Utilization of Scientific Method as a Tool of Architectural Design

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Abstract

Science (natural science) is the systematic attempt to understand and interpret the nature phenomenon. For this reason, architects have used science to adapt nature to their design. With the rise of modern science, architecture became more closely related with science. Science available to develop new technology for architecture and it influenced architect's idea and concept. Symbolically, Architects use method or process of science to generate building form. The Rules of compositing particles in the chemistry or DNA (deoxyribonucleic acid) in the biology are used to generate a form of building. Literally, Architects use technology as a tool of science to improve physical performance of architecture. Like mathematical understanding of structure load enabled people to construct enclosure without columns or any of support system inside of architecture. Still natural phenomenon is not fully understood as science and science is still discovering a new phenomenon or changing its theory to adapt new discovery. New discovery or limitation of science influenced architecture throughout the history. This paper is to discuss how architectural theories are rest upon idea set forth by science. In addition, how technology as a tool of science has been utilized in architecture.

Keywords: Science, Nature, Simulation, Technology, Performance, Parametric

1. SCIENCE AND ARCHITECTURE BEFORE 19TH CENTURY

Science (natural science) has been related with Architecture and in certain way it was limitation or opportunity for architects to express their ideas to their design. Adapting nature phenomena to architecture, as ultimate objective can be go back to when first architecture book is published and it has been issue for many centuries. Like Palladio’s (1965) book “The Four Books of Architecture (I Quattro Libri dell’Architettura)”, Which influenced Neoclassicism till early 20th century gave several chapters about the building performance. Like location of chimney, depth of room according to window size, and cooling and heating method. Especially he gave example of villa utilizing cooled air in the cave to their houses by “ventiducts”. However his description was based on experience not by mathematical or physical terms. Interpreting nature by means of scientific method as mathematical and reasonable rule to architecture can be say that it start in 17th century. When Claude Perrault (1613-1688) published “Ordonnance des Cinq Espèces de Colonne (Regulation of the Five Sorts of Columns—1683)” in which he expressed doubts about the proportional rule without mathematical and reasonable rule (Kagis, 1993).

Perrault’s doubt was start from Francis Bacon. Bacon proposed a new type of knowledge derived from the observation of natural phenomena, independent of transcendental matters. Thinkers like Perrault came to regard phenomena not simply as what could be perceived but primarily as what could be conceived with mathematical clarity. Perrault cited the rules given by other masters, such as Vignola, Palladio, and Scamozzi (Kagis, 1993). His intention was to examine and compare these rules, showing where they concurred and differed, in order to establish those precepts that could be most widely accepted as mathematically and reasonably.

Even though, 18th century can be categorized as Rococo period, In Marc-Antoine Laugier’s book “An Essay on Architecture”. He wrote, “An artist should be able to explain to himself everything he does, and for this he needs firm principles to determine his judgments and justify his choice so that he can tell whether a thing is good or bad, not simply by instinct but by reasoning and as a man experienced in the way of beauty.” (Herrmann, 1977)

Even though he emphasized on beauty his approach to beauty was from science. His beauty was from reasoning, which could be found from the Enlightenment. Belief in reason as a means to ensure human progress was combined with a questioning of tradition and authority, the systematic collection and categorization of facts, and the study of nature on a scientific basis (Curl, 1999).

18th century was the beginning of the new science yet other most science area’s attempt to systematize and criticize was not so successful. Similar to architecture criticize, systematize, and organize knowledge that did not lead to dramatic results. Science was not influenced personal life so much as in architecture also. Neoclassicism was emerged and popularized at this time.
Even though a lot of architects’ idea was based on or agree with natural philosophy. Utilizing science to architecture was limited to the definition of the beauty in architecture.

2. MODERN SCIENCE AND ARCHITECTURE

In the beginning when modern physics arises physical science viewpoint can be found in the architecture as in a mechanical aesthetic. Viollet-le-Duc (1987) mentioned in his book that new form of architecture has to be come forward for new materials and new structure.

He stated that “… steam-ship, and machinists in making a locomotive, do not endeavour to reproduce the forms of a sailing vessel of the time of Louis XIV., or of a stage-couch ; they simply conform to the novel principles with which they have to deal, and thus produce works which have a character, a style of their own, as indicating to every eye a definite purpose.

… we architects have for a long time been making guns while endeavouring to give them as much as possible the appearance of crossbows, or at any rate that of arquebuses…” (Viollet-le-Duc, 1987)

Also new definition for new type of building had to be established. As industrialization produced new culture and new transportation, such as train station, department store, and office building have to be defined in architectural language. For new type of building, architects like Sullivan and Gropius try to find their answers from Functionalism and Machine Aesthetic, and led into 20 century Rationalism.

One of the best examples of new building for new century is the Bauhaus building at Dessau, which was designed by Gropius, and it overwhelmed architects by its use of glass in the skin of the building, so that sunlight fully comes into the indoor (Banham, 1969).

Confidence about machine like architecture was possible from improvement in building environmental control technology. In 1784, James Watt had his own office heated by steam. Even though the proposal of using hot water to circulate through pipe goes back to Renaissance, sophisticated and practical application technology belongs to late 18th century and it became commonly used after mid 19th century (Banham, 1969).

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More energy efficient equipments for heating are developed. Improved method of heated air circuit made possible to hide the stove to the basement. Hot air box and duct distribute heated air to the parts of the house where heat was needed. Engineers and researchers able to measured and draw diagram of the temperature and wind circulation in the room. Moreover, in 1891, Clarence Kemp, a Baltimore inventor, patented the first commercial solar water heater (Tzikopoulos et al., 2005).

Physical studies on building environmental control gave a confidant that architecture can be controlled in any circumstance. This perception has been shared with architects at that time. New ambitious technologies were adapted to the new architecture. Like Le Corbusier proposed “murs neutralisants” system that control the indoor space temperature only by closed double glass skin and warm air circulating between skins. In 1933, “Air-conditioning” was invented by Carrier, which was called as “Man-made weather”.

Now it was possible for residents to stay at modern buildings in most climate areas without effects of hot summer climate.

Beginning of 20th century, the discovery of X rays and radioactivity revealed an unexpected new complexity in the physics. Additionally, the special theory of relativity, by Albert Einstein in 1905, not only made a doubt in the physics but also redefined physics. What was observed, and therefore what happened, was now said to be a function of the observer’s location and motion relative to other events. No longer could physicists speak with confidence of physical reality, but only of the probability of making certain measurements (Britannica, 2006).

Also in architecture, Mechanical aesthetic base on physical science has generated contradiction. New findings and applications in architecture did not sufficiently satisfy the basic rule of the physical comfort of the building.

Philip Johnson later said that staying at Bauhaus was uncomfortable because of glaring lighting. Le Corbusier’s “murs neutralisants” system, he mentioned that this system could be used in any place in the world. (Banham, 1969) This technique might work in Russia, as a buffer zone in winter. However, in most area of Europe or in the US, this would not work as what he might think. He, like other engineers at his time, did not consider effect of solar radiation, which causes the direct heat gain by sunlight and can affect the indoor space. In late phases of Le Corbusier’s work, he adapted shading devices into his architecture, such as “The High Court of Justice” at Chandigarh and “The Carpenter Center for Visual Art” at Harvard University.

Moreover, many buildings had to give part of the façade to this “man made weather” machine. Flat simple façades had been understood as an evolution of architecture in modern time, as architects expressed their beauty of simplicity in their façades. Installing the units in building façades meant that architect find too many design conflicts (Banham, 1969).

Problems of new type of architecture caused by application of new findings in science is because of complexity to understand physical behavior of nature, for that reason architect has to give up his part of creativity to engineers to compensate the lack of acknowledge in complexity of physics.

Scientific and technological advances were used in architecture without being absorbed by architect, the engineer remained subordinate to and detached from the architect. The architect, on the other hand, was left isolated from the most important movements going around him (Giedion, 1967).
3. NEW SCIENCE AND ARCHITECTURE

Conflict caused by the limited understanding of science and applying it to architecture can be found today also. As the mainstream revolution of science has shifted to chemistry and biology and led to hitherto undreamed capabilities for the manipulation of atoms and molecules and of cells and their genetic structures. Chemists perform molecular tailoring today as a matter of course, cutting and shaping molecules at will. Genetic engineering makes possible active human intervention in the evolutionary process and holds out the possibility of tailoring living organisms, including the human organism, to specific tasks.

Today in architecture, biology and chemistry are adapted to design process such as Nonlinear Fabrication (NSO, 2010). Kinetic Architecture, Algorithms architecture (Terzidis, 2003) and so on. Terzidis state in his book that new methodologies, which adapts newly developed science, employs regression, randomness, recursion, cellular automata, probability and so on, which outcomes are unknown, unpredictable and allows to explore uncommon, unpredictable and uncharted formal properties and behaviors (Terzidis, 2003).

Karim Rashid, Greg Lynn and others utilize dynamic modeling software and animation application such as Maya, Rhino, form Z and 3dmax to architecture. They are using this technology not merely to render and refine their ideas, but to shift their ideas to a new level by using these programs as collaborators in the creative process and discover new things through this process.

This approach to design emulates the process that is facilitated by methods of animation. In the New York Port Authority Gateway competition, Lynn utilized his new approach in virtual space. Architect animated movement and flow of pedestrians, cars and buses across the site by introducing particles into his virtual design space that would change position and shape according to the influence of the motion forces that was applied to particles.

Lynn notes, “Unlike conventional geometric primitives such as sphere, which has its own autonomous organization, a metal-ball is defined in relation to other objects. Its center, surface, area, mass, and organization are determined by the other fields of influence.” Those “fields of influence” can be used to simulate anything from the motion of the sun to the movement of people to changing brand identities, anything whose influence can be assigned a value. (Braham, 2005)

As Hugh Aldersey (2004) mentioned “Building shapes are making exciting departures from the rectilinear boxes that have dominated in architectural history, leading people to draw similes with the natural world. But there is the potential for architects to learn more deeply from nature, and use Biomimetic materials and technologies in improved buildings for the future.”

As discussed in previous sections, in different centuries, architects have been used science as a tool to interpreting nature to architecture and still architects are using same interpretation method that nature as inspiration for decoration and form. One noticeable difference is the new invention of computer is applied to design process.

Currently some architects use animation programs that are based on certain simplified physic equations to animate natural phenomena to their creative process of design. For example in a closed virtual world, architects evenly distribute nodes in the virtual world and randomly locate a certain flow within the boundary of the virtual world after that they animate a fluid flow. Once the flow has filled in the limited virtual world, the animation will stop and forces of the flow will relocate nodes, and the designer is able to capture the node points to generate a building form.

Another application of computation is parametric design method, which utilizing scripting function in CAD program to it is a different approach of utilizing CAD compared to conventional drafting use. In conventional CAD designs were object driven, that meant if you changed the object the dimension would change. In parametric modeling, changing the dimension then the object will change.

For example, in a parametric modeling, if the pitch of the roof is changed, the walls automatically follow the revised roofline, a parametric modeling is aware of the characteristics of components and the interactions between them, it maintains relationships between elements as the model is manipulated.

The parametric design into the design process allows the development of novel design solutions, difficult or impossible to achieve by other methods. Grammar-based techniques exploit the principle of database amplification, generating complex forms and patterns from simple specifications. Evolutionary systems from natural science may be used in combination with aesthetic selection to breed design solutions under the direction of a designer (Innocent, 1999).

Using newly developed methodology as a morphogenetic design procedure like mentioned in above did pose certain problems. In a time-based process, an endless flow of geometric transformations gives rise to the problem of selection.

Architectural form used to appear as the ultimate result of a process of research. As Norman Foster insisted that “silent, invisible electronic world” of virtual design must ultimately end in “physical reality.” (Waters, 2003) Its beauty was the beauty of the end, of the equilibrium. The equilibrium was often dynamic, but the form was supposed to dominate the movement, to encapsulate it. (Picon, 2003)

For that reason the selected geometry form animation is not the ultimate result of a research process, it is difficult to claim that it presents a better performance-based solution than another.

As Rykwert (1992), lamented while architects have long been preoccupied with nature as inspiration for decoration and form, there is not yet a “theory of architecture based on direct appeal to . . . the nature that biology and chemistry study.” Also Aldersey (2004) mentioned that “If we are prepared, as apparently we are, for our buildings to look like animals and plants, perhaps we should be working to
make them function like them as well.”

In mid 20th century, movement to understand and application of natural phenomena to design in scientific mythology can be notice. Such as Victor Olgyay (1963) suggested the bioclimatic chart in his book. In 1940, the Sloan Solar House in Chicago, designed by Keck, became the first contemporary building making use of passive solar heating. In 1953, Dan Trivich of Wayne State University made the first theoretical calculation of the efficiencies of various materials based on the spectrum of the sun (Tzikopoulos, et al., 2005).

In early 1960’s, researchers developed method called “Site Analysis” to consider microclimate of site and generate a form. This method is able to consider certain time of year as static condition usually for the worst conditions of site. This method takes into account physical conditions such as solar radiation, shading, wind, lighting, etc independently and each domain is analyzed and controlled independently.

Date from the late 1960s, researchers attempt to apply computer application to the simulation of building behavior. In the late 1970s, and continuing through to the 1980s, substantial programming and experimental testing efforts were invested to expand the building simulation codes into versatile, validated and user-friendly tools. Until the mid 1990s the landscape of tools was dominated by the large simulation codes. As new simulation domains came along, there tools tried to expand into these domains and outgrow their traditional energy origin. (Malkawi and Augenbroe, 2003)

Simulation algorithms have been designed to predict answers to domain-based questions, such as lighting, thermal or structural problems. Each of these domains has sub-problems that must be modeled and simulated differently. (Kolarevic and Malkawi, 2005) For that reason in the late 1990s, domains other than energy were increasingly covered by specialized tools and varieties of computational simulation tools were developed.

Recently, architects are able to apply building performance simulation to their design. Best example will be Norman Forster. He used building performance simulation tools like CFD (Computational Fluid Dynamics) in his design. One of the good examples using CFD was Swiss Re in London, he generates a form that minimizes the unpleasant wind effect on local microclimate and assists internal building ventilation.

![Figure 1. CFD study: Air movement around the building](TC Chan, 2006)

Building performance simulation tools, such like CFD and ES (Energy Simulation), have been largely used these days. However, their usages are very limited to certain ways. Simulation tools are mostly used for assessment or prediction at final design stage or in middle of process when architects meet with certain problems and rarely used in design creation process. Forster also used CFD simulation more likely as assessment tool and simulation tools are mainly used by professional experts not by designers themselves.

4. BLURRING THE LINES

Even though advanced simulation tools are developed, its application to the design process is limited to analysis. Moreover, recent development as discussed in previous section, digital design process is limited scientific application as interpretation method that nature as inspiration for decoration and form. Hardly find integration of advanced simulation in design creation procedure.

However, one interesting observation is that both area computational building simulation and digital design process frequently discuss about the high-performance building.

“Performance” in a building may imply the notion of efficiency as in a machine or engine, but may also imply an experiential notion of performance as may be seen on the theatrical stage or heard in a concert hall. In this manner the concept of “performance” may differ from profession to profession.

The architect considers issues of appearance or proportion, the structural engineer examines issues of strength, the lighting specialist considers illumination and task lighting, the acoustics specialist considers the perception of acoustics in a space, and so forth. The different professions experience different worlds, and thus have different goals in mind. (McCleary, 2005)

Performance can be defined not only as efficiency of system (quantity) but also as representation of experience or perception (quality).

New approach that to achieve qualitative performance by digital design process. Clearly share an equal part of definition in computational building simulation. Such as in closed virtual space, introducing forces as variable, and observe behavior of the movement shows similarity to building simulation. As a computer simulation is an attempt to model a situation on a computer so that it can be studied to see how the system works by changing variables.

Building simulation is used to help architects refine building form, and may be used to achieve a set of target criteria that the architect has established. Given recent developments in the area of simulation processes, its capacity will influence the analysis of variables in order to provide a better comparative study during design phases. Furthermore, it will facilitate developing the synthesis (design generation based on performance) model.

Michael Hensel (2006) makes note of such potential in
his book, where he mentions the Lindenmayer system or L-system. An interesting example featured in the book is the integration of biomechanics into plants development, which allows informing the plant growth with extrinsic physical, biological and environmental input. In his book, he suggests that the L-system could be applied to architecture. Building systems and envelopes could thus be informed by multivariable input and optimized to satisfy multi-performance objectivity. The gravity input can inform structural behavior that is then negotiated with exposure to environmental input. For example, energy-generating photovoltaic or photosynthetic elements – over a building envelope that is at the same time optimized towards multiple objectives such as sun path, prevailing wind direction, and so on.

Recently, researchers in building simulation approaching to the problem by using recently developed knowledge-based algorithms such as genetic algorithm with building simulation tools to develop a self-form generating program. Figure 2 shows a result of the new methodology for site specific form optimization, using building simulations to evaluate, and Genetic Algorithm (GA) to optimize the building form in response to its surroundings. This method has the potential to allow users to take advantage of performance driven form-making in the early design stages.

The study explored the integration between Energy Simulation and CFD to generate robust microclimate condition data to be used as a base for site-specific optimization studies. The research developed a new representation for building geometry, controlled by introducing hierarchical relationships that able to explored performance-based building form.

In addition, Balmond (2002) suggested possibility of computer program to generate form by means of leaning itself and optimize mechanical concerns.

New attempts to integrate building simulation with design creation are still in the initial stages and many problems still exist (Malkawi, 2005). However, building simulation has the potential of providing an alternative method of generating architectural form. If building simulation tools are used not merely for analysis, but also for synthesis, architects can perhaps extract a new paradigm of performance based generative design by blurring the lines between the qualitative and quantitative performances.

Figure 2. Building form morphing by site specific conditions (Yi, 2008)
5. CONCLUSION

In the beginning of modern science, architects mostly adapted science as method or theory for analyzing expressions in the architecture as a tool to measure or categorizing architecture. After science was able to welding with technology, not only utilized science as analysis of architecture but also utilized the benefit of new technology. New space, new expression, new structure was achieved.

However, not fully understanding of limit and complexity about science, sometimes it misleads architects. Diversity and complexity of science restricted architects to understand new science fully and architects have to withdraw some of part to engineers.

Unlike past, development of computer and new discovery in science field able architects to utilize science to generate new kind architectural forms easily. Currently architects utilized scripting or parametric functions in CAD program to animate the deformation or generate endless forms. However, as their predecessor misunderstood of science sometimes mislead architects as they did before.

As advanced simulation tools are possible, recently several researchers are try to combine science and architecture in a different way that enables computer to generate a form that corresponds to surrounding natural phenomenon. Like form follows by natural law of science.

Figure 3 shows general relation between science and architecture from beginning of modern science.

Figure 3. Relation between science and architecture from beginning of modern science
Figure 4. Current practice and possible new method to integrate design and building performance.

REFERENCES

Dollens, Dennis (2005) Digital-Botanic Architecture, Santa Fe, New Mexico, Lumen, Inc.

T. C. Chan Center for Building Simulation and Energy Studies (2006), San Jose Office Building Design CFD analysis
Yi, Yun Kyu (2008) Integration of computational fluid dynamics (CFD) and energy simulation (ES) for optimal energy form generation. Dissertations, University of Pennsylvania, Philadelphia, USA.

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