

The Place, Product, and Process of Design Thinking Inside the Building Information Modeling (BIM) Domain

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Abstract

Integrated practice delivery methods and its affiliated Building Information Modeling software enrich stakeholder collaboration. The shared knowledge resource functionalities and the real-time simultaneous collaborative attributes optimize the design interaction amongst industry experts. This may not be the case when novices collaborate on a group design project in a university setting. University novices do not have the individual intellectual capacity to communicate design ideas in the same way as industry experts. An artifact analysis on the intervention of BIM reveals that design education lacks a critical reflection and an approach that addresses how students with novice prerequisite knowledge should collaborate in the BIM domain. The hallmarks of best practices are provided to ground a collaborative design methodology.

Keywords: BIM; Collaboration; Design; Architecture education

Introduction

Architecture education has encountered many interventions in the recent decades from the oil embargo to the introduction of computers. Interventions arrive from institutional missions, accreditation boards, professional societies, employers, vendors, or by public necessity. Some transiently influence individual courses and professors whereas others induce broad curricular change. Not all interventions are welcomed. For example, the computer technology interventions have the characteristics of an industry uniter and sometimes an academic divider. Regardless, its collaborative attributes are the common ground between industry and academia, and the foundation of an inevitable design methodology.

In industry, architects found that the digital technology of Building Information Modeling (BIM) shifted forward when project stakeholders initially collaborate [1]. Earlier collaboration resulted in a positive change in the owner satisfaction benchmarks of cost, quality, and time. As a result, industry leaders called for new business strategies that supported a collaborative model facilitated by a digital environment [2-4]. The Associated General Contractors of America (AGC) was the first stakeholder group to rollout contracts concurrently addressing integrated practice and BIM [5]. The AGC has a tri-party collaborative contract where the designer, builder, and owner sign the same agreement in a joint venture relationship. The American Institute of Architects (AIA) followed with a family of contract documents where the stakeholders enter into a single purpose entity relationship requiring the formation of a limited liability company [6]. Eventually, the architects, engineers, and contractors, the three primary industry drivers, introduced and formalized integrated practice delivery methods facilitated by BIM. Each supports an earlier collaboration.

In academia, the owner satisfaction benchmarks are not the motivators of curricular change. Curriculum development should include the consideration of its constituents [7]. Accreditation boards have greater degree of engagement than professional organizations, employers, and vendors [8,9]. The National Architectural Accrediting Board, Inc. (NAAB) solicited information from multiple sources during the 2008 Accreditation Conference to inform changes in their requirements for degree granting programs. The NAAB was informed by the Trends in the Professions Task Group (TPTG) and Trends in the Education Task Group (TETG). The TPTG ranked collaborative design

as the third most significant industry trend [10]. The TETG reported that digital fabrication, distance learning, and interdisciplinary collaboration are the three top trends within the academy [11]. The 2009 Conditions for Accreditation includes three student performance criteria associated with the industry collaboration and digital technology trends [12]. The visual communications skill criterion includes a broad requirement where students must have the ability to use media such as digital technology. This avoids placing NAAB in the positioning of favoring a particular program or methodology. The criterion of leadership states that the students must understand the techniques and skills necessary for collaboration. The criterion of collaboration asserts that students must possess the ability to work in multidisciplinary teams. Although NAAB does not have a BIM requirement, the Barison and Santos study discloses that 103 institutions use BIM in the form of a single, an interdisciplinary, and a distance collaborative course, 90%, 7%, and 3% of the time, respectively [13]. The TETG noted, "The evolving role of technology in the academy is greeted with both intrigue and apprehension" [11]. Most blossoming technology is conceivably a dividing issue.

Any apprehension experienced by the academy may be due to their mindfulness that the industry context for design activities is not the same as the university context for design activities. Product vendors originally developed the BIM technology for collaborative industry consumption and not academics. The prerequisite design knowledge is disparate between industry experts and university novices. In the formative years of architectural awareness, students possess a novice level of design knowledge primarily acquired through individual development. How can these students possibly learn design in a collaborative setting, and even worse, using BIM? Noted philosopher and author Henry David Thoreau alerted us to the potential individual

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peril of collaboration and now it is here. When Thoreau recognized the broader community's contribution to his dwelling, he made an astute observation. "No doubt another may also think for me; but it is not therefore desirable that he should do so to the exclusion of my thinking for myself" [14]. The intervention of BIM in academia poses the unintended consequences of having others thinking for the novice designers inside the BIM domain.

BIM is an exceptional collaborative mechanism for expert designers in industry, but the current pedagogy has not adequately coupled BIM and the novice designer in university settings. The collaboration within the BIM domain remains enigmatic as very little is known about how BIM influences student design. Architecture education desperately needs a critical approach that properly contextualizes BIM and collaboration with education. This paper contextualizes BIM then provides the hallmarks for best practices to ground a collaborative design methodology.

Procedure

The central phenomenon is the intervention of BIM on architectural design in industry and in university settings. To examine the nature of this phenomenon, a qualitative inquiry was conducted in the narrative tradition with an artifact analysis at the heart of the study [15-17]. Unobtrusive artifact data permits the revealing of unintended residue from individual and group activity, which is suitable for collaborative topics. The post-positivist's philosophy with regard to ontology maintains that reality exists, but is never fully understood. From an epistemological viewpoint, reality is only an approximation. The authors' generalizations are the focal point of the analysis and the approximation of reality.

Findings

The findings represent the authors' selected interpretations of the relationship between BIM and collaboration woven through design. We found that the landmark Boyer and Mitgang architecture education report holds the universal definition of design. The Carnegie Foundation for the Advancement of Teaching funded the study. The researchers evaluated a wealth of data from 15 institutional site visits and the associated formal interviewing of 300 students, 150 faculty, and 25 administrators; the open-ended surveying of 500 students, faculty, and alumni; and conducting course observations. In addition, they received 80 surveys from deans and department heads from 65 different schools, and conducted 24 firm visits. Boyer and Mitgang define design, "For much of this century, design has dominated the architecture curriculum at nearly all schools. It is a place – the design studio – where students spend as much as 90% of their time and energy. It is a product – the tangible result of thinking about and making architecture. And it is a process – a way of thinking during which many elements, possibilities, and constraints of architectural knowledge are integrated" [18]. BIM and collaboration are positioned within the three cornerstones of design as a place, product, and process.

Place

A layperson may consider place as a physical location containing recognizable artifacts with spatial boundaries. On a rudimentary level, this is an accurate assumption. An environmental psychologist may interpret a place as a condition rather than a physical presence. Mehrabian describes that places should, "have a positive effect on one's ability to perform work and on one's desire to stay, explore, and interact with others" [19]. The industry and university places of design have a common physical presence, but operate under vastly different sensibilities as one shrinks and the other expands.

In industry, one common pattern elicited from published exemplar BIM projects was the deployment of a "Big Room" [20]. The AIA coined this term from the Japanese obeya, which is the place where the team members gather, work, and resolve conflicts. The stakeholders generally selected the architectural firm as the initial Big Room setting for the conceptualization phase and criteria design phase activities. The Big Room then moved to the job site for the latter detailed design and implementation documents phases. The purpose was to improve the coordination amongst the design disciplines then between the designers and construction entities. The Big Room illustrates a shift from performing services at discrete locations towards an open design studio without the physical or competitive barriers. In essence, this industry model is contracting into a university prototype.

In a university setting, the physical place where architectural exploration occurs is a single-room design studio, a home for 12 to 16 students. The studio course accounts for about one-third of the semester course-credit load. As a result, the studio is normally accessible 24 hours per day and 7 days per week. The place is contributor to a broader culture. The studio exposes students to unique design experiences such as immersion in critical thinking that leads to a public display and criticism of the product. The studio is where a personal design identity is borne through the self-actualization from thinking about the making of the product and its process. This has an individual sensibility that becomes more competitive than collaborative. The consequences of this academic pressure contributed to the reevaluation of the studio environment. Due to the competitive nature within students, the studio all-nighter culture leads to sleep deprivation and possibly student injuries and deaths [21]. The habits and patterns extruded from the cumulative studio experiences form a studio culture [22]. The NAAB requires a studio culture statement. This is critical for a place where student spend 90% of their time and energy. The studio is already a Big Room, but the students are discrete islands of protected individual ideas.

When BIM intervenes into the studio place, some studio models engage other disciplines beyond the studio walls. The Penn State University (PSU) established one exemplar interdisciplinary model. PSU developed a Collaborative BIM Studio composed of three teams of six students where one student each was from the disciplines of architecture, landscape architecture, construction, structural, mechanical, and lighting and electrical engineering [23]. The project was a relocated and modified a prototype elementary school for sustainability purposes. The researchers observed the significances of defining leadership within groups and the use of technology to improve communication. This PSU model responded to the NAAB student learning criterion of collaboration and to the AIAS-SCTF recommendation that, "Collaboration must also occur beyond the walls of the studio classroom, and across campus" [22]. Please note that the Boyer and Mitgang study concluded, "Making the connections, both within the architecture curriculum and between architecture and other disciplines on campus, is, we believe, the single most important challenge confronting architectural programs". The collaborative model is an example where the students were only permitted to think for themselves as each person was accountable for their respective discipline.

The PSU BIM Studio occurred in one place. There is one example of a distance collaborative model that confronted Boyer and Mitgang's critical challenge, and sought off-campus connections. The University of Wyoming, Montana State University, and the University of Nebraska-

Lincoln connected architecture and architectural engineering students. The students designed a performing arts center. The collaborative model was unusual where the engineering students were enrolled in architectural design classes. Many architects are unaware that the architectural engineering degree programs require architectural design studios for their engineering accreditation. Hedges et al. observed the significance of student teams establishing identities, managing the knowledge gap between the different disciplines performing the same tasks, and negotiating individual design ideas in team situations [24]. This distance model challenged the notion of being on campus, but the discrete locations did not have the benefit of the Big Room as in the PSU model. Furthermore, the teams were in groups composed primarily of four students performing activities associated in the architecture discipline. This is an example where the students were less accountable in thinking for themselves as they shared their design ideas. As BIM in industry is contracting to the Big Room, the university studio is on the verge of expansion. The intervention of BIM in industry and university settings is creating an intersecting path for a BIM “Big Studio”.

Product

The tangible results have different levels of refinement in industry and academia. In industry, the designers and builders create two primary products through integrated practice. The designers and builders collaboratively develop a digital representation of the work for private consumption, whereas the builders unilaterally construct the work for occupancy and public display. Since the design professionals do not construct the physical product, their focus is on making the digital representation and associated data exchanges for client validation. The outcomes from the final design phase requires that the, “Building is fully and unambiguously defined, coordinated and validated” [6]. The tangible results are achieved with BIM. The National BIM Standard Project Committee defines BIM as, “A digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle” [25]. The digital representation is interdependent with the notions of sharing and collaboration.

In university, the studio focus is on creating the visual communications to defend the design idea. This is subordinate to the technical validation of the digital representation. The university outcomes in conventional design studios include plans, sections and elevations, renderings, walk-throughs, typical construction details, physical models, etc. The intervention of BIM introduces a virtual building model. BIM generates nearly instantaneous generation of photorealistic renderings. Rather than renderings being used as a design defense for critiques, there is an opportunity for continuous in-process design evaluations [26]. Some institutions use dual monitors to evaluate design decisions (Figure 1) [27]. Although this should inform and improve design, some students may view renderings as a disposable commodity. The industry and university deliverables are on a converging trajectory for an articulated virtual building model.

Process

The way of thinking about architecture is dependent on how we share and credit the design. In industry, project success is dependent on the collective achievement of the joint venture relationship and the limited liability company in the integrated practice model. Profits are commonly distributed on a shared risk and reward system. In academia, there are fundamental issues with sharing. Students in team settings overly value their individual designs and have difficulties progressing someone else’s design.



Figure 1: Three students evaluating design alternatives in the BIM domain [27].

Integrated practice in the architectural contractual model is recognized as Integrated Project Delivery (IPD). The AIA/AIACC defines IPD as an, “approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction” [6]. Although we think of design as an iterative process, design has four sequential phases: conceptualization, criteria design, detailed design, and implementation documents. The conceptualization phase develops the performance, cost, and scheduling goals, and identifies the communications strategies for BIM platforms and its administration and maintenance. The team validates the goals in the last phase and is only accomplished through a cooperative journey.

Architectural design is a very personal and arduous journey. The individual journey is an important experience in the foundation years as the students begin to establish a personal design identity. More time spent in the studio intensifies their bond with the design. This attachment to their creative ideas inhibits sharing. In a team setting, students accustomed to individual design activities may have a difficult time casting aside their design in favor of another. As if they are kids in a sandbox claiming that the shovel is theirs, students may believe that ownership of the selected design will earn the highest grade. The American Institute of Architecture Students, Studio Culture Task Force (AIAS/SCTF) recognizes this weakness as, “Architecture studios should be known for promoting a culture of sharing” [22]. Furthermore, the AIAS/SCTF brought forth several myths about studio culture. One myth states, “Collaboration with other students means giving up the best ideas” [22]. A collaborative project offers more design dialogue that may elicit and restructure the individual design ideas into a better cooperative design response.

Collaboration provides an opportunity for leadership. The AIAS/SCTF noted that one of their respondents commented on leadership and collaboration where, “No true leader works in isolation, no true leader would not listen before showing the way, and no true leader imposes his or her own individual dreams” [22]. The accreditation board recognized the value in this quality, and instituted new overarching realms for student performance criteria. The criterion for collaboration is positioned in the realm of leadership and practice and reads, “Ability to work in collaboration with others and in multidisciplinary teams to successfully complete design projects” [12]. The criterion sets in motion

the formation of teams to include other disciplines that resembles a professional practice model.

BIM reduces the time necessary to converge upon a quality design borne from several design ideas. Research shows that using the extra time to generate more ideas may not improve the design. An idea has multiple levels of complexity as ideas progress from familiar ideas to original ideas to creative ideas. Familiar ideas are commonly precedential in nature. Bourne et al distinguishes between the original and creative production where a creative idea is “both original and useful” [28]. The initial parti and the subsequent design ideas should be within this higher creative realm. Furthermore, one may arrive at a robust and creative design without an overly abundant number of schemes. “As more ideas are generated, there will be an increase in the sheer number of creative ideas, but a larger increase in the number of poor ideas. The average number of quality ideas decreases as more ideas are produced” [29]. This indicates a diminishing return regarding the number of designs. There is a point of refusal or exhaustion where fewer quality ideas are forthcoming. As a result, there is more time available to think about design. This is a great opportunity for using the BIM platform to discuss the organization and orchestration of the project data. The dialogue will facilitate the recognition of ideas that have the most potential, versus ideas that do not add value to the concept. Rather than increasing the number of bad ideas, students may now have opportunities to ponder the quantitative data and re-inform their designs.

Discussion

The purpose of the study was to gain an understanding of the nature of BIM as it intervenes on design. Figure 2 highlights the generalizations extruded from an artifact analysis. Sharing, creative exhaustion, disposability, and Big Rooms are significant attributes that universities must address when faculty implement BIM in the design studio. These four attributes are the foundation for the hallmarks of best practices.

Hallmarks for a collaborative design methodology

Increased collaboration implies a product that is more difficult

to resolve, but richer for its process of balancing the values and ideas of a wider range of individuals. “Collaborative production, where people have to coordinate with one another to get anything done, is considerably harder than simple sharing, but the results can be more profound. New tools allow large groups to collaborate, by taking advantage of nonfinancial motivations and by allowing for wildly differing levels of contribution” [30].

The pedagogy surrounding the notion of sharing in collaborative production is complicated. Subordinate themes range from establishing mutual respect to the more technical concerns of sharing digital data. To address sharing the initial design ideas and garnering mutual respect, we suggest that instructors implement a rotating mentor-protégé relationship within each group to establish the parti and the overall form and character of a building [31]. The mentor-protégé relationship mutually negotiates the design idea and role-plays between expert and novice scenarios. The intent is to allow students to think for themselves. The role of the mentor is to demonstrate skill, provide guidance and subjectivity while reviewing all of the members’ creative ideas exclusive of the mentors. The protégé carefully listens to others’ perceptions and critiques of the individual design strengths and weaknesses. For example, a team of four will have four rotations. Each student will be a mentor once and protégé three times. If each student generates one parti and three designs, then the process generates a compliment of four partis and twelve designs. When the roles are rotated, each student has the opportunity to be elevated and exhibit leadership. For some students this will be a true mentor-protégé relationship, and for others this is a reverse mentorship condition. This is important to build social equity in the team dynamic. The likelihood of having an individual student’s design idea holistically accepted for the final design is one-fourth. The challenge in collaborative design is the release and sharing of the design ownership within the group. The purpose is to extrude the smaller creative design nuggets from each student more than converging to one parti and one design. Adequate participation will garner mutual respect, which is a necessity for collectively advancing a singular design.

Sharing digital data is interconnected with the areas of expertise

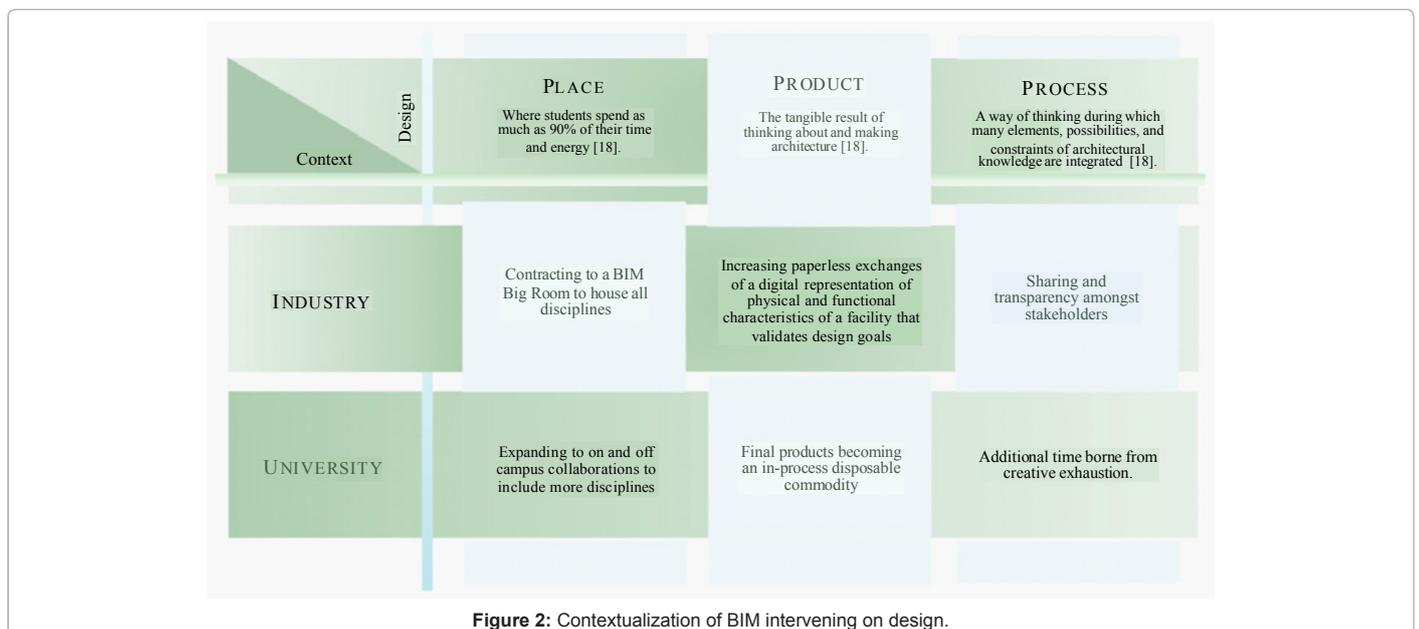


Figure 2: Contextualization of BIM intervening on design.

as the design evolves. To develop an accepted design idea, we suggest that students move into a peer or co-mentoring relationship. In this next design phase, students should define their roles through an area of expertise such as building envelope, structure, lighting, interior space planning, etc. BIM permits real-time simultaneous collaboration and has the capacity to partition the individual roles through any combination of worksets. The students must have a greater degree of trust when the worksets are not initiated as the work is exposed to unintended changes. When collaboration occurs within the industry walls, a single server is suitable for managing the model. Simultaneous collaboration is more difficult with multiple universities. There are higher order issues when collaborating outside the university and the handling of the institutional security access protocols and the location of the server.

Determining the correct point in the process where creative exhaustion occurs is a difficult task. If an instructor normally permits six weeks for the parti and conceptualization phase, they may observe that students using BIM achieve this degree of completion in four weeks. Rather than eliciting more design ideas with a greater frequency of inadequacy, the time should be reinvested into BIM. Modeling a design within BIM allows for improved collaborative criticality. In much the same way that a quality digital rendering can convey ideas of form, proportion, adjacency, and materiality to a non-designer client, a BIM model allows for cleaner communication of ideas within a design team. Moving beyond the visual foundations of design, a BIM model expands upon critical review by also allowing for evaluation of cost and constructability, building simulation, and iterative design thinking. Discussing as a team the visual implications of a design may be subjective, but is still defined under basic common values held within the profession. Studying and employing specific design data generated from a BIM process allow for direct design intervention by the team negotiating the most efficient solutions with the strongest design concepts. This does not inhibit the design creativity and complexity [32]. Design projects within the university studio need to orchestrate the review and evaluation of the BIM data to improve a student's understanding of the balance between visceral design thinking, and analytical design evaluation. If a virtual model is to be assessed, the National Institute of Building Sciences (NIBS) has a mechanism in place where the models may be evaluated using a downloadable Interactive Capability Maturity Model (I-CMM) spreadsheet [33]. Even though this is an industry tool, academics may choose to evaluate any of the eleven weighted measures such as life cycle views, spatial capability, or roles or disciplines.

The final products of the industry and the academics design processes are on converging trajectories. The product is moving away from an organized set of two-dimensional documents (the profession binds them in a book, the academy hangs them on the wall) and toward an articulated virtual building model. The renderings reposition into a byproduct of a successfully articulated model. What educators' once held in high regard as the embodiment of the design idea is now an archival trace of the design journey. This may be somewhat alarming to instructors as it infers an academic devaluation of a rendering as a disposable commodity. The university setting must find the positives to inform and influence the profession beyond the productive value of paperless project submission. Improved collaboration, mass customization, construction verification, and accurate as-built documentation should all have value added qualities in a process where the product moves toward a fully articulated BIM model if the possibilities are explored and developed at the academic level.

The Big Room is contracting from discrete locations to a single-room studio. The design studio is expanding to include more disciplines. The notion of a Big Studio is a university setting that accommodates the broad needs of several different user groups in the form of physical volume, contents, to infrastructure. This requires an information technology infrastructure to access information outside of the department. Additional interoperable software will be required for the other disciplines. We do not recommend one disciplinary model over another (inter-, multi-, etc.), but we do suggest that diversity of knowledge plays a critical role informing the initial design ideas.

In summary, we identify six critical hallmarks: (1) Initially apply a rotating mentor-protégé relationships to facilitate sharing while negotiating the early design ideas to establish a mutual respect and trust within the team dynamic and to balance novice and expert scenarios; (2) Exercise peer or co-mentoring relationships to advance the accepted design in the subsequent phase; (3) Engage real-time simultaneous collaboration in specific areas of expertise with clearly defined roles for design development; (4) Evaluate the data garnered from BIM such as performance simulations to inform the design, during the time gained from creative exhaustion rather than generating more designs; (5) Use renderings to continually inform the design in-process and to act as an archival trace of the design journey; and (6) Create a Big Studio place that supports each discipline equally. The hallmarks are intended to invoke notions of a collaborative design that will smoothen the transition for design courses as BIM intervenes in the classroom.

Implications of future research

Since industry accepted BIM, schools must understand the techniques and skills necessary for collaboration in the BIM domain as required by the accreditation board. There will no doubt about an increase in the scholarship of design pedagogy as BIM engages more studio courses. We are just now embarking on this new journey of discovering BIM in academia. Future qualitative research should include various disciplinary models and different collaborative strategies and roles. Studies constructed in the narrative tradition lead to insightful inquiries on the nature of the intervention of BIM upon education. Our hope is that this investigation is a springboard to propel scholarship that opens the window into any of the six hallmarks for best practices.

Significance

Early mentoring relationships in the academy will lead to—wards improved downstream professional collaborations. Exposure to building simulation techniques during the conceptualization and criteria design phases will help minimize a building's contribution to climate change. Writer and architect Jerry Laiserin illustrates that the larger picture of sustainability is de—pendent on the parametric attributes of BIM based upon, “Performance simulations – the ability to manage information about building materials and building processes” [34]. Currently, buildings account for almost 40 percent of the primary annual U.S. energy consumption where over 85 percent is supported by non-renewable, fossil fuel energy resources [35]. Performance simulations not only measure the operational energy, they also support carbon neutral design and can close the loop on our eco—logical footprints.

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