6 CONCLUSIONS

Two innovative tools used for the quantification of building efficiency and sustainability are presented. These performance tools rapidly evaluate building performance with regard to floor area efficiency and equivalent carbon footprint when only the perimeter form of the building is known.

With increasing complexity and efficiency requirements of tall buildings, innovative platforms must be developed that rapidly inform designers during initial stages of development. It is envisioned that the EA Tool and PCM could guide designers toward synergy-oriented design of new urban centers and rehabilitation of existing districts.

Expanding traditional metrics of design at planning stages to include embodied carbon emissions, saleable area, climatic influences, probabilistic seismic damage, and construction materials facilitates a holistic approach to design. Multi-objective optimization routines could be implemented for investigation of concurrent performance of competing design objectives. Such implementations would facilitate a new generation of sustainable design, where efforts of the past begin to inform environments of the future.

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CONDITIONING ELEGANCE:
A DESIGN EXPERIMENT ON INTUITION AND ANALYSIS

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ABSTRACT

This paper offers an assessment of two methods for design—one based on intuitive design skills, the other on feedback from performance analysis—offered within a course with a biomorphic focus. The project demands a design solution that operates on two levels, function and aesthetics; students focused on proposing an "elegant" building component without compromising structural efficiency. The results are discussed with regard to aesthetic theory, as indicators toward integrating analysis tools in creative processes and also understanding different learning paradigms for students. Furthermore, the students' perception of the process within two different rule-based systems is discussed. Finally, the evolution of this experiment within a clinical framework by collaborating with neuroscientists is contemplated, with the scope of collecting quantifiable data about aesthetics and establishing a connection with data-driven design processes.

1 INTRODUCTION

Throughout the history of architecture we have tried to identify qualities that define our understanding of construction. Since the archetypal definition of venustas by Vitruvius, it is clear that beauty has always been considered a significant part of design experience. With the emergence of digital tools, designers have been less explicit in defining beauty and have adopted other, similar parameters that may better describe the qualities of digital form. One such term that has been discussed within recent theoretical discourse (Rahim and Jamelle 2007) is elegance. Describing the difference between elegance and beauty is perhaps not necessary here; it may suffice to say that something elegant will very likely qualify as beautiful, whereas the inverse statement may not be true.

1.1 What Is Elegance? Can It Be Enhanced Through Performance Analysis?

Our reference to "elegance" in this paper will adhere to certain attributes that have been argued within the context of digital design and are mentioned later on. Based on this understanding, the project negotiates the creation of elegance through different approaches that may help us define how we teach, design, and learn.

The traditional definition of "elegance" relates to the following qualities:

1. *Refinement*, grace, and beauty in movement, appearance, or manners; tasteful *opulence* in form, decoration, or presentation.
2. *Restraint* and grace of style; scientific exactness and *precision*.
   (See http://www.thefreedictionary.com/elegance.)

Ali Rahim and Hina Jamelle's work is concerned with *precision, surface refinement, and restrained opulence* (Rahim and Jamelle 2007). As a concept that is instinctively associated with the same family as "beauty," elegance may connote a certain degree of subjectivity; one might expect it to arise from purely imaginative processes. It may be interesting, nevertheless, to situate its provenance within the more complex realm of digital "integrative design" (which borrows influences from computation, biology, and engineering, as well as other potentially advisory disciplines, and can operate at similar or different scales). As scientific disciplines increasingly overlap, architects find themselves engaged in "synthetic" relationships, using palettes of tools outside their immediate area of expertise. These new digital ecologies—by which we refer to the new frameworks of operation that have appeared due to the synergetic nature of architectural practice that relies on digital methodologies—improve and augment our understanding of virtual and physical constraints. The question is, can these "other" analytical processes be married with our creative instincts successfully? *Can analysis and simulation generate elegance*? As an effort to trace historical references to aesthetics, it is worth noting the criticism of Geoffrey Scott toward the rationalization of design during the period leading up to modernism, and his belief that architectural beauty exceeds the notion of "good structural performance. As Scott wrote, it is not only a result of "intellectually tracing forces," but must also encompass greater aesthetic and formal issues (Scott 1947). This distinction may be relevant to our discussion of cognitive processes later in this paper.

1.2 Project Description

This project was introduced to 11 students as an exercise in form generation. (The author's interest in form extends beyond aesthetic concerns, and lies in the relation of form to other parameters such as structural and material performance. Aesthetics remains our primary assessment, but only in so far as it has grown out of other, more performative criteria.) The participants were asked to design a column based on their understanding of proportion and elegance. The column, whose notional dimensions were 30" × 30" × 20', would support a structure over a double-height space.

The project was executed in two autonomous stages: first, the students designed with Rhinoceros assuming vertical loads and developed narratives; the second stage required decision making based on visual results from finite element analysis (FEA) software. FEA analysis typically uses mesh subdivision to calculate forces on doubly curved surfaces. For this stage, we used Scan&Solve, a plug-in for Rhinoceros. The stages were intentionally organized to stimulate different ways of thinking for the students, who later completed a questionnaire about their preference of the assigned methods.

2 PROJECT DISCUSSION

2.1 Column v.01: Intuitive Emergence

Our expectation was to reach an "emergent" result in form. Emphasis was placed on producing versions, each one resulting from the one before after assessment and improvement. As an operating framework, we discussed with the students the possible factors to be considered besides structural integrity (Table 1), namely, the various factors that influence proportion, such as variations in thickness, length, shadow, and color.

Students worked in groups or individually, developing concepts and 3D models in Rhino. Their influences included the human form, fractals, sound, and natural patterns. I will discuss the most successful iterations of the first stage of the project, with the goal of identifying which are the most elegant and why. The three selected designs are distinctive in their conceptual approach.

Table 1: Parameters for design of Emergent Column project, v.01: Intuition.

Parameter	More +	Less -	Normal ~
Length	Effect is eliminated (redundant)	Effect is exaggerated	Effect is realistic (Elegant?)
Thickness	Non-uniform: Base larger	Non-uniform: Top larger	Uniform: Over-scaled
Shadow Amount	contradictory to contextual conditions		Harmonious to context
	Thinner	Thicker	Observer position awareness
Shadow Position	Top: artifact appears smaller	Bottom: artifact appears larger	uniformly distributed: artifact appears balanced
Color Amount	Distraction from Form	Emphasis on Geometry	normal: equal amount (case by case basis)
Color Type	Dark: artifact appears thinner	Light: artifact appears thicker	
Color Position	Top: Volume increase; attention to higher features	Bottom: attention to lower features	
Material	n/a	n/a	n/a

Project 1: Reverting to the biomorphic focus of the course, one project looked for inspiration in the human muscles. Through watercolor drawings (Figure 1), geometries were investigated to understand the interrelationships within a muscle-bone system. A solid mass was broken down into four large pieces that were linked by smaller components to provide stiffening. The primary pieces were later reduced to three, to decrease the column mass.

Two "families" of columns were produced; the first featured a smooth surface, while the second incorporated grooves to explore the effect of shadow on the surface. The flutings (Figure 1) were further developed and adjusted along the overall height so they would appear prominent at the ends of the column but dissipate toward the middle, exposing the smoothness of the surface. This iteration proved more successful because the shadows caused the column to appear lighter despite its significant height.

figure 1

figure 1

Column, v.01: Concept study of muscle; family of columns (elevation and plan); perspective of final iteration. (Design: Richard Brewer.)

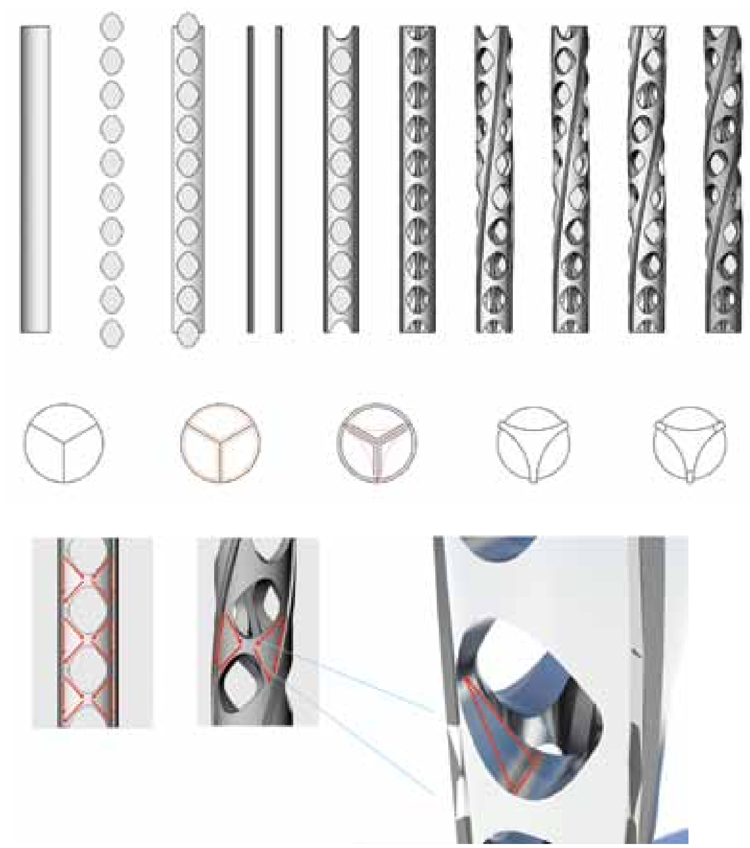

figure 2

As mentioned earlier, we are concerned with the pursuit of elegance, as it is defined within contemporary digital design. This column seems to display all three attributes of elegance according to Rahim's definition: precision, surface refinement, and restrained opulence (see section 1.1).

It may also be worth examining the designer's perception of his own proposal. During the questionnaire session following the project, the students were asked which attribute makes their column elegant. Although this particular student consciously designed for opulence, his project is inherently precise and refined: The "stitching" of the larger volumes with smaller surfaces required a parametric definition for "minimal surfaces" to achieve the least possible impact. The flutings introduced refinement of the large surface. Overall, the column demonstrates richness in features, within a controlled fashion, so we may conclude that it has achieved "restrained opulence."

On another level, this design is intriguing because the flutings and connotation of muscular connections refer to a kind of classical quality. The biological nuances inherent within the design are exemplified in Viollet-le-Duc's analysis of Doric capitals (Antoniades 2000). In his Lecture No. III, Viollet-le-Duc argues that "the sectional profiles of Greek capitals are reminiscent of the muscles which are at the extremities, and cover the gap between the bones. When the artist tries to assign a presence of strength to some part of his composition, he is careful to adopt in the design of his sections, the fine lines displayed by the human body when the muscles are under the tension of sudden movement or effort." This project is likely to display such a "tension" within its geometries. It is interesting to make this comparison between classicism and biomorphic form.

figure 2

Column, v.01: Column evolution; diagram showing transfer of force; designation of weak areas to be reinforced. (Design: Jammy Chong.)

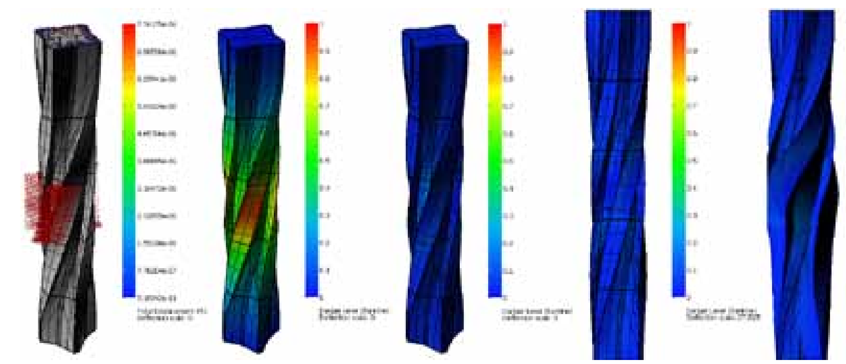

figure 3

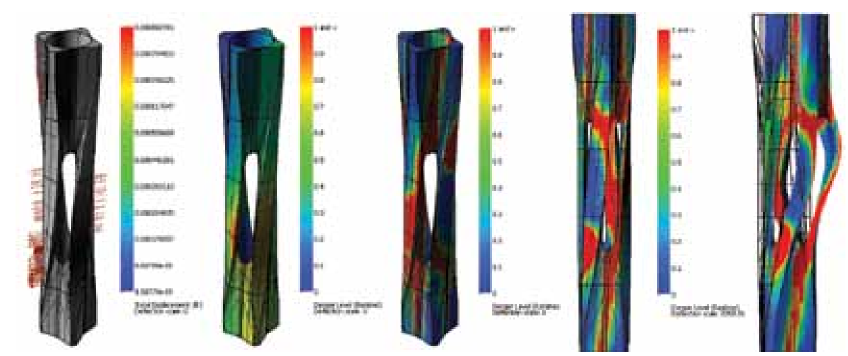

figure 4

Project 2: This project uses intuition in a different way than others. Starting with a simple shape, the student followed a subtractive process to reach a sophisticated result (Figure 2). Material was removed from a solid cylindrical mass; the shape was then twisted to appear complex. (Does this introduce the impression of opulence in the column?) Finally, material was added at the top and bottom of the circular openings, where the column was likely to be weaker.

The project clearly demonstrates an iterative development, each stage being more complex than the one before. In addition, the student uses his instinct well, trying to guess where the column might fail in order to improve the design. According to the student, the main criterion for elegance was "refinement." The column arguably displays precision as well, because it is carved very carefully where needed, leaving the minimum amount of material to support the weight.

The student's attempt to understand the column's behavior is very effective and almost approaches the second method of design (feedback driven), only without the FEA software. The design of this column was executed in a very similar fashion as an engineer would proceed, by simulating the shape and finding the weak points, then reinforcing these points alone. This "anticipation of feedback" may later be compared with results from the second stage. (See section 3.1.)

Having students of different backgrounds in the course introduced variety in the design approaches. Another case worth mentioning is the design from a student in multimedia design with knowledge of scripting, who used fractals as a form generator. The design was based on an infinite recursion,

figures 3 and 4

Column v.02 evolution: Applied forces; structural simulation of two iterations showing "total displacement" and "danger (Rankine)" diagram; side view and deflected view of danger diagram. Note: numerical scales correspond to the figure on their right, respectively. (Design: Dimelsa Medina.)

which caused small changes to become massively amplified within a closed loop. The application of scripting to the design resulted in a formal complexity that yielded an impression of lightness and fragility. By the student's standards, the project aimed to create "refinement and precision" in the pursuit of elegance. With regard to our cognitive assessment of these processes later on (section 3.3), it is interesting to identify how scripting translates into a neural activity: is it more left- or right-brain oriented?

2.2 Column v.02: Conditioned Emergence

The second approach to column design tried to eliminate the "tabula rasa" approach of the first method, which involved no restrictions. The instructor wanted to supply the students with a "design aid" that would help them understand the implication of their decisions and optimize their column. This additional constraint was introduced through Scan&Solve, a plug-in for Rhino that permits structural simulations using finite element analysis (FEA). The use of the software would ensure that all students began their design on equal terms, so we were interested to see whether this would result in similar projects, if the columns would be efficient structurally, and whether the students would find this method easier.

Could the interpretation of the simulation results "condition" the students to a certain character of design? As in the first stage of the project, the students were asked to use a footprint of 30"× 30" × 20'. They were allowed to expand around this footprint no more than 8", and they were encouraged to create the lightest possible design.

The software was introduced to the students during an online webinar, where they were taught how to select their material, apply forces choosing the right amount and direction, and run the simulation with higher and lower mesh resolution. The instructor demonstrated how to save the results of the simulation and generate a report. As the students had no prior experience, a civil engineer was consulted to define the amount and direction of the forces. To make the project interesting, the engineer suggested the use of side forces to simulate the conditions of an earthquake. The students were therefore given the option to apply either a vertical force at the top, or two side forces at the bottom and middle third of the column. I will discuss the most representative of the projects using this method.

Project1: This project began by progressively removing material at the four corners of a solid square extrusion, and twisting the resulting shape to produce a more dynamic effect. The second and third iterations are shown below (Figures 3 and 4). Using a constraint at the top and bottom, unequal forces were applied from the two sides to simulate conditions during an earthquake (Figure 3a). This yielded a "total displacement level" with major stresses toward the middle of the solid (Figure 3b) and an overall "danger level" (from blue to green, in Figure 3c) that is rather uniform. The evolution of this shape is a hollowed-out volume with large perforations to introduce lightness (Figure 4). As expected, the perforations result in weakening the solid, as one can observe in the "danger level" diagram by the areas in red (Figure 4c). Furthermore, the possible deflection (Figure 4e) is much greater that in the previous iteration (Figure 3e).)

If we consider the iterations from an aesthetic standpoint, the second iteration (Figure 4) is arguably more elegant; this perception may result from the impression of instability that is evoked by the perforations. This, of course, is not just an illusion; the column is actually less stable, as we see from the considerable deflection (Figure 4e). Due to the rationalized, quantitative nature of this working method with Scan&Solve, this stage of instability seems necessary; before finding an interesting form that responds to structural constraints, one needs to push the material limits by proposing forms that may go beyond equilibrium. This proved to be a challenge for the students using this method: they would typically either be too modest in their iterations, or model shapes that were unrealistic structurally. Ideally, they should proceed with carefully weighed decisions, to push an extreme geometry but with logical, gradual steps. The next step, given more time, requires the student to select this version and render it more stable by adding material while maintaining the perforations, to produce an elegant and efficient result altogether.

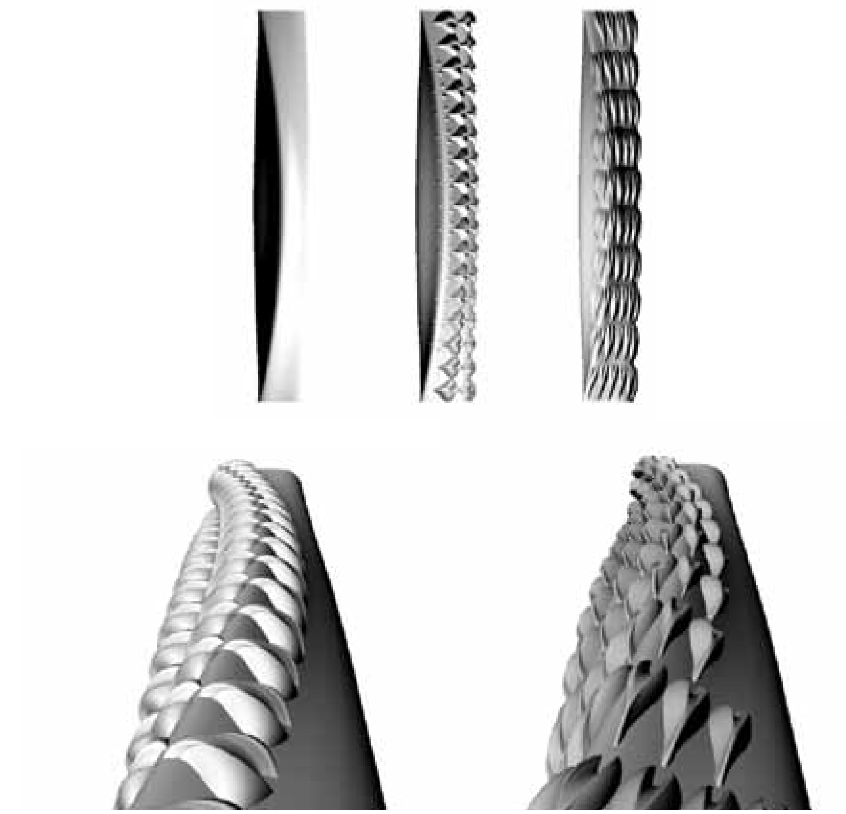

figure 5

figure 5

Column v.03: Evolution of water-channeling surface using Grasshopper: side views of plain and populated columns; perspective view with horizontal and vertical populations, respectively.

Our experience from the Scan&Solve version of the assignment indicates that almost all students found it difficult to use the software due to their limited experience in FEA. Typically, emergence is likely to arise from designers' unique response to data. *Has this been the case here*? Controlling the parameters in the analysis method proved to be more challenging and less helpful than anticipated. The project discussed using Scan&Solve possibly yielded visuals that are helpful for determining the next step. Without the FEA, designers would normally stop at this point because they would find the results pleasing without being aware of weaknesses.

We will proceed to assess the two methods and discuss the students' perception of the process in order to understand the reason behind the difficulties mentioned.

2.3 The Possibility of v.03: Parametric Emergence

In our attempt to evaluate the impact of computational tools in design methodology, it is worth considering a possible third approach: parametric tools. The column discussed below (Figure 5) was designed using Grasshopper, a parametric plug-in for Rhinoceros. The concept considers a surface that uses ornament to collect rainwater and channel it to the ground. A component was designed to populate an asymmetrical surface and subsequently applied to the surface in a horizontal (Figure 5b) or vertical (Figure 5c) fashion.

As the component directs water along its length using a valley in the middle, the vertical orientation (Figure 5c) is more faithful to this secondary performance of the column. (We assume that load bearing and aesthetics are the primary functions of the column.) While the simplicity of the base surface may already display elegance, the application of ornament that follows the column geometry may enhance the appreciation of the effect of that elegance. Nevertheless, we propose that some of the components be removed, exposing the smoothness of the base surface. This may create a contrast between the plain and textured geometry, but may also strengthen the function if the components are only oriented toward the side that anticipates rain. If, for example, this is a column in an arcade or a building facade, the sides facing the front would be textured but the rest might remain pure.

It is worth discussing the aesthetic quality of this design with regard to the work of philosopher Edmund Burke. In "A Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful" (Burke 1757), Burke criticized the belief that one perceives and appreciates beauty due to proportion—an understanding that was a result of the scientific rationale introduced during the Enlightenment—and claimed that such empathy is only caused by intuitive/emotional factors. Proportion cannot be the cause of beauty because, he argues, some things continue to be beautiful when they are seen from a different perspective. Some of the characteristics that Burke believes cause beauty are small scale, tactile smoothness, gradual variation of lines, fragile delicacy, and gradients and variations in color. Burke posited that "a variety in the direction of the parts" was among the qualities of beauty. Within our parametric column one finds small-scaled components, smooth geometries, and line variation as the components are applied irregularly. If we change their scale to create a gradient from small to large, they would fit closely Burke's canon of beauty. Such a gradient in the scale of components may also reinforce the nature of their performance: to capture and channel water, the bottom ones could be larger, as they would need to control water coming with greater speed, accumulating as it travels down the column surface. In general, it has become fairly common in parametric models to create gradient relationships of parts. This indicates a further adherence to Burke's rules.

(It is interesting that the attributes observed in parametrically driven design are not too far from Burke's views, which favor predominantly right-brain thinking (discussed later in this paper). Although there have been no studies as far as I know, I would say that parametric design through Grasshopper encourages an analytical way of treating design, because it involves an interface of input/output that produces visual data. It is intriguing, then, that a more left-brain-oriented process like parametric thinking may yield results of an aesthetic quality that adhere to aesthetic theories that favor intuition! The author is interested to further discuss this conflict in another paper.)

Although the parametric method was not tested with the students, its analytical nature and the paradox of its affinity with some of Burke's rules warrant further examination in the future of this experiment, possibly by conducting MRI imaging to observe brain activity. (See section 3.3 for a more detailed discussion on cognitive processes associated with design methods.)

3 COMPARISON OF METHODS

3.1 Assessment Based on Definition of "Elegance"

According to Rahim, elegance requires one to possess a combination of skills; mastery of technique is not enough, and it requires a certain sensibility that allows the designer to use the technique to "…realize nuances that exude Elegance within the formal development of their projects" (Rahim and Jamelle 2007).

Based on the column project, the first method seems more likely to operate within these requirements. However, conquering the design techniques and analysis tools in the second method remains a valuable asset. The combination of both methods, intuitive and data driven, may be beneficial in creating a powerful synthetic set of skills.

There is no better example of elegant form than natural systems. Every feature of an organism, item, or product is indispensable to the system's integrity; form is a direct result of structural and material performance. It is logical to assume, therefore, that the optimum structural form would yield an inherent elegance because it has an all-around consideration of its purpose. If this is the case, any successful outcomes from the second stage (v.02) should strongly display elegant characteristics.

The projects executed based on analysis are very diverse: some display elegant attributes, while others are strange looking. Overall, one could say that the most elegant projects can be identified among the first stage outcomes, albeit their structural efficiency remains to be tested. (The author believes the two projects discussed from the first method are likely to be structurally efficient but would like to carry out tests on all projects from both methods.) What has been the reason for not yielding the expected result based on our earlier comment? The students were asked to complete a questionnaire assessing the two processes.

3.2 Assessment Based on Student Feedback

Which method is easier/more engaging? Which one do the students prefer? Why? Is the latter restrictive?

A large portion of the students (67 percent) devoted equal time to the two stages of the project. A few students (22 percent) spent more time on the first stage, while 11 percent of the students spent more time on the second stage. The dedicated time indicates either an affinity with the method in question—the students enjoyed spending time—or difficulty in figuring out the project. Based on the questionnaire responses, it seems that the students who spent more time on the first stage did so because they enjoyed the loose approach to design, while students who spent more time on the second stage were trying to understand the software.

Almost all students considered the designs from the first stage of the project more elegant (Table 2). The majority of the students (73 percent) preferred the first method of intuitive approach to design because they thought the analysis approach with Scan&Solve limited their design ability. Almost everyone (90 percent) considered the software a limitation rather than an enhancement!

Table 2: Student perception of two design methods.

Parameters for assessing Elegance	Precision	Refinement	Formal Opulence	Proportions
	64%	64%	45%	18%
Time allocated to each method	Equal	method 1 longer	method 2 longer	
	67%	22%	11%	
Method preferred	Design by intuition		Design by Analysis/Feedback	
	73%		27%	
Impact of introducing Analysis in Design through Scan&Solve™	Enhanced design		Limited design	
	10%	90%		

3.3 Assessment Based on Cognitive Process: Where Does the Experiment Fall Short?

The student feedback received has shown that one's perception of the two methods for design can differ greatly. This is partly because the thought processes involved are neurologically different: the first method requires thinking more with the right part of the brain, whereas the second requires the left.

The left-right brain theory is based on the work of Roger Sperry, a neurobiologist and Nobel laureate who observed the effects of removing the corpus collosum (tissue connecting the two brain hemispheres) from patients with epilepsy. According to the theory, people whose right part of the brain is more active are "visual," while those with a more active left part are "verbal." The former are able to see the "big picture," perceive concepts as images, and are creative and intuitive, while the latter are more logical, analytical, objective, and good with numbers. Naturally, the one or other inclination affects how people behave, but more importantly, how they learn.

In relation to this experiment, the author recognizes the difference in the two assigned methods: the first is intuitive, and the second is data-driven and therefore more analytical. We are interested to observe which model is dominant within creative fields like architecture, but also how students may respond in dealing with the other model. Does such a shift in methodology based on feedback contradict the traditional notion of architectural thinking that is more unbiased? (It is the intention of the author to address these questions later.)

We have concluded so far that students need a good understanding of the analysis software during the second stage of "conditioned elegance." Based on their responses, the software has limited their creative ability. This is interesting if we consider this statement within a disciplinary context: architects are used to thinking creatively within often-loose frameworks, and so it is difficult to make them operate within strict rule-based systems, if the end goal is (primarily) aesthetic. They are more "right-brained." (An interesting case may be that of Jammy Chong (Project 2, v.1), who used logical thinking to improve his design. Within an intuitive process, he may have demonstrated a left-brained tendency.) If the same assignment were given to engineers, the author expects the second method would be preferred, because the first would seem too "open-ended." Engineers are used to dealing with data—they are more left-brain oriented—and so they would approach this problem from a different perspective. The question that arises is, can aesthetic improvement rely on performance analysis, or is it entirely instinctive?

Based on our consultation with a neurosurgeon, our hypothesis for the cognitive aspect of the project makes sense but needs to be pursued more systematically, using randomized samples for our data collection. We have been advised to offer the two methods simultaneously and alternate between two groups; one will begin with the intuitive process, the other with the conditioned, and the groups will change later on. Finally, the author wishes to test the students to detect whether they have a right- or left-brain tendency.

4 DESIGN PEDAGOGY

In addition to exploring an inclusive way to design, the aim of this exercise is to help students practice with both sides of the brain. How can this help us formulate pedagogical tools to improve learning experience?

4.1 How Can We Classify Our Teaching Methods Until Now?

Studies have shown that there are two ways of processing problem solving: convergent and divergent thinking. Convergent thinking includes deductive logic, gathering data and putting it together to arrive at a conclusion. The second method, using Scan&Solve, employs this type of deductive reasoning. Divergent thinking, on the other hand, is thinking "outward" instead of putting things together. It requires the ability to develop unique ideas and come up with an answer; it is a nonlinear type of thinking. Poststructural theorists insist that both are necessary, which seems aligned with the requirements of the architectural discipline.

Based on the students' feedback, we find that architects prefer to operate based on their intuition unless they have complete control over the analysis tools available. They have employed divergent thinking in their design with great ease. Nevertheless, they met difficulty when asked to use deductive reasoning. How can we overcome this challenge within the context of education? The nature of courses in higher education is typically discipline specific. As architects, we teach our students to think creatively, learning through a right-brain approach for the most part. This type of thinking is encouraged in design studio. There are, of course, courses that deal with analytical thinking and logical reasoning, yet they operate within a self-contained framework. Since architecture has always been regarded as a synthesis between art and science, it is important that architectural pedagogy deploys itself around courses that engage both methods of learning. If schools of architecture include courses that embrace both right- and left-brain-inclined thinkers, could this have an impact on the students' intellectual capacity (IQ)?

The author is interested in examining this matter comparatively with schools of engineering. Should we conduct this experiment with engineers to compare the results? One can predict the engineers' possible preference of analysis over instinct, of convergent over divergent thinking; however, there have been notable cases of visionary engineers who did not fit this profile, so it would be interesting to look for exceptions to the anticipated result. *How can one, within the spirit of creative thinking in architecture, find a way to take advantage of analysis without compromising the creative genius of the designer?*

4.2 What Are the Advantages of a New Design Paradigm?

The influence of digital tools in architecture, according to Greg Lynn (Lynn 2010), manifested itself through a "structural expressionism" within several leading schools of architecture over the past several years. This included "translating the wireframe geometry of NURBS surfaces architecturally into the structural framing, curtain wall mullion patterns and louvered panels of building elevations." (NURBS—nonuniform rational B-splines—is a type of mathematical representation of a curve within 3D-modeling software.) Lynn eventually tried to replace this approach by using the "louver" as a means of treating the facade, but this no longer seems adequate. He has recently followed another paradigm, looking into "fusiform (tapered) hydrodynamic and aerodynamic surfaces." This paradigm negotiates geometries that are defined by performance factors and therefore analysis. It is worth observing Lynn's self-criticism for rejecting this same paradigm several years ago, because he wanted to move away from what he called "phenomenal animation." Contemporary circumstances and technological advances, however, have brought back this tendency to adopt data-driven design. This is also increasingly common in design firms that have the appropriate in-house resources to conduct analysis, or close collaboration with engineering specialists (e.g., in the practice of Norman Foster).

The results of the project discussed here only reinforce Lynn's preference, demonstrating not only the need to turn to analysis tools, but also the importance of becoming skilled at specialist software/hardware so we can learn and teach an all-around thought process. Perhaps the way to combine ways of learning is to bring left-brain-oriented thinkers onboard; for example, the stage of the column project that includes Scan&Solve could be taught by an architect and an engineer together. This would seem appropriate for another reason: structural design in architectural practice presupposes the coordination of both professionals.

5 CONCLUSION

In retrospect, this paper has tried to quantify the parameters that define our perception of "elegance" by comparing two assigned methodologies: intuitive vs. feedback related. The results have been assessed to understand the cognitive differences behind these processes. The comparison between the methods exemplifies the demanding nature of architectural projects and shows that a convergence of multiple skills that require various modes of training and operating is necessary.

The students' response to the project is an indicator that "synthetic" processes utilizing both intuition and analysis have not yet embraced each other but require a reconsideration of teaching methodology within (and between) architecture and engineering. Aesthetic preoccupations of designers may exceed the normative creative framework and expand into the scientific/analytical domain of our mind.

Our experiment has helped raise important questions about pedagogy, design optimization, and aesthetic investigation. Is emergence likely to result by combining intuitive and rational techniques? According to Lynn, analysis tools are critical in this pursuit because they ensure a sound performance and also bring out qualities that are not necessarily available in digital software but require additional layers of exploration to unfold. "Although the elegant go-fast boats are designed using digital tools and CFD (Computational Fluid Dynamics), their forms are not 'found' in the computer" (Lynn 2010).

In our inquiry, one thing remains a constant: the student participation and their perception of their own learning, as well as the introduction of specialists, e.g., neuropsychologists, who may clarify parameters that remain undiscussed. According to the suggestion of a neurosurgeon, one issue that is worth examining is whether the students were right- or left-handed. As the hand preference cross-references to the opposite hemisphere, the presence of left-handed students may change the accuracy of the results. In our case, the sample was fairly small (11 students), and so this factor is negligible but should be considered with larger sample pools in the future.

ACKNOWLEDGMENTS

The author would like to thank all the students in his Bio-prototypes course for their participation in the project and their valuable feedback for the process, particularly Richard Brewer, Jammy Chong, Carlos Echeverria, Scott Hill, Dimelsa Medina, Ana Ros, and Sitki Sipahi. Special thanks to Professor John Sandell for proofreading the manuscript and Dr. Nikos Haliasos of the National Hospital of Neurology and Neurosurgery (London) for his suggestions in matters of a cognitive nature.

Additional information on differences between left and right hemisphere:
http://frank.mtsu.edu/~studskl/hd/hemis.html

and on convergent and divergent thinking:
http://www.problem-solving-techniques.com/Convergent-Thinking.html
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PERFORMATIVE TOPOLOGIES:
AN EVOLUTIONARY SHAPE OPTIMIZATION FRAMEWORK FOR DAYLIGHTING PERFORMANCE COUPLING A PARTICLE-SPRING SYSTEM WITH AN ENERGY SIMULATION TOOL

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ABSTRACT

This paper develops a methodological approach for use in design practice that combines an external simulation tool (EnergyPlus™) with an evolutionary optimization strategy for the form finding of complex fenestration systems. On the one hand, based on previous research, it presents a novel approach for the shape morphogenesis that exploits a genetic algorithm technique to control a limited set of parameters; on the other hand, it facilitates the integration of a simulation tool capable of handling increasing levels of complexity with greater data interoperability. In doing so, the paper will argue the heuristic potential of the proposed method in aiding the designers' decision making while increasing the formal possibilities of their final design solutions.