by balancing parametric freedom and simplicity of an approach—structuring parameters for effective and creative use.

Dynamics–based generative models can become stepping stones for parametrically driven BIM models. This tendency can be seen in the case of CS-FEM plug-in for Maya software, [Vollen et al. 2007] which is a further step towards integration of generative and validation tools within a single design environment.

BROADER REFEECES

This design approach relates to ideas discussed by Eduardo Torroja in *Philosophy of Structures,* where he emphasized the priority of qualitative over quantitative structural thinking. [Torroja 1958] Computationally based digital performance simulations address Torroja' postulate of qualitative structural thinking.

Additionally, digital simulations allow designers to look at more complex systems and to better understand their behavior. Specifically, educators can extend structural teaching models into interdependent systems that consider an entire structure. While calculations, in an architectural 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.

VALUE OF "SUBVERTING" TOOLS

This approach addresses directly "lateral thinking" ideas proposed by Edward Buono. A "subversive" (mis)use of software tools maps directly onto Buono's concepts of Random Entry Idea Generating,, Provocation Idea Generating, and Challenge Idea Generating Tools. These concepts allow for conceptual shifts and creative "adaptive reuses" of software tools.

In recent years, we have witnessed a growing number of papers on the topics of generative and performance-based designs. These studies focused on theoretical underpinnings and/or relatively narrow applications that addressed particular functionalities. This study attempts to broaden this framework into multiple dynamics tools by interconnecting them into an integrated and comprehensive model. This is seen in an example that combines multiple dynamics tools, such as inverse kinematics (IK) and the cloth engine interoperability, into an architecturally relevant model.

Furthermore, this case study (student work) interrelates behavioral aspects of the dynamics-based tools with database models. It specifically maps individual capabilities and correspondences between both platforms and proposes a direction for further developments in the BIM platform. It shows the need for and opportunities associated with combining behavior-based and database characteristics into a single design model: broadening BIM not only as a database, but also as a behavior/performance model.

Finally, this case study allowed students to discuss an integrated design process, first by developing strategies for conceptual design and later by recreating conceptual designs within the BIM platform by mapping relationship between dynamics and BIM tools.

Figure 8 Design incorporating multiple instances of a parametrically defined structural column.

CONCLUSIONS

The examples discussed above illustrate a number of software “hacks” that offer an alternative, and broader, use of mainstream software. These “subversive” (mis)uses attempt to reconnect intutitive designers with tools that respond to creative input and consider a wide number of design parameters.
This simulation-based, interactive approach shifts the designers’ focus from the visualization of buildings or data to the visualization of physical processes and behaviors. The move is from static to more dynamic thinking. Consequently, through the (mis)use of dynamics-based software, a new and promising direction in generative architectural design emerges. An architectural form not only can be analyzed based on its structural performance, it can actually be derived from the process of generating structural simulations. This method of form generation brings the promise of greater design integrity within new creative horizons.

Finally, consideration of discussed topics,and referenced works could help to bring digital design onto the next level of physical reality, one that considers not only form, but also material properties and behaviors, important characteristics to fully engage digital tools with real-life design practice.

REFERENCES

Aish, R: 2005, From intuition to precision, *The 23rd eCAADe conference*, Lisbon, Portugal, pp. 10-14.

Benoudjit, Mohamed Amine and Coates, Paul S., Artificial networks for spatial analysis, *International Journal of Architectural Computing (IJAC),* 2008.

Boeing, A, and T Bräunl. 2007. Evaluation of real-time physics simulation systems. *Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia GRAPHITE 07* 1, no. 212: 281. http://portal.acm.org/citation.cfm?doid=1321261.1321312.

Burry, J, Felicetti, P, Tang, J, Burry, M and Xie, M: 2004, Dynamic structural modeling, *The 22nd eCAADe Conference*, Copenhagen, Denmark, pp. 312-317.

Kilian, A: 2004, Linking digital hanging chain models to fabrication, *Proceedings of AIA/ACADIA,* Cambridge and Toronto, Canada, pp.110-125.

Kloft, Harald; Non-standard Structural Design for Non-standard architecture; in *Performative Architecture: beyond instrumentality; ed. Branko Kolarevic and Alim m. Malkawi;* Spon Press, New York and London, 2005.

Narahara, Taro. 2010. Designing for Constant Change: An Adaptable Growth Model for Architecture, *International Journal of Architectural Computing (IJAC), issue 01, volume 08. 2010*
Ophir, Y: 2008, Go with the flow: particle systems for program modelling in high-rise buildings, *International Journal of Architectural Computing (IJAC),*, Vol.06, pp. 172-196

Oxman, R: 2008, Performance-based design: current practices and research issues, International journal of architectural computing, Vol. 06, pp. 1-17.
Polanyi, Michael 1983, The Tacit Dimension; Peter Smith, Gloucester, MA, p.20

Sasaki, Matsuto; Morphogenesis of Flux Structure, in From Control to Design: Parametric/Algorithmic Architecture; Verb Monograph, 2008 p.106; also available at www.isozaki.co.jp
Schein, Markus and Tessmann, Oliver 2008, Structural analysis as driver in surface-based design approaches in IJAC p.19.

Shea, Kristina 2004, Directed Randomness, in N. Leach, D. Turnbull and C. Williams (eds), Digital Tectonics, London: Wiley-Academy, pp.89-101.

Spuybroek, Lars; The Structure of Vagueness; in Performative Architecture: beyond instrumentality; ed. Branko Kolarevic and Alim m. Malkawi; Spon Press, New York and London, 2005, p.167.

Torroja, E. Philosophy of Structures. Trans. J. J. Polivka and Milos Polivka. Berkeley: U of California P, 1958. 1-3.

Vollen, J, Clifford, D, Winn, K, and Gindlesparger, M, 2007 Digital Fabric: Generating Ceramic Catenary Networks.” Expanding Bodies: Proceedings of the ACADIA 2007 Conference. Ed. Brian Lilley and Philip Beesley. Halifax, Canada: Riverside Architectural Press, 2007. 48.

ENDNOTES

1 http://www.langorigami.com/science/treemaker/treemaker5.php4.

2 http://www.tsg.ne.jp/TT/software/index.html.

3 Referring to the material aspect of the surface "A word associated with the Russian Constructivists artists. In the period after the Russian Revolution, new definitions of art had to be found, such as the definition of art objects as "laboratory experiments". "Fakture" was the single most important quality of these art objects, according to the critic Victor Shklovsky, referring to the material aspect of the surface. The surface of the object had to demonstrate how it had been made, exhibiting its own distinct property." http://www.babylon.com/definition/faktura/English.