Building (Understanding): A Systems Approach to Building Information Modeling (BIM)

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"The idea that science can, and should, be run according to fixed and universal rules, is both unrealistic and pernicious."[1]

Architecture in practice is a combination of both skill and calculated chance. The growing complexity of building sciences, myriad technologies as well as insatiable material development has continued to challenge the skill of architects, in many cases forcing specialization or mediocrity. In addition, the external forces impacting architecture; social, political, economic and spatial, continue to increase at a similar rate. We live in an increasingly 'connected' world; an open system of flows and exchanges.

This paper stems from a reaction to the prevalent view that architectural education is largely executed within an academic bubble, cut off from the world of practice. This view conditions many to believe this hermetic environment is in fact the way the profession functions: 'I design and it gets built'. This paper is based on the work completed in a course entitled 'Advanced Building Systems' taught at the School of Architecture during the fall semester of 2005, attempting to dispel this view. The course utilized current building information modeling [BIM] techniques, seminar readings as well as the ideas of general systems theory to analyze and evaluate landmark architecture through the case study method. The course proposed that a thorough understanding of both the internal and external factors influencing architecture would allow students a more realistic analysis of building and its mutable role in society today.

Building Information Modeling

Building information modeling [BIM] continues to gain widespread attention with the promise of streamlining the design and construction process.[2] BIM, the process of constructing a single 3-D building in virtual space which integrates all of the major building systems, allows the architect and their consultants to share better information with each other and with the contractor. These models, drawn by the various consultants and compiled as a single document, also have the ability to be used for quantity surveys, site studies of shadow and sunlight as well as visual time lines for the construction process. As a result, more information is discovered earlier in the design process, errors and omissions are discovered earlier, reducing questions and costly change orders as well as reducing the construction time, cost of construction and increasing the value to the owner. Much of the excitement in BIM has come from the contracting world as aspects of documentation and the construction process is where, at least initially, BIM appears to exhibit the greatest value.

As BIM is gaining acceptance in practice, it is also gaining popularity in architectural education as a design and presentation tool. Three-dimensional modeling has replaced conventional 2-D drawing and the ability to show structural, mechanical and enclosure systems, has revolutionized the presentation of design projects.

The use of BIM in this way allows students a more thorough understanding of the complexity of design and integration as systems are coordinated together to form a holistic design solution. But while the use of BIM would appear to expand the limits of design, it is this authors contention that students view the presentation of both design and construction documents as a closed system, distinct from the ideas that generated the design; in other words, once the documentation is complete, the project and related systems achieve a state of equilibrium where the final design work is in essence *'complete'*, with no further input or output.

Figure 1. Student Design/Build 2005 Information Model [BIM]

While this may be true for student design work, the actual world of building is based on open systems; a continuous flow of materials that achieve not equilibrium but a continuous steady state.[3] These open systems are contingent upon many diverse systems interacting with one another to produce desired or undesired results. Many of these systems are not related to physical building but impact the building process nonetheless. This is space that is "*produced*" as Henri Lefebvre describes in The Production of Space. Utilizing nature as a resource, space is the product '…of an activity which involves the economic and technical realms but which extends well beyond them, for these are also political products, and strategic spaces. The term 'strategy' connotes a great variety of products and actions: it combines peace with war, the arms trade with deterrence in the event of crisis, and the use of resources from *peripheral* spaces with the use of riches from industrial, urban, state-dominated centres."[4] With this description, Lefebvre illustrates the far reaching effects that dictate spatial production. Global economics, a-spatial activities and political will, through the use of 'labour, technology, knowledge, property, institutions and the state'[5], all have an impact on spatial production and thus influence, in large part, the built environment. These diverse systems in many respects are paramount to the built environment and therefore impact society in profound ways. I believe it is an understanding of these systems that begins to expand the boundaries of design and sheds light on architecture's complex relationship with society. To expand upon the systems that impact architecture, it may be useful to examine the tenets of the general systems movement during the 1950's.

General Systems Theory

Figure 2. GST founders, source: www.isss.org

In 1954, a group of men conceived of a research society devoted to the understanding of complex systems through interdisciplinary inquiry.[6] A year later the group would form the Society for General Systems Research and based on the work of Ludwig von Bertalanffy almost two decades before, would assume a radical position with regard to the structure of scientific research; they would openly question the scientific method and the mechanistic world-view based on the writings of Descartes some 330 years before. This radical position would be based on the thought that the scientific method could no longer thoroughly explain certain complex phenomena found in research fields including biology and the social and behavioral sciences. They believed that a more holistic view was required that would essentially reverse the traditional logic of reductionist thinking; the breaking down of a whole into it's smallest pieces to explain the dynamics of the system, and begin to look at the dynamics of the whole to understand the properties of it's constituent parts.[7] This would revive the Aristotelian argument that the whole was more than the sum of the parts. They would have many admirers and detractors over the years.

In what may be considered the systems theory manifesto entitled, "General Systems Theory: The Skeleton of Science", author Kenneth Boulding placed systems thinking "between the specific that has no meaning and the general that has no content"[8].

General systems theory was not intended to be a "theory of everything" like the quest for a unified field theory in physics but instead sought an "optimum degree of generality"[9] which would link theoretical models in different areas of study thus filling in the gaps that existed between research fields. In the minds of these systems thinkers this would solve the crisis in science due to specialization that did not allow for an analysis of the wholeness of any discipline to be seen and understood.

> "Specialization has outrun Trade, communication between the disciples becomes increasingly difficult, and the Republic of Learning is breaking up into isolated subcultures with only tenuous lines of communication between them – a situation which threatens intellectual civil war."[10]

Boulding felt that with increased specialization there would be less communication between various branches of science and thus stagnate the growth of knowledge. Within the wholeness that would emanate from systems theory, a renewed sense of interdisciplinary learning would appear. Fields such as social psychology and cultural geography, as hybrid disciplines, owe their origins to the concept of systems theory and the foundations of a holistic worldview.

The position of the systems theorists at mid-century has been forwarded by thinkers including Fritjof Capra, who see the world as an interconnected "whole". This world, again, is more dependant on the "dynamics of the whole, defining the properties of the parts" and not the properties of the parts explaining the whole. For Capra, whose book *The Turning Point* became the genesis for the systems theory movie, *Mindwalk*, interconnectedness [or systems thinking] is used to explain all of life, from physics to economics to biomedical and related human health issues:

> "To associate a particular illness with a definite part of the body is, of course, very useful in many cases. But modern scientific medicine has overemphasized the reductionist approach and has developed its specialized disciplines to a point where doctors are often no longer able to view illness as a disturbance of the whole organism, nor to treat it as such. What they tend to do is to treat a particular organ or tissue, and this is generally done without taking the rest of the body into account, let alone considering the psychological and social aspects of the patient's illness."[11]

This current fascination with systems theory has resulted in hundreds of books on the subject in a wide array of disciplines. While widespread acceptance of systems theory is far from a reality, we can see the effects of systems thinking in many fields of study, including, to a certain degree, architecture.

Architecture in practice has always had to negotiate systems thinking as a necessity of material integration. With the introduction of building materials comes the responsibility of integration in Vitruvian terms: firmness (how does the integration work?), commodity (how does the integration respond to economics) and delight (how does the integration work visually?). Examples of integration over time, utilized in academic settings, include Kahn's "served and servant" space as well as the work of many British "high tech" architects, these provide illustrate a need for integration which BIM. The following description of the Advanced Building Systems course is intended to address these issues as well as expand the traditional boundaries of architectural investigation to areas of study that impact the way we see building.

Course overview

While architecture has become increasingly specialized, working in scientific reductionism to isolate smaller and smaller systems and parts of the whole, the application of General Systems Theory, in contrast, works towards a holistic view to understand the myriad interactions and implications that ultimately influence the 'whole' architectural product.

This holistic view frames the basis for the course described below, Advanced Building Systems, a four hundred level course taught in conjunction with professional practice and a comprehensive design studio. The goal of this

Advanced Building Systems course was to encourage students to evaluate case study buildings in the context of architecture as an open system; a flow of input and output between the building organization and its environment. This research was conducted utilizing three tools of inquiry, first, the investigation of landmark buildings through the use of building information modeling. Second, the use of the case study method as an investigative tool to encourage the students to better understand the complex decision-making that is inherent to the architectural process. Finally, general systems theory was employed in the form of seminar readings to instigate or provoke discussion of systems outside the realm of building that could be utilized for a comprehensive investigation of their particular case study buildings.

Tools of Inquiry

The creation of a building information model [BIM] for a selected landmark building was completed by the students, in teams of two. Over the course of the semester the students created a series of building information models depicting four of the five primary systems: structure, envelope, mechanical, and either the interior or site for their particular case study buildings.[12] Each information model was presented in 24x36 board format with pertinent written and graphic information. All four individual models were successively integrated to form a master 3-D model in the same way a master building information model would have to coordinate all systems in an office environment. In addition to the building information models, the students also had to analyze each of the primary systems with six performance mandates: building integrity, air quality and visual, thermal, acoustic and spatial performance.[13] The use of the mandates required the students to fully analyze all of the major building systems together, utilizing some of the systems in a secondary and tertiary fashion to connect the system in question to the particular mandate. As an example, one would have to consider the mechanical and envelope systems when describing air quality as a performance mandate of the structural system. This allowed for a more thorough investigation by the students forcing them to synthesize various information sources and make evaluations based on that information.

The students were encouraged to select any well documented landmark building for case study research and were also asked to initially create a comprehensive bibliography, ensuring that necessary project information, both written and pictorial was available. For case study research, the students utilized the *Development Checklist for the study and practice of Case Studies in Architecture*[14] prepared by the AIA and the Large Firm Roundtable. Almost all of the projects selected limited the students to case study information gathered through printed sources with no client or architect correspondence. This placed a premium on gathering thorough bibliographic information so a full case could be constructed and cross-referenced for accuracy. The *Development Checklist*, specifically the sections related to project abstract and project perspectives and analysis, provided questions regarding each project that challenged the students to evaluate areas including measures of success, financial implications and special resources required. As important as the physical systems integrated into the buildings are the decisions that make these system choices possible. Logistics, technological limitations and design constraints are only a part of the overall process of building. Throughout the semester, students were continually asked to investigate their case studies within this holistic open system approach.

The weekly seminars were centered on a group of readings intended to expand the notions of architecture and building. They were also meant to represent the General Systems Theory portion of the course to provoke a greater sense of the external forces surrounding architectural production. Readings including, the production of space on a global scale, control, hyper-reality and representational questions of material and systems are a few of the topics covered during the semester.[15] The readings were issued on a weekly basis and discussed in class. Questions were issued at the beginning of each class and then discussed in a seminar format.

Each team of students produced four 24x36 presentation boards for each case study building with accompanying text. The boards were graded on the overall presentation, thoroughness of research and completeness of the BIM. One shortfall of the course was that case study information discovered through the seminar readings, information the students found to be external of the physical building systems , was not found uniformly by all teams. Additionally, the information found was somewhat superficial and not achieving the depth of inquiry necessary to fully understand the issues surrounding spatial production in Lefebvrian terms. This may have been due to factors including project selection not lending itself well to these types of discoveries or the particular perspective each respective student team. Additionally, this level of investigation may not have been realistic within the course structure and expectations. In many instances the students discovered the information as part of their research, as opposed to seeking out these larger issues framing their projects. This was in many ways the most exciting aspect of the case studies, witnessing the students uncover findings on their own and presenting them to the class, dispelling many myths regarding design, academia and practice.

As a teaching and learning model, the three aspects of the course allowed the students the opportunity to analyze particular case study buildings from a systems perspective, not limited to just the building but to include larger external issues that influence or dictate how buildings comes into being. As a final analysis, the students were issued a blue book final to present an essay that culminated their findings over the semester. The essay was a response to Michael Benedikt's introduction to the *Center 10* publication entitled, *Value*, where he contemplates that our physical environment must not be valued due to our built environment becoming increasingly more commodified and devalued, subject to short term investment and resale.[16] The student responded favorably to the opportunity of an essay final, one student writing, "It is time for architects to embrace the scientific approach used by other industries to develop and utilize new materials which will improve the manner of living experienced by the general public."[17]

Case Studies

What follows are examples of the student's case study projects and their findings.

British Pavilion, Seville expo- The British Pavilion at the Seville exposition in 1992 by Nicholas Grimshaw and Partners is an intriguing case study from the aspects of sustainability as well as the projects fabrication, delivery and assembly methods. As a study in sustainability the building is a collection of passive energy and climate moderating systems working together to temper the scorching heat of Seville. Fabric shading devices, a water cooled curtainwall and trombe wall created from water filled shipping containers were employed to create a tempered environment inside the pavilion while photovoltaic panels created energy from the sun for electrical pumps and other necessary items.

As a study in energy conservation and sustainable technologies, the building is a virtual cornucopia of interrelated systems working in concert to create a pavilion that was both innovative and comfortable for thousands of visitors.

Equally important to the sustainable issues is the fabrication, delivery and assembly of the building as a study in the logistics of global architecture. The building, produced in Britain, was constructed almost entirely of prefabricated parts, transported to Seville and assembled on site. With the building being produced in Britain, the logistics pertaining to international shipping routes, container sizes as well as trucking to the site became critical to the design of the project.

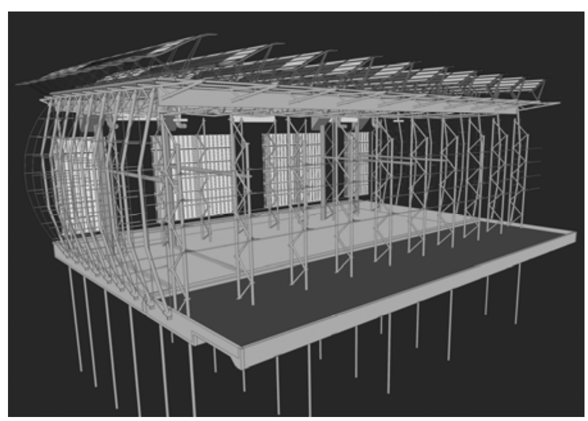

Figure 3. Image from British Pavilion [BIM] student presentation.

It could be argued that these criteria were the primary design constraints imposed on the project, occupying the talents of both the designers and fabricators:

> *"...These too would have been fabricated in Britain and shipped in containers, probably via the nearby port of Cadiz. The more distant port of Santander on the north coast offered more flexible handling facilities, however, and after checking the road route via Madrid for possible bottlenecks, the designers and fabricators decided that it was feasible to transport much larger components, up to 24 metres long and weighing up to 7.5 tonnes."*[18]

In addition to the travel logistics, the building is also a study in prefabrication and the use of related technologies, in this case yacht sail and rigging design. The students realized this during the initial case study research and were able to look at the design of the pavilion through the lens of fabrication and transportation, similar to Grimshaw's office, in their documentation of the systems.

Milwaukee Art Museum- The Milwaukee Art Museum completed in 2002 by Santiago Calatrava has become a landmark and destination museum for the City of Milwaukee. The building is best identified by its distinctive curvilinear skeletal form with prominent mobile brise-soleil 'wing' shading devices.

The students had assumed that the winged brise-soleil shading device was in fact that, a shading device, and had reserved this item to be included in their mechanical system analysis. They were surprised to conclude that in fact the shading device was nothing more than 'signage' for the museum.

"It is most intriguing that the most captivating elements, the mobile wings, are in fact not an integrally important component to any of the systems. Paraphrasing Charles Loomis, facilities engineer at the museum- there have been many speculations as to the operation and functionability of the brise-soleil, but in fact, it is really just a tourist attraction."[19]

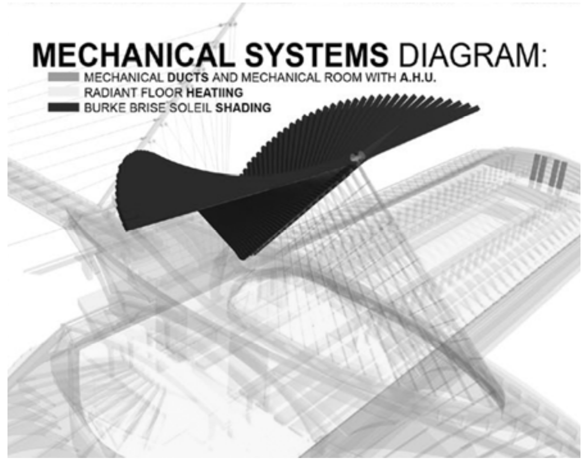

Figure 4. Image from Milwaukee Art Museum [BIM] student presentation.

This is part of the landmark status that museums have gained over the past few years. Museums in many ways have become destination points for economic gain. This global phenomena is best expressed by David Harvey in his article, *The Invisible Political Economy of Architectural Production*, discussing explorative economic success similar to '...the Cargo Cultists of Papua New Guinea, who seek to lure passing aircraft to earth by building imitation landing strips in the vague hope that some might land.'[20]

Blur, Swiss expo**-** The 'Blur' project, one of the pavilions for the Swiss exposition in 2002 by Diller & Scofidio creates a case study in the variability of the environmental systems employed, in this case fog, as well as in the unpredictability of the capitalist system at large. Constructed on the shore of lake Neuchatel, this temporary structure was equipped with a state of the art fog system and other technologic innovations that created a pavilion that became much more than the sum of its parts.

One such move was in the areas of marketing and advertising. The project was accompanied by a massive marketing blitz that resulted in the image of the 'blur' on vodka bottles, candy bars, packets of sugar, stamps, phone cards and even lottery tickets throughout Switzerland.

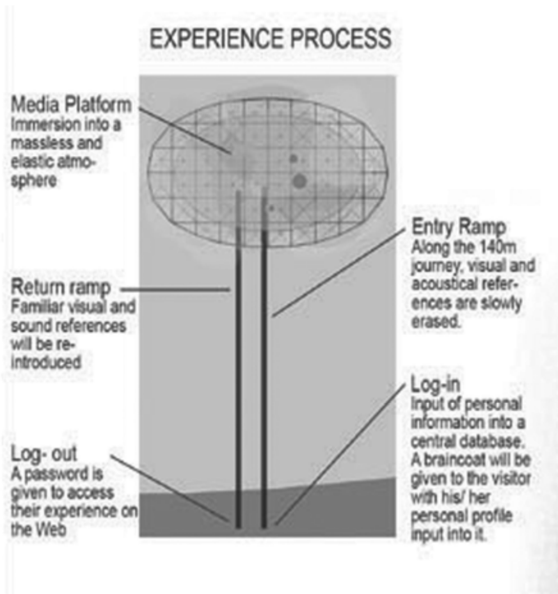

Figure 5. Image from 'Blur' [BIM] student presentation.

Another intriguing aspect of the Blur project, and tied to aspects of capitalism, was the 'braincoat' raincoat. The 'braincoats' were technologically enhanced raincoats that incorporated smart systems to store personal data of each individual wearer for 'communication' while in the cloud. Utilizing tracking and location technologies, the coats were able to compare personal data between individuals that came into proximity and light up or produce sounds to react to the degree of attraction found between each individual's personal data. Sadly, the 'braincoat' was never to be utilized due to lack of funding by a corporate sponsor. In this case the students were able to see how design is subject to the fickle world of corporate finance and economics. Financial systems, unrelated to architecture, in this case substantially impacted the desired effect of the architectural experience and while capitalism was able to exploit the branding of 'blur' as a national icon, it was unable to ensure one of the more intriguing aspects of the project.

Conclusions

In summation, the building information models, presented in a system by system format, gave the students an opportunity to analyze the material and building systems that were utilized in each project. It also made them more aware, through the construction of the models, of the interrelation and interdependency of each major system to the building as a whole. The performance mandates enhanced the level of investigation between the various systems allowing for in depth synthesis and evaluation that could not have been possible with a more conventional case study analysis. Finally, I believe the reading and seminar discussions stimulated an additional level of investigation into each project with an understanding of the logic and decision-making processes that occurred before, during and after the initial design and on into the construction process.

Endnotes

[1] Paul Feyerabend, *Against Method*, (London: Verso, 1975): 295.

[2] [BIM] related articles have regularly appeared in *Architectural Record* since 2004, the most recent being: Larry Flynn, "Getting on Board with Building Information Modeling: Using 3-D modeling to integrate the design and construction process", *Architectural Record*, (April 2006): 163-167.

[3] L. von Bertalanffy, "The Theory of Open Systems in Physics and Biology", from F. E. Emery, editor, *Systems Thinking*, (England: Penguin Books, 1969): 71.

[4] Henri Lefebvre, Translated by Donald Nicholson-Smith, *The Production of Space*, (Oxford, UK and Cambridge, MA: Blackwell, 1992): 84.

[5] Ibid., 85.

[6] The principal members of the Society for General Systems Research were Ludwig von Bertalanffy, Kenneth Boulding, Ralph Gerard, James G. Miller and Anatol Rapoport. See The International Society for the Systems Science, www.isss.org.

[7] Ervin Laszlo, editor, *The Relevance of General Systems Theory: Papers Presented to Ludwig von Bertalanffy on His Seventieth Birthday*, (New York: George Brasiller, 1972): 5.

[8] Kenneth E. Boulding, "General Systems Theory-The Skeleton of Science", *Management Science*, 2/3 (April 1956): 197.

[9] Ibid., 198.

[10] Ibid., 198.

[11] Fritof Capra, *The Turning Point, Science, Society and the Rising Culture*, (New York: Simon & Schuster, 1982): 157.

[12] These are the generally recognized 'major' systems categories. See Leonard R. Bachman, *Integrated Buildings: The Systems Basis of Architecture*, (New Jersey: Wiley, 2003) and Richard D. Rush, editor, *The Building Systems Integration Handbook*, (New York: John Wiley & Sons, Inc., 1986).

[13] See Richard D. Rush, editor, *The Building Systems Integration Handbook*, (New York: John Wiley & Sons, Inc., 1986). This is the same mandate list sans the matrix connectivity.

[14] AIA, *Case Studies in the Study and Practice of Architecture, Development Checklist and Submission Guidelines*, (AIA: New York, 2001).

[15] A partial list of readings includes, David Harvey, "The Invisible Political Economy of Architectural Production", from *The Invisible in Architecture*, O. Bouman and R. van Tourn, editors, (London: Academy Editions, 1994): 420-427., Colin Davies, "Introduction: High Tech-A tentative definition", from *High Tech Architecture*, (New York: Rizzoli Press, 1988): 6-21., Margaret Crawford, "The World in a Shopping Mall", from *Variations on a Theme Park, The New American City and the End of Public Space*, Michael Sorkin, editor, (New York: Hill and Wang, 1992): ., Michel Foucault, "Panopticism", from *Discipline & Punish*, (New York: Vintage Books, 1995): 195-228., Albert Borgmann, "Hypermodernism", from *Crossing the Postmodern Divide*, (Chicago: University of Chicago Press, 1992): 82-97.

[16]Michael Benedikt, "Introduction" from *Center 10/Value*, Michael Benedikt, editor, (Austin, TX: University of Texas Press, 1997).

[17] Student, Corwin Dormire final essay, fall 2005: 13.

[18] Colin Davies, *British Pavillion, Seville Exposition 1992: Nicholas Grimshaw and Partners*, (London: Phaidon Press Ltd., 1992)

[19] Milwaukee Art Museum case study. Students: Lance Hayes and Josh Vernon.

[20] David Harvey, "The Invisible Political Economy of Architectural Production", from *The Invisible in Architecture*, O. Bouman and R. van Tourn, editors, (London: Academy Editions, 1994): 426.