ART FOR ENGINEERS: HOW DESIGN AND VISUAL PROCESSING ENHANCE PROBLEM SOLVING SKILLS IN ENGINEERING

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Abstract *— In 1996 the Departments of Mechanical Engineering and Art at the University of Houston began an interdisciplinary teaching initiative designed to foster integrated thinking skills through visual processing. In its original form, the engineering course included an introduction to design awareness through a design, build, and compete project. While this multi-faceted project remains part of the collaboration, the interaction with art has brought about notable changes in how the project is administered. Here, we focus on this design project in an effort to illustrate that combining mechanical and aesthetic considerations enhance the performance outcome of student solutions. Included in our discussion is the design process from the perspective of art (i.e., how one moves from nothing to something, from unknown to known). Rather than promote visual protocol we focus on the mechanics of dynamic thinking in the context of design to identify essential features of effective problem solving.*

Index Terms — Collaboration, Critique Method, Design process, Studio format

DESIGN

While design is an inherent part of engineering it is not regarded as a primary course of study. More fundamental to engineering is the canon of science. Science represents a systematic study of the natural world that characterizes and quantifies the physical attributes of matter and phenomena. In search of essential truth, scientific methodologies "reduce and describe and separate things into cause and effect, and draw the world in lines and boxes."[1] The field of engineering gives relevance to this phenomenon, helping to proliferate a Newtonian world view. In the context of engineering, design germinates from a narrow directive of utility, representing an application of scientific principles to the physical world. Consequently, design is less about aesthetic judgment and more a feature of problem solving. But engineering is not idle; its role is not passive. In other words, engineers are not merely technicians following the authority of science. On the contrary, engineers are innovators. As the twentieth century visionary, Buckminster Fuller explains, "The consumption and digestion of facts and statistics is somewhat like eating and chewing hay and thistles. There is nourishment in them in their raw state, to be sure, but a cow is needed to convert them into milk."[2] In a sense, the "cowing" of science is engineering. But engineering's close proximity to science and its penchant for practicality have left it vulnerable to compartmentalized thinking.

In an art curriculum, design is a pillar on which artistic expression is built. Design is a regulating force that guides shape, form, proportion, and scale, making "one great thing instead of a quarreling collection of many little things."[3] It is not style or dogma but a means to synchronize the built environment with the order and organization "on which all phenomena and all objects of nature are based."[4] Rather than divide, label, or place at a distance, design seeks to reconcile, harmonize, and unite, representing a different mind-set from science based culture.

In the context of art, design exists within a framework of aesthetics. Through line, form, and gesture design silently mimes its message. On a cognitive level, meaning is perceived in the non-verbal realm of feeling and intuition. And while science, in its effort to objectify reality, goes to great links to minimize subjectivity, scientists agree that discovery is a result of intuitive way finding. The mathematician, Henri Poincaré has noted, "logic is the instrument of demonstration; intuition is the instrument of invention."[5]

With global interests in new technologies, there is a lot of pressure on engineers to innovate. And yet, engineering programs are slow to revisit existing methodologies that fall victim to the pragmatic nature of utility. While usefulness remains a primary objective, as a regulating agent, practicality can impose subliminal limitations that hinder creative thinking and impede innovation.

LARGE THOUGHTS

Discovery and invention are a consequence of thoughts that are large enough to scale the banality of routine and habit. On a daily basis the mind encounters a myriad of thoughts; most of which, operating on the fringes of awareness, go unnoticed. Novelist Nicholson Baker describes thoughts

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worth thinking about as "detonations of fist-clenched hope, and hundreds of cellos; a thought that can tear phone books in half, travel overnight toward Truth, and shake it by the indifferent marble shoulders until it finally whispers its cool assent."[6]] Baker offers three conditions of large thoughts: (1) *All large thoughts are reluctant*. They are not easily grasped. Like a slippery fish brushing against skin, large thoughts dart to the surface only to dive again, escaping awkward attempts to snare them. (2) *Large thoughts are creatures of the shade*. They inhabit areas that are protected from the glare of scrutiny, stationed in the cool shadows of the unconscious mind. (3) *Large thoughts depend heavily on small thoughts*. In other words, large thoughts are large because they are rich, faceted, compound, and complex. Additionally, large thoughts are distinguished from small ones because when they stretch and turn they press against the psyche, moving in ways that elude the rational mind. We know that thoughts are ripe when they grow agitated, burdensome, and uncontainable.

To entertain *large thoughts* and realize potent ideas requires that intuitive and rational faculties work in tandem. It is important to note that when processing ideas, the relationship between thought and feeling is not a linear one. When unraveling and directing thoughts, instinct and analysis remain alert, active, and in constant contact throughout the entirety of problem solving. Intuition charts the course and regulates progress; reason navigates towards intuitive parameters, wielding feeling into form. An assertion that truth resides in reason alone is inconsistent with the findings of modern science. In other words, reality cannot be discerned from a single point of view. Poincaré explains that invention is an aggregate process, whereby "logic and intuition each have their necessary roles."[7]

THE MECHANICS OF INVENTION

As a harborer of large thoughts, Buckminster Fuller gives insight into the mechanics of invention. Working at a time when the modernist ideal was driving new paradigms in science and art, Fuller put forth an equation: *Science + Art + Industry = Universal Architecture*[8]. Fuller revealed in this theorem that in combination reason, intuition, and purpose have a synergetic relationship. In this instance, architecture was not a feature of the built environment or a stylistic proposition (e.g., International Style); it was rather a description of universal order. His instincts were substantiated when a 60-atom carbon molecule was found to have the same geometric configuration as a structure Fuller had designed for the 1967 Montreal Expo. Witnessing Fuller's geodesic dome resulted in an epiphany that led scientists, rappelling with the geometry of this molecule, to the 1985 discovery of the "buckminsterfullerene," otherwise known as "buckyball."

Twice dismissed from Harvard, Fuller never received a formal degree. Despite his lack of academic credentials, he received 44 honorary doctoral degrees and lectured at 550 universities worldwide. Almost fifty years after he was expelled from Harvard, Fuller returned as Harvard's Norton Professor of Poetry. This may seem like an odd appointment, but as Fuller explained, " The word poet in this professorship is a very general term for a person who puts things together in an era of great specialization wherein most people are differentiating or "taking" things apart."[9]

We cite genius to substantiate the assertion that discovery is best served by comprehensive thinking. While it seems obvious that a full battery of cognitive functioning is needed to tackle complex problems, specialization in academia, which bifurcates science and art, dissuades an integrated approach. Engineering schools developed to "establish the precise rules of governing the objective performance of physical operations, not to consider the emotional experience of human beings."[10] When we consider, "The objective and subjective views of reality have been at odds since the dawn of recorded history,"[11] trying to discern the superior route is futile. And yet, biases persist at the expense of discovery and invention. The intent of this teaching initiative is to develop techniques for integrating intuitive and rational processing. By aligning engineering and art a more comprehensive and, therefore, dynamic approach to problem solving is cultivated.

PROJECT BACKGROUND

Initially engineering's interest in art was prompted by a desire to address visual issues, specifically to enhance the appearance of the engineered devices. An emphasis on performance measures resulted in devices that lacked visual integrity. Through preliminary discussion and planning it was determined that art's influence would be greater if an exchange began early in the course. In other words, the assumption that art's input could be used in the final phase of a device's development (e.g., color selection) underestimated the role that art could play in the formulation of a solution. On a superficial level the domain of art may appear to reside in surfaces and appearances, but "Visual solutions are not found hovering on the surface. When designing, one must dive deeply into the unknown and stir the yet to be discovered."[12] What was lacking in the engineered devices had less to do with visual ineptitude and more to do with an absence of method to connect rational and intuitive processing. By design standards, however, the engineering project was too comprehensive for a single exercise.

As originally configured, teams of students were charged to design and construct a device that lifted, propelled, or in some cases, projected a given element (e.g., tennis ball), while satisfying performance criteria (e.g., distance, duration). Additionally, the device had to fit within a given set of parameters (e.g., weight, size, cost, timeframe). Under the circumstances, students were ill prepared for a project of this scope. This resulted in solutions that focused on certain aspects of the project criteria (primarily performance) at the expense of the entire enterprise. Introducing too many objectives without first establishing a means to manage and balance complexity was undermining the results.

Although most of the stated project objectives centered on attributes of teamwork, the overall organization of the project served to de-emphasize cooperation. Consequently, teams worked "secretly" to develop their devices at the expense of developing their ideas. Structuring the project as a competition overly emphasized the final product, minimizing the process. It may be argued that fostering a competitive spirit exposes students to real world practices, but it does little to advance the idea of collaboration. This approach is antithetical to how design is taught in art. This is not to suggest that end results are insignificant or that art students are not competitive. By focusing on the process, art strives to improve the outcome. In other words, time spent developing and refining ideas is where the quality of a product is determined.

While including a large-scale design project exposed students to hands-on learning, given the structure and content of the course the project was an anomaly. Lecture-formatted courses tend to emphasize a single authority, running counter to the conditions necessary to inspire invention and discovery. This type of learning environment is in a sense too orderly, rigid, and confining for a type of exercise that discourages compliance and prizes ingenuity. And yet, the spatial organization of the classroom (rows of desks facing in one direction) spoke more of boundaries and conformity. The size of the class, which was more suited to a lecture-based delivery (about 50 students), represented another obstacle. In this setting there was greater tendency to "profess," rather than enable students to explore.

In an effort to enhance the learning experience of the existing design project, it was necessary to factor visual processing into the course structure. This was achieved by introducing a series of preliminary design projects intended to acclimate students to a process-oriented environment. This fundamental change required a new venue, that is, a move from a classroom based setting to a studio format. In addition, students were subjected to a new method of evaluation (i.e., a critique).

DESIGN PROCESS

Learning to design requires a shift in attitude. Rather than a narrow focus on outcomes, designers surrender to the charm of exploration. Most students are impatient to "wrap it up," anxious to leave a realm of ambiguity. But in fact, this approach is the exact opposite of strategies used by inventive minds. Consider the remarks of the architect, Louis Kahn on the subject of processing. Citing a contemporary of Buckminster Fullers, Kahn asserts, "Einstein travels like a poet."[13] As Kahn describes, a poet begins from a realm of immeasurability (i.e., intuition), moving towards a measurable state, never losing sight of the immeasurable. Ultimately, a poet "succumbs to the word,"[14] condensing a vast and vague intuitive journey into a concise set of syllables and sounds. The scientist, although possessing immeasurable qualities, "does not travel with the unmeasurable….he allows nature to come to him, and then he grabs it." In the case of Einstein, however, "he holds the unmeasurable for a long, long while….reaching nature at its doorstep."[15] And like a poet, Einstein returns to give succinct expression to very large thoughts.

Conventional wisdom teaches that efficiency is measured through an expenditure of time and energy (i.e., less effort equal greater efficiency). For many, this results in unforgiving problem solving. In other words, the only valuable thoughts are those that are small enough to have direct application. And yet, as Kahn illustrates, an ability to shift attention to an undirected realm, to ponder, or think deeply, as in the case of Einstein, is highly effective when dealing with large ideas. There is a tendency to dismiss undirected thinking as a folly of subjectivity, a waste of time. What Kahn suggests is that a state of awareness unencumbered by preconceived ideas is poised to recognize and seize upon novel patterns and relationships. In contrast, thinking that is confined to immediate results relies on premature assumptions that impede an ability to see greater possibilities.

To produce, suggests result; to process, suggests duration. Processing is time spent in the company of ideas. It is where average thinking transforms into a contemplative, heightened state of awareness. Because processing requires one to spend time in an unresolved state, students often take measures to short circuit the process, moving quickly to a solution. From a design standpoint, it is critical for students to acclimate themselves to the power of processing. In an effort to "ease the pain," a project was developed to address the discomfort students experience when confronted with unknown circumstances.

The project, based on an odd Japanese form of product design, is known as *Chindogu* or "useless object." By definition, engineers function from a level of purpose and utility. Requiring students to put time and effort into a project that has a stated objective of *uselessness* places them in an awkward and uncomfortable situation. However, achieving discomfort is the teaching objective. Once this is accomplished, students can be taught to deconstruct fear and work past uncertainty. Problem solving begins with ambiguity. Solutions are dependent on the development and refinement of ideas. It is, therefore, imperative that students learn skills that enable them to linger in uncertainty rather than sprint towards resolution.

In addition to the design and fabrication of a product, a subsequent phase gives students an opportunity to consider their solutions in a broader context. To promote their *Chindogu*, teams produce videos that are marketing oriented. Because *Chindogu* are by nature ridiculous, solutions typically employ humor, serving to debase restraint and caution, exposing students to the playfulness of creative thinking. Under these conditions, students feel more adventurous and are more inclined to take risks.

To incorporate risk taking into problem solving, it is necessary to develop certain instincts that signal awareness when it is advantageous to step outside the bounds. Taking a risk is always rendered at a gut level, requiring both courage and discrimination. Working visually helps hone these skills.

ABSTRACTION

While invention is well served by imaginative ideas, engineers are conditioned to circumvent fanciful thinking. As engineers translate theory into application they are more focused on the here and now. As a consequence, reality is more fixed and finite. Visualization, on the other hand, is more aberration than actual, drawing attention inward to a more primal state where thoughts are not subject to the limitations of physicality. As the historian, Eugene Ferguson comments, “pyramids, cathedrals, and rockets exist not because of geometry, theory of structures, or thermodynamics, but because they were first pictures – literally visions – in the minds of those who conceived them.”[16]

Directing students to “use your imagination,” “be creative,” and “brainstorm” are not sufficient tools to cultivate creative thinking. Equally as ineffective are bulleted directives, such as step one, two, three. This approach may appeal to the efficient minded, but a regimented strategy runs contrary to the rebellious nature of creativity. Students appreciate a need to be creative; they do not necessarily understand how to be creative.

An affinity for actualized circumstances places awareness in a conclusive rather than anticipatory state. An effective strategy for rerouting awareness is a use of visual exercises that are conceptual and abstract. Abstraction is a more complex way of processing, requiring an ability to see past obvious conditions to a more essential state. In a sense, abstraction and conceptually based projects force students to *close the eyes* and disengage from their immediate surroundings. Maneuvering in the dark elicits visualization as imagination steps forth.

One particular in class exercise, while small in size, is a potent catalyst for redirecting thinking. Students are asked to imagine a continuum of flatness, undistinguished and undefined to envision how nothing becomes something. From here, they are told that this field of flatness has been disturbed; and, the first permutation of the field reveals an elegant line. Once they have imagined this scenario, students are given materials to model visually the process of field manifesting line. Here is where they learn that mental space and physical space are different creatures. All ideas are great ideas when in the protective custody of the mind. The teaching objective is to expose the idiosyncrasies of mental pictures and physical reality for the purpose of acclimating students to visualization.

In the case of the major design project, students now write preliminary narratives describing possible scenarios as a means to “visualize” solutions. Initially, their ideas are focused on mechanics, describing what they are going to do. This precursory phase provides an opportunity to ask “how” they plan to execute their ideas. In other words, what will the device look like? This scrutiny provokes discussion and debate about the roles of form and function.

FORM FOLLOWS FUNCTION

The aphorism, *form follows function* is often heard when measuring appearance against utility. This oft-quoted phrase, spawned from the essay, *The Tall Office Building Artistically Considered*, is not, as many believe, an attempt to subjugate visual attributes. On the contrary, what the architect, Louis Sullivan was addressing when he surmised, “form ever follows function”[17] was aesthetics.

In the late nineteenth century, as architects debated the design protocol of tall structures, Sullivan observed, “the heart is ever gladdened by the beauty, the exquisite spontaneity, with which life seeks and takes on its form in an accord perfectly responsive to its needs.”[18] In other words, “the sweeping eagle in flight, the branching oak, the winding stream, the drifting clouds,”[19] are shaped by an impulse that gives outward expression to innate characteristics. For Sullivan, the impetus for the anatomy of a tall office building was not a matrix of iron, deliberation of engineering, or application of style, but “the force and power of altitude.”[20] While Sullivan cited the importance of practical considerations, in the case of tall buildings, it was the “proud and soaring”[21] aesthetic of modernism that gave purpose and, therefore, substance to architecture.

Those who adhere to the primacy of functionality may dismiss Sullivan’s remarks as the sentimental gyrations of an artistic mind. But a Noble Laureate physicist reveals that motivations in science are, “from the beginning, manifestations of the aesthetic impulse.”[22] Lofty words and poetic verse indicate that in theory an urge to create or explore is first registered as feeling.

To understand aesthetics, it is helpful to consider its opposite – anesthetic, *without feeling*.[23] The value of introducing aesthetics is not about visual protocol, but is an effort to cultivate responsiveness to emotional impulses that contribute to integrated thinking.

Beauty

Engineering students have difficulty with aesthetic discourse as a consequence of a conditioned belief that aesthetic judgment is strictly a function of beauty; and, beauty is a superficial attribute. On the contrary, science is not immune to the ideal of beauty. As Poincaré describes, “The Scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is so beautiful.”[24] A search for authenticity has revealed an alliance between beauty and truth. According to Keats, “What imagination seizes as beauty must be truth – whether it existed before or not.”[25]] Beauty, therefore, is a valuable ally to engineers.

Misunderstanding arises because, as Goethe observed, “Beauty is as various as nature herself.”[26] Consequently, beauty gets tangled in surface values where it is trivialized as an unreliable indicator (e.g., appearances, sensuality, cultural preferences). Aware of these discrepancies the physicist, Subrahmanyan Chandrasekhar cited two criteria for beauty. The first was inspired by Francis Bacon who qualified beauty as “some strangeness in proportion.”[27] In this instance, “strangeness” was clarified to mean, “Exceptional to a degree that excites wonderment and surprise.”[28] The other criterion was adopted from Werner Heisenberg who declared, “Beauty is the proper conformity of the parts to one another and to the whole.”[29] Chandrasekhar presents beauty not in terms of commonly described attributes (e.g., elegance, harmony, handsome), but as a dynamic occurrence resonating between paradoxical extremes. On one hand, beauty is “strange” and “exceptional” and at the same time beauty “conforms” to ideal conditions. When conjoined, however, these inconsistencies reveal the play of consciousness within a highly ordered and organized universe. By Chandrasekhar’s standard, beauty is a means to couple individual awareness with universal law. This is why “proportions which we feel to be harmonious arouse deep within us and beyond our senses, a resonance, a sort of sounding board.”[30] This sounding board is the “axis on which man is organized in perfect accord with nature.”[31] Rather than a fixed asset, beauty is a mediating force that authenticates existence by aligning “artificial” conditions with natural order. Chandrasekhar’s assessment of beauty underscores Sullivan’s point about form and function.

Synthesizing Mechanical and Aesthetic Considerations

More than an imperious sound bite, Sullivan’s essay is instructive in problem solving. Sullivan advocates broad parameters to establish an intuitive beacon that guides the application of practical considerations. He counsels, “proceed step by step from general to specific aspects, from coarser to finer considerations.”[32]] Because engineering students are conditioned to specificity they can lose sight of a greater context. To sort through a minutia of detail, reason and logic must draw near, creating myopic conditions.

In the case of the principal design project, students were more focused on performance measures, neglecting the visual integrity of their projects. This approach resulted in devices that were more “rigged” than designed. Consequently, many devices were not stable and the smallest variation in conditions (e.g., temperature, humidity, surfaces, airflow) caused projects to fail. The criticism was not leveled at the appearance of the devices, but was directed at the “disconnect” between form and function. The lack of synthesis between mechanical and aesthetic considerations was an indication that students were not working to full capacity unable to shift their thinking between general and specific modes.

Projects that compel students to think broadly and precisely exercise the mechanics of integrated thinking. One particular project uses found objects as the basis for a model-scale, multi-level environment. Emphasizing interfaces forces students to balance small-scale features, such as connective details, with large-scale decisions, such as the shape and contour of the overall form. In this way, awareness moves back and forth between isolation and community (i.e., parts and whole), exercising a full range of motion. The phenomenon of fluctuation (i.e., a process of moving back and forth) cultivates a more dynamic mode of processing.

COURSE MECHANICS

Integrating visual processing into engineering curricula prompted changes in the learning environment that were altered to facilitate teaching objectives. For the most part, these changes were modeled after facilities and processes indigenous to art. Art education is accustomed to the scale and nuance of visual work.

The Value of Collaboration

The interdisciplinary nature of this collaborative venture is essential. Not only does it bridge disparate academic cultures, exposing students to different methods of thinking; but it establishes a pedagogical structure that optimizes learning conditions. In other words, this arrangement confronts students with differences that are indigenous to specialization. An interdisciplinary alliance serves to test and exercise a student’s ability to cross lines and boundaries, cultivate an ability to see past given conditions and existing circumstances, and forge new relationships. As the author, James Gleick describes, “Often a revolution has an interdisciplinary character – its central discoveries often come from people straying outside the normal boundaries of their specialties.”[33] Ideally for collaboration to work, it is first necessary to create a shared understanding. Although they speak different languages, one in facts and formulae, the other in impulses and images, engineering and art find communion in design

Dimensional Learning

Building models cultivates spatial awareness, enabling students to witness multiple views and comprehend complex relationships. Dimensional exercises reveal relationships that sometimes go unnoticed when working mentally or on paper. A process of moving thoughts from “head to hand” exposes inconsistencies and flaws in thinking and provides opportunities to calibrate ideas.

The Critique Method

To reorient the focus of the principal design project from product to process, it was necessary to introduce a critique method of evaluation. In this setting, teams are required to submit their in-progress work for the inspection of the larger group. This provides an opportunity for students to share in the development of all the projects, learning from each other's mistakes and achievements. This method serves to expand assessment from judgment of outcomes to refinement of thinking, enabling students to advance their ideas and strengthen outcomes. This type of exchange fosters collaboration. Discussion of this nature also aids in comprehension. An ability to articulate ideas and offer observations contributes to understanding.

Studio Format

The interdisciplinary teams now meet in large studio spaces provided by the Art Department. Because art is structured around direct experience and hands-on learning, studios are spacious and work surfaces are ample. In this environment, teams can more easily gather and deliberate. The "unstructured" nature of a studio setting has a quality of openness and transparency. The single authority is debased and the atmosphere is more egalitarian. These features assist students in an exchange of ideas. Besides the psychological influences, the practicality of this arrangement provides students with a place to work that is conducive to visual learning.

CONCLUSION

By reducing matter and phenomena to numbers and formulae, engineers understand the world on a very elemental level. However, it is the application of this knowledge that distinguishes engineering from other science-based disciplines. Engineers are not merely observers of phenomena but are, rather, innovators. Innovation requires ingenuity and ability to process creatively. Creative processing requires thinking that is synthetic, combining both rational and intuitive faculties.

An inability to reconcile precision, exactitude, and accuracy, with charm, elegance, and attraction has led to a segregation of knowledge that isolates reason and intuition. By distancing itself from liberal education and humanist ideals, engineering has lost touch with aesthetics, undermining an ability to discover and invent. To affect the outcome of the principal design project it was necessary to expose students to aesthetic discourse, for the purpose of cultivating integrated thinking skills. In partnership, engineering and art serve to align disparate features of cognition, giving rise to comprehensive thinking. Exposing engineering students to design and visual processing fosters a more dynamic way of thinking, adding value to problem solving skills.

REFERENCES

[1] Wheatley, M. J, *Leadership and the New Science*, San Francisco: Berrett-Koehler Publishers, 1994, p. 28.
[2] Fuller, B. R., *Nine Chains to the Moon*, New York: Anchor Books, 1971, p. 47.
[3] Wright, F. L., "Organic Architecture," in Ulrich Conrad's *Programs and Manifestoes on 20th Century Architecture,* Cambridge: MIT Press, 1986, p. 25.
[4] Le Corbusier, trans. Fredrick Etchells, *Towards a New Architecture,* New York: Holt Rinehart and Winston, 1960, p. 192.
[5] Poincaré, H., *The Value of Science*, New York: Dover Publications, 1958, p. 23.
[6] Baker, N., *The Size of Thoughts*, New York: Vintage Books, p. 10.
[7] Poincaré, H. *The Value of Science*, p. 23.
[8] Fuller, B.R., "Universal Architecture," in Ulrich Conrad's *Programs and Manifestoes on 20th Century Architecture,* Cambridge: MIT Press, 1986, p. 131.
[9] Fuller, B.R., *Education Automation, Freeing the Scholar in Return to His Studies*, London, 1962.
[10] Bloomer, K.C. & Moore, C. W., *Body, Memory and Architecture*, New Haven: Yale University, 1977, p. 21.
[11] Kurzwell, R., *The Age of Spiritual Machines*, New York: Penguin Books, 1999, p. 62.
[12] Patton, A. H. & Zinkhan G. M., "Cultural History as a Thematic Study: Analyzing Advertisements to Interpret American Home Design," *The Journal of Interior Design,* Vol. 24, No. 2, 1998, p. 25.
[13] Lobell, J., *Between Silence and Light: Spirit in the Architecture of Louis Kahn*, Boston: Shambhala, 1979, p. 14.
[14] Lobell, J., p. 14.
[15] Lobell, J., p. 14.
[16] Ferguson, E. S., *Engineering and the Mind's Eye*, Cambridge: MIT Press, 1993, preface.
[17] Sullivan, L., "The Tall Office Building Artistically Considered," *in Kindergarten Chats and Other Writings*, New York: Wittenborn Art Books, 1947, p. 208.
[18] Sullivan, L., p. 208.
[19] Sullivan, L., p. 208.
[20] Sullivan, L., p. 206.
[21] Sullivan, L., p. 206.
[22] Chandrasekhar, S., *Truth and Beauty: Aesthetics and Motivations in Science*, Chicago: The University of Chicago Press, p. 60.
[23] Tuan, Y., *Passing Strange and Wonderful: Aesthetics, Nature, and Culture*, New York: Kodansha International, 1995.
[24] Chandrasekhar, S., *Truth and Beauty: Aesthetics and Motivations in Science*, p. 59.
[25] Chandrasekhar, S., p. 66.
[26] Eckermann, J. P., *Conversations with Goethe*, 1827.
[27] Chandrasekhar, S., *Truth and Beauty: Aesthetics and Motivations in Science* p. 70.
[28] Chandrasekhar, S., p. 70.
[29] Chandrasekhar, S., p. 70.
[30] Le Corbusier, *Towards a New Architecture*, p. 187.
[31] Le Corbusier, *Towards a New Architecture*, p. 192.
[32] Sullivan, L., "The Tall Office Building Artistically Considered," p. 203.
[33] Gleick, J., *Chaos: Making a New Science*, New York: Penguin Books, 1987, p. 37.