Representing complexity: Understanding performance in integrated design

Clifton Fordham[1]

[1]Temple University, Philadelphia, PA

ABSTRACT: A discourse of sustainability in architecture promises to be an immutable fixture of research, a shift that can be attributed to climate change and natural resource depletion. Sustainable buildings can be achieved through numerous avenues including material selection, HVAC and lighting system selections, and enclosure detailing. The effectiveness of these strategies depends on an understating of climate, site, building activities, form implications, construction methods, regulatory and social context.

The term "integrated design" best describes the synthesis of multiple design factors so that they resulting solution is meshed as opposed to layered. Central to the practice of integrated design is a necessity for knowledge, particularly technical knowledge grounded in science; knowledge that has to coexist with other types of design knowledge. This shift challenges limits of current architectural theory and pedagogy. It also represents a move toward increased complexity in design, especially at the beginning of the design process when decisions offer the best probability of high performance buildings.

The notion of complexity challenges current limits of design thinking. In his essay *Embracing Complexity in Building Design* Leonard Bachman compares complexity in building design to dynamic systems thinking as opposed to an understanding of buildings as static objects. The apparent static nature of buildings encourages a reductionist understanding of buildings typified by photographic images, and renderings. Since complexity in high performance buildings is not only evident in the material of building, how can it be better understood by stakeholders in the design process, as well as non-participants, seeking a better understand of building performance?

Legibility challenges exist since a complex design does not necessarily appear complex. If complexity to woven into buildings, historical means of representing and evaluating buildings become inadequate. Diagrams have become a part of academic analysis in high performance buildings since they are particularly helpful in illustrating abstract principals and non-geometric activity in buildings including movement and relationships. However, there are limits to the effectiveness of diagrams, particularly those that use arrows to represent air flow and heat transfer.

Data in design research has been relatively scarce despite the fact that buildings are material objects that lend themselves to quantification. When data is used, is usually limited to areas counts, and metrics are buried in performance benchmarks such as energy and load criteria. Research on building performance by architects must incorporate increased use of data if it to illuminate the complex factors that underpin high performance buildings including energy flows, space effectiveness, efficiencies, materiality, and user satisfaction. This paper provides cases on how data can be utilized alongside traditional graphics to better understand integrated design

KEYWORDS: Integrated Design, Complexity, Knowledge, Data, Representation.

INTRODUCTION

Designers of buildings are required to address a multiplicity of program and regulatory requirements. The additional objective of achieving high-performance building results in additional complexity since it is necessary to understand complex natural systems in which buildings are situated as well as suitable building technologies. (Moe 2008, 6-7) In close relation to need for suitable knowledge is the availability of tools to process information and assist in the evaluation of design proposals. Currently most of the tools for evaluating energy performance and other performance factors are utilized late in the design process, or after a building has been constructed. As a result, architects rely heavily on experience based intuition early in the design process. (Lawson & Dorst 2009, 84, 96-100)

This paper addresses two primary challenges to integrated design, understanding how buildings perform, and the problem of measuring performance of buildings early in the design process. Understanding is closely related to our ability to recognize information and situations. This paper focuses on the designer's ability to see, and make more sense out of what is perceived. More specifically, it focuses on tools available to measure building performance which are tied to quantitative factors as well as methods under-development for measuring qualitative components of the built environment. Hurdles to developing measurement systems include the prototypical nature of buildings which makes comparison difficult. This study utilizes an evaluative analysis to explore different measurement tools, and explain how these tools relate to questions of building performance. (Walliman 2011,11-12)

1.0 DIFFERENCES OF PERSCRIPTIVE AND PERFORMANCE OBJECTIVES

Building outcomes are difficult to measure because designs are shaped by forces emanating from different locations, including goals that are not comprehended at the time of project initiation. They are also difficult to measure because the source of measurements for prescriptive and performance objectives can be applied to the same project. Owner goals for a project are typically codified in a project brief supplemented by input during the design process. Because forces impact the design process deriving from outside the owner's demands, it is difficult to measure project success against owner established goals whether prescriptive or performance based. These external forces include regulations, design team input, and builder input. Rule based conventions are easier to implement than performance criteria. (Lawson 2009, 68)

Examples of rule base conventions that shape buildings include building codes, for which compliance is relatively easy to measure. Similarly, rating systems such as LEED are prescriptive in nature as opposed to performance based, and offer a baseline for clearly identifying success or failure within the system. However, closed rule based systems such as LEED do not adequately address performance objectives that do not fit within the rules established by the system. Rule based systems often miss alternate paths to high-performance buildings available earlier in the design process limiting the overall performance potential of buildings. An example would be the opportunity to shape building form to respond to local daylighting conditions prior to designing an optimal HVAC system. (Schwitter 2005, 113)

Although design objectives need to be identified early in the design process, if goals are too prescriptive or detailed, they prevent architects from identifying additional problems to solve; something that is pivotal to the ability of designers to make meaningful contributions to specific projects. This is because architects make intuitive creative leaps by producing solutions before all of the facts of a design have been solved for. Inherent in this process is the application of knowledge to identify problems beyond those specifically identified in the brief. By making creative leaps, the architect can understand and evaluate proposals by critiquing proposals, and generate more appropriate solutions. This results in an iterative process where more knowledge gained about the problem. When performance based criteria allows for more architectural thinking, complexity can be better integrated into building design. (Lawson 2009, 34-42)

Integrated design emerges from a process that recognizes that high-performance buildings are not autonomous objects, but rather perform in a manner that encompasses ecological, sociological, psychological, economic, political, climatic and technological and natural systems. (Kolarevic 2005, 195) By necessity, high-performance buildings account for time after commissioning. It also raises the need for designers to have more knowledge on how individuals use facilities, how they are serviced, and maintained. This necessitates better communication between designers and owners about how a facility will be used, as well as common ground for understanding and measuring building performance. Clearer communication and measurement tools are needed to assist designers and owners in locating a common understanding of how designs match owner expectations. It also calls into question the notion that architecture falls outside the boundaries of quantification and measurement, an argument that has been supported by many architects and architectural critics. (Augenbroe 2005, 99)

There are legitimate reasons why many architects disagree with the notion that building performance should be measured and quantified. Operational aspects of buildings have traditionally been associated with accommodation of specific activities, structural and mechanical systems. Rational understanding of building in this light is reductionist in nature, and has led to uninspired and banal buildings, omitting benefits of architecture independent of function. Architecture of the post-war years provides a plethora of examples of impoverished buildings that represent the sum of functional components, and neglect the representative side of architecture. This perspective illuminates the dichotomy between art and function, and the murky area where they overlap. It also presumes that buildings are not machines like automobiles, which are designed for limited applications. (Leatherbarrow 2005, 8-9)

2.0 SOURCES OF BUILDING INFORMATION

It is no surprise that attempts to measure building performance emanating from outside of the architectural profession have been the most successful. The most common source for building information comes from the construction of the buildings. Data derived from cost indexes can be used to anticipate and compare the initial costs of components, assemblies, and entire structures. While aggregate data collected by organizations such as RSMeans, do not reveal specifics of survey samples, cost data can be useful in establishing project cost discipline, prior and during construction. This data does not speak to the myriad buildings objectives; and loosely addresses building quality. Architects are correct to be wary of the weight given to this information because of large quality deviations in buildings. Cost is only one means of measuring buildings, and must be combined with other factors to gain a true idea of building value. (Ashworth & Hogg, 1-9)

Individual components and products within buildings can be measured more easily than composite structures. They are subject to universal testing, and contain data that contributes to greater understanding of design and built structures. Quantifying building materials has benefits other than supporting cost estimating prior to construction, namely measuring the environmental impact of materials prior to installation, including embodied energy of materials. Utilizing BIM software and updating design documents to reflect construction changes, and builder design input, is not perfect reflection of future as-built conditions, but accurate enough to derive and understanding of the material reality of buildings. BIM Software has been developed by Autodesk and its partners to link databases of information on the embodied energy of building materials and products.[1]

Anticipating and evaluating systems performance is easier if a product is lab tested as opposed to assembled on-site. Systems such as conveyance systems can be tested after installation against manufacturer's product data based on laboratory testing. Similarly curtain wall and lighting can be modeled, commissioned, and tested after installation against performance criteria available from codes, or factory testing scenarios. However, some systems such as lighting react more dynamically when situated within actual site conditions, many of which are not anticipated at the point of design and specification. This can lead to design solutions that underperform because decisions are based on typical industry assumptions instead of specific site conditions that can be anticipated through better communication and modeling.

3.0 OVERCOMING HURDLES FOR MEASURING BUILDING PERFORMANCE

In their book *The Integrative Design Guide to Green* the 7group and Bill Reed provide an example of lighting designers using design standards provided by industry trade originations such as ASHRE, instead of utilizing information available that would change their design assumptions. By utilizing high reflective paint, they discover that lighting levels could be reduced by 25%in a new school building. The architect on the project was unaware that such an option was available and that if the right paint color was selected the mechanical engineers could reduce the size and capacity of the HVAC system saving money and resulting in a more energy efficient building. By not sharing data such as paint specifications early in the design process, decisions are made that diminish building performance for decades in the future. The authors found that some vital communication between consultants early in the design process, almost never happens. (7group and Reed 2009, 19-22)

Some engineers are moving past utilizing prescriptive criteria, to work with architects to develop solution better suited to specific problems where solutions evolve during the design process. Practices such as Bruno Happold have utilized advanced software programs including TENSYL to analyze cable structures which emerge from performance-based designs. The same program has been adapted to assist with the design of amorphous shapes, including long-span structures out of non-typical materials such as cardboard. CFD (computational fluid dynamics) modeling (fig. 1) has been applied by some mechanical engineers to model air flow in non-conventional design proposals, and to support advanced technological design proposals. CFD has also been used to modeling light pollution on a complex urban site. Similarly, CAM tools are being used to model and test prototypical building components early in the design process. (Schwitter 2005, 115-117, 119-12)

Figure 1: CFD Model of Performing Arts Center. Source: *Performative Architecture: Beyond Instrumentality.*

Parametric modeling is being used to correlate area requirements with structure so that form and structural components can be adjusted to respond to subtleties in program and site. An example is the TGV train station in Avignon, France that balances where software was used to adjust a repeating section to respond to nuances in anticipated program use and site conditions. Variety was instilled in the enclosure material treatment, and the changes in cladding shape derived from their specific location on the building, resulting in shifting glass treatment across the entire building surface. Thermal criteria for the project derived, not from standard codes, but from the anticipated use of the structure. RFR an engineering practice in France found similar benefits in early project modeling with the railway extension in Strasbourg, France, where structure, glass, enclosure, and HVAC considerations were meshed with formal objectives. (Blassel 2005, 126, 131-132)

4.0 MEASURING SPACE AND FUNCTION

Numerous factors make it difficult to measure the performance of building spaces, and their relationship to each other; particularly before a building is commissioned. Among the factors are the social and psychological nature of architecture space; as well as the variety of space configurations brought about by uniqueness of location and program nuance. Additionally, the formal nature of architecture creates challenges to measurements as a means to valuing aesthetics and space; something theorist David Leatherbarrow notes, is difficult to when future contingencies about how space will be used and interpreted is almost impossible to predict. To avoid bland and overly efficient buildings such as many building constructed after World-War II, he advocates that contingency be factored into buildings to allow for a loose fit between program and design. (Leatherbarrow 2005, 8-9)

When program requirements are stringent, as in the case of health care facility design, case study databases have been created to assist in the evaluation of designs, an approach known as EBD (evidence based design). EBD utilized information gained from designers, and surveys of occupants regarding how they perceive buildings to serve their needs. Data gleaned from post-evaluation studies (fig. 2) can be used to make cases during the design process as an alternative to relying of testimony from experience. The user centric nature of this evidence runs counter to current ideas of expert evaluation and control of design. Another challenge of EBD is that for it to work effectively, information derived from design, construction, and surveys, must be widely accessible; something that is contrary to the way that building participants handle information about projects. (Hamilton & Watkins, 2009, 22-23)

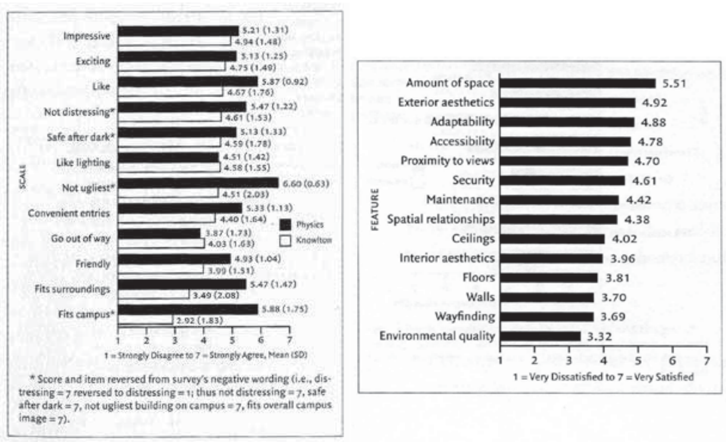

Figure 2: EBD study tables. Source: *Designing For Designers, Lessons Learned From Schools of Architecture.*

Efforts to develop databases of precedent in architecture parallel processes that have been implemented across the board in medicine and law as a means for providing common sources for learning and evaluation. In the case of law, precedence plays a key role in the advancement of working standards that includes knowledge from outside of law such as from economics and sociology. The legal system is not a closed system, but rather an organic system that evolves in reaction to external influences which are then codified in new law. Similarly, the medical profession relies on knowledge gained from scientific studies that are recorded and disseminated to practitioners as a common basis for practice. (Bachman 2012, 55)

Systems have emanated from outside the architecture community that can measure performance of individual building systems against quantitative benchmarks, building codes, or manufacturer's data. A building performance rating systems called *Standards for Whole Building Functionality and Serviceability* has been developed by ASTM (American Society for Testing and Materials). The system has partitioned building performance factors into thirty-two categories including floor measurements, energy management, air quality, and disaster risk. Hypothesized methods of evaluating building performance have been developed such as the *General AEC Reference Model* utilizing performance indicators (PI's) where building functions and systems are divided into manageable chunks. The system has yet to be adopted in practice, with advanced variations of this PI system currently under development. (Augenbroe 2005, 99-104)

5.0 COMPLEXITY AND PERFORMANCE

There are architects who are using computer algorithms to generate forms with program algorithms derived from program databases. Examples include Nox Architects who test out new forms of utilizing software to study new ways of organizing program areas based on data including usage rates to bring down the size of an office that would normally allocate space without considering activity intensities. The result was a building approximately thirty percent smaller. The process utilized by Nox is significant because it incorporates information deriving from specifics on the project, and not from outside the project, resulting in a complex appearing form. (Spuybroek 2005, 164-166)

More often attempts by architects to introduce the notion of complexity into buildings have confused the aesthetics of complexity, which often result from complex appearing computer generated forms, with performance-based complexity. Actual complexity in buildings can exist within simple forms and understated articulation. Complementary elements produce results that are greater than the sum of parts, an important characteristic of complexity. Integrated or meshed complexity operates below, or within, visible surfaces challenging observers to comprehend complexity and necessitating techniques for recognizing complexity beyond form. This is important because the benefits of high-performance buildings derive from their complexity. (Kolarevic 2005, 195)

The amount of knowledge and expertise necessary to design buildings generally lie beyond the capabilities of a single organization. With high-performance buildings this is more acute as there is greater scope of performance considerations, and a larger set of questions to respond to. Part of the role of architects is to identify and assemble experts who work with the architect and owner to develop a building that incorporates the collective contribution of talents. Architects must be able to recognize, identify, and understand broad issues inherent in the design problem and evaluate feedback. Despite high levels of knowledge which are required, skilled architects can filter knowledge that would prevent them from moving beyond pragmatic questions. (Lawson & Dorst 2009, 38, 126-132)

6.0 ADDRESSING TRADITIONAL PROJECT DELIVERY CHALLENGES

One of the keys to designing and constructing higher performing buildings is making decisions earlier in the design process that factor in criteria that are difficult to address later. In the traditional project delivery process, broad decisions including site placement, form, and program organization, and are made early in the process by the architect. Consulting engineers, particularly mechanical engineers, provide their greatest contribution after the schematic stage, adapting mechanical systems to the initial design. This leaves little opportunity for the mechanical engineers expertise to influence design decisions already made earlier in the process. Construction knowledge brought by builders related to constructability and cost also enters the process late in the traditional project delivery process, often leading to decisions that compromise building performance under the guise of value-engineering.

Attempts to rectify these liabilities have included bringing builders into the design process earlier, in some part prompted by a lack of confidence in architects. Often costs become the paramount topic in these relationships, as the builder take the role of providing downward cost pressure, crowding out a view of longer-term operating costs and value. This is problematic considering that it is estimated that construction costs represent a small fraction of overall ownership costs over the lifetime of a facility; estimates that are understated since they do not address productivity losses due to cost reductions made during the design process. Part of the challenge for designers to preventing decisions being made that lead to under-performance over time is including key issues in initial design and programming exercise, including strategies for making cost reductions.

Currently there isn't a common method of categorizing design objectives, against which results can be measured. As a result it is difficult to compare projects and projects across time and space. The possible beginning of universal system can be found in the post-occupancy study of Wolfgang Preiser and Jack Nasar who identified the follows categories of evaluation: health safety, security, functionality, workflow, efficiency, social performance, psychological performance, and cultural performance. Notable from their list is adaptability of structure for future uses, embodied energy, operating energy use, assembly durability, and space-efficiency; performance factors that have a better track record being measured objectively. (Naser, Prieser & Fisher 2007, 63-64)

7.0 REPRESENTATION WITH TRADITIONAL DESIGN DOCUMENTS

Because effective integrated requires greater input and cooperation across participant specialties, communicating information effectively becomes imperative. Some of the hurdles to more effective communication can be found in the way drawings have been produced, and the objectives addressed by different media. The primary means of representing design information had been two-dimensional plans, elevations, and sections; supplemented with perspective images and/or a physical models early in the design process. Information embedded in design proposals is dispersed throughout drawings and specifications.

As drawings accommodate technical information, including notes and hatches; they lose become more difficult to read by lay individuals. It is also necessary to construct a mental picture of the design because portions of the design are located on different drawing sheets and in narrative specifications. Often very few project participants ever construct a complete picture.[2] Computer models allow for the continual development of three-dimensional images throughout the design process, but presentation quality images are rarely are produced after schematic design, although mock-ups are produced late in the design process, or during construction. Alternatives to traditional line drawings and three-dimensional representations include diagrams which are especially usefully in conveying concept ideas including form progressions, program and site relationship diagrams, structure, and program area diagrams.

Diagrams are helpful for distilling fundamental concepts and can be scaled and graduated to represent hierarchy. Structure, circulation, massing, and zoning strategies are examples of characteristics that are conveyed. More often than not diagrams have are used to communicate fundamental design decisions after they have been solidified in a proposal. Available data includes building volume, relationship statistics such as volume to user population, estimated seasonal BTU use, embodied energy, estimated replacement times and costs, opportunity costs, and functional efficacy metrics. Data is critical to the functioning of most disciplines, including those rooted in the social-sciences. Statistics are used to identify patterns, and pose solutions in professions such as law and medicine. Although information is packed into buildings, architects are reluctant to utilize data to better understand and communicate value of their services. (Bachman 2002, 9-10)

8.0 CHALLENGES TO VISUALIZING INFORMATION

There are limited visualization techniques available for illustrating sustainability performance of designs. Much of this has to do with the static nature of buildings, versus the dynamic reality of light movement, energy flows, and interactions of buildings within ecological systems. A common answer is to use diagram section drawings to illustrate air flows through naturally ventilated buildings has led to the use of diagramed sections (fig. 3). Another is to use light studies depicting scenarios at different times of the year. More often dynamic activity is conveyed verbally with standard drawings. Some of this can be explained by the tradition of presenting buildings as static objects independent to larger systems that interact with them. Systems based relationships rely in objective principles, and can be quantified, something seen as subservient to larger architecture goals.[3]

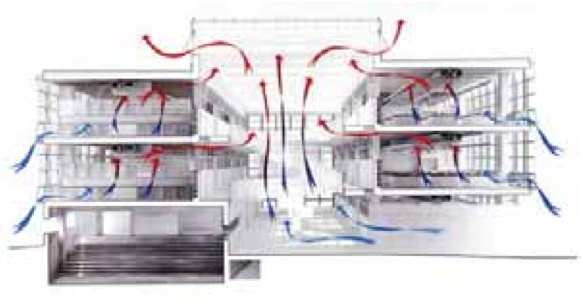

Figure 3: Section with Air Flow. Source: *Integrated Design in Contemporary Architecture.*

9.0 COMPUTER SIMULATIONS

Another challenge is the fragmented nature of design computation tools. Some of this is due to use of programs including Rhino and Sketch-up early in the design process, as opposed to BIM. Computational tools offer great potential to aid in the generation and analysis of designs, particularly early in the design process where intuitive hypothesis can benefit for immediate feedback and adjustment. This belies the tendency for most performance based computation tools to be use later in the design process to verify solutions that already have significant amounts of detail and are difficult to change. (Schwitter 2005, 115) Programs have been developed that are based on graphic engines that are suited for building design. Chief among these are programs that work Autodesk including REM and Ecotect, Greenbuid, Talley, and CFM modeling that build on BIM platforms. Chief disadvantages to using BIM models for analysis is the amount of detailed information that BIM models general hold, and the fact that early level schematic design is difficult with BIM relative to other modeling programs such as Sketch-up and Rhino which were not developed for building professionals. Another liability of analysis tools has been the specialized nature of programs necessitating working across different platforms. (Yi 2012, 164)

Sefaira which is plug-in and web-based program compatible with Sketch-up and Revit address some of the liabilities of other energy analysis software. Aimed a use in the beginning of the design process, when decisions have the largest opportunity to be integrated with site conditions, the program permits real-time feedback of design changes. Its user friendly interface also allows for easy comparison of design options by filtering key measures such as building area and volume, glazing areas and type, shading types, insulation factors, and BTU use over time of day. Sefaria is designed for architects and does not include advanced mechanical and ventilation analysis tools. Like most visualization tools, there is not yet capability to integrate quantitative information derived from systems performance with cost information, durability statistics, and qualitative functions derived from post-occupancy evaluations. Adaptable interfaces that are streamlined like the Sefaira's allow for progressions in design to be understood, conveyed, and measured by experts and lay individuals who are stakeholders in project decisions.

Figure 4: Interface from Sefaria Modeling Program. Source: www.sefairia.com

CONCLUSION

Increasing performance objectives necessitate development of better tools for understanding building properties early in the design process, through construction and commissioning, to operation. Right now most of the tools are effective later in the design process when it is too late to implement many design strategies. This study addresses some of the factors that have retarded development of better tools and measures of building performance. It also identifies examples of where data is used to shape evaluate building projects. Because availability of this data is limited, the building industry misses common grounds for problem solving. Also, because architects have been slower than other building professionals to use data as a means of evaluating building performance, there is reason to consider what the ramifications will be if they do not develop more objective methods for assessing performance.

REFERENCES

Ashworth, Allen and Hogg, Keith. 2000. *Added Value in Design and Construction*, Pearons Education, Edinburgh Gate, England.

Augenbroe, Godfried. 2005. "A Framework for Rational Building Performance Dialogues" in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York.

Bachman Leonard. 2012. *Two Spheres: Physical and Strategic Strategies in Architecture*, Routledge, Abingdon, England.

Blassel, Jean-Francois. 2005. “Engineering in a Performative Environment”, in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York,.

Hamilton, Kirk and Watkins. David 200., *Evidence Based Design for Multiple Building Types*, Whiley, Hoboken,.

Kolarevic, Branco. 2005. ”Computing the Performative”, in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York, NY,.

Lawson, Brian and Dorst, Kees. 2009. *Design Expertise*, Architectural Press, Oxford, England.

Leatherbarrow, David. 2005. ”Architecture’s Unscripted Performance”, in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York.

Moe, Kiel. 2008. *Integrated Design in Contemporary Architecture*, Princeton Architectural Press, New York.

Naser, Jack, Prieser, Wolfgang & Fisher, Thomas. 2007. *Designing For Designers, Lessons Learned From Schools of Architecture*, Fairchild Books, New York.

Schwitter, Craig. 2005. “Engineering Complexity: Performance Based Design in Use”, in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York.

Spuybroek, Lars. 2005. “The Structure of Vagueness”, in *Performative Architecture: Beyond Instrumentality*, Spoon Press, New York.

Walliman, Nicholas. 2011. Research Methods: The Basics, Routledge, New York.

Yi, Yun Kyu. 2012. “Building Performance and Computational Simulation”, in *Design and Construction of High-Performance Homes: Building Envelopes, Renewable Energies and Integrated Practice,* Routledge Abingdon , England.

ENDNOTES

[1] KieranTimberlake partnered with Autodesk and PE International to develop a software program called *Tally* which is used with Revit to provide life cycle assessments.

[2] General contractors rely significantly on subcontractors from specific trades to decode documents.

[3] The larger part of Leonard Bachman’s Leonard book, *Two Spheres: Physical and Strategic Strategies in Architecture* address the chasm between what he identifies as physical design and strategic design.