How the Impact of Building Information Modeling (BIM) on the Cognitive Paradigm May Influence the Future of Architectural Education

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Introduction

This qualitative study explores the intervention of Building Information Modeling (BIM) in the cognitive paradigm of users. This study was performed in the narrative tradition. The primary purpose is to better understand how BIM may influence learners' activities as they encounter new and accelerated information in the form of design technologies. A secondary intention is to study the broad implications for the future of design education as BIM is introduced into the curriculums during the formative years. The paper addresses persons interested in architecture, education, and BIM.

Previous authors have evidenced that BIM has created a recent industry movement led by an integrated practice that is a more efficient means of providing architectural design services over traditional methods.[1] When applying the traditional design techniques for the schematic design (SD), design development (DD), and construction document (CD) phases, the time spent is 15%, 20%, and 40%, respectively. Incorporating BIM adjusts the billings to an evenly distributed 25%.[2] This accounts for a 67% and 25% forward shift of the proportional weightings to the SD and DD phases, respectively. The shift encourages integration with other design disciplines at an earlier juncture. Thom Mayne recently stated, "If you want to survive, you're going to change; if you don't, you're going to perish. It's as simple as that."[3] Therefore, BIM will have to be embraced for design practices to survive financially.

The design community has responded to integrated practice by acquiring BIM products in significant amounts. Autodesk has acknowledged that revenues from new commercial seats for their associated BIM products have increased 93% from 2004 to 2005.[4] The current units sold from an Autodesk supplier are in the neighborhood of 3.5:1 in terms of BIM purchases to CAD purchases.[5] The design impacts of BIM are just now making their way into the architectural community. In May 2005, the American Institute of Architects (AIA) conducted its first annual BIM Awards through the Technology in Architectural Practice (TAP) Knowledge Community.[6]

Similar to other traditional design communications methods embraced by practitioners, BIM will find its path into higher education. Curriculum development should include the consideration of their stakeholders;[7] however, integrating BIM into architectural design courses has far reaching implications. BIM applications would extend into the prerequisite courses for architectural design, their subsequent design courses, and adjunct courses. "Unfortunately, if there is one element in our academic program that tends to be overlooked, it is the design and assessment of this roadmap for learning: the curriculum and its constituent courses."[8] Including BIM too early in the curriculum could affect students' learning as seen from recent changes in scientific psychology thinking.

The initial transition from passive (ink on mylar) to mechanical (CAD) design communications techniques occurred when the learning process perspective of scientific psychology was in a state of transitional flux. Scientific psychology recognized a swing from an associationist-behaviorist (A-B) paradigm towards the cognitive paradigm.[9] The A-B paradigm focused on the external environmental influences of behavior such as stimulus and response mechanisms. The BIM conversion is happening at a time when psychologists have redefined meaningful learning as the cognitive paradigm. This involves the internal brain structures and processes through memory, thinking, problem solving, and decision making. The two primary indicators of meaningful learning are: "(1) what learners already know and how their knowledge is structured and (2) learners' activities as they encounter new information and the consequences of these activities."[10] The indicators are the basis for establishing the required prerequisite knowledge of the users.

Figure 1 illustrates the shifts from CAD to BIM[11] and A-B to cognitive paradigms in the plotted context of effort versus contract time. The conservative straight-line BIM and the parabolic curve on the left represent the accelerated timelines influenced by BIM. The right curve represents the time associated with traditional design services without BIM implementation. Regardless of the differences between the Strong and Birx relationship, the forward shift is as dramatic. The directional arrows highlight the difference between the current emphases on internal brain functions versus the past emphasis on the external influences.

Two unique aspects are attributable to BIM. First, BIM is equipped with an automatic change management system[12] that instantly updates drawings that the designer has not yet observed. Second, the designer will have to process accelerated information from the 67% conservative increase in the schematic design phase.[13] The coupling of the change engine applications and the speed at which the information is being delivered creates a considerable problem. The design students encounter new and accelerated information without the comparable skills of a licensed professional. Licensed professionals are equipped to decipher and comprehend entire building systems relationships, while students do not have a developed palette of educational tools at their disposal.

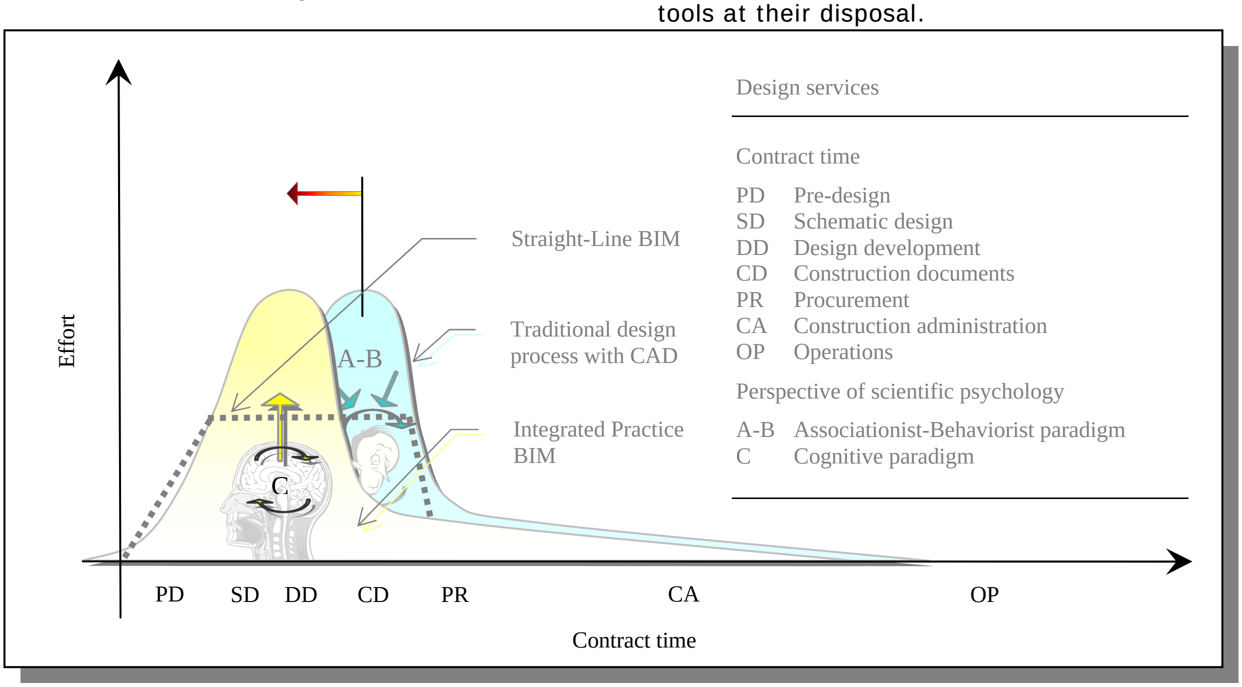

Fig. 1. Shifting the curve to the left: External influences to internal structures and processes.

BIM's implementation is taking place at a unique point in time when the perspective of scientific psychology has identified that meaningful learning occurs in the cognitive paradigm.[14] Since we know more about how we learn, we may ask the questions, *how may BIM influence learners' activities as they encounter new and accelerated information, and what are the broader implications for the future of architecture education as BIM is introduced into the design curriculums during the formative years*?

Methodology

The central phenomenon is the intervention of BIM on learning. To examine the nature of this phenomenon, a qualitative inquiry was conducted in the narrative tradition with a constructivist approach. The autobiographical method of the narrative study is used to capture the author's storied knowledge of his first BIM application. The rationale, sample and site, and data collection and analysis strategies are described below.

This inquiry selected a narrative study to personally capture a detailed, lived experience of utilizing BIM. The narrative tradition draws from the author's subjectivity with the constructivist approach.[15] The constructivist's philosophy with regard to ontology maintains that the attainment of an absolute reality is not knowable. From an epistemological viewpoint, multiple human constructions of reality are acquired through the accumulations of individual perspectives. One construct is the observations of the lived experience, and is presented here as participation in a three-day BIM workshop. The experience represents the first time that a parametric building model was generated by the author.

The sample is the author, the site is the office of Avatech Solutions, Inc. (Avatech) in Englewood, Colorado, and the engagement is a computer software workshop in an Autodesk Authorized Training Center (ATC) course that applies the BIM software *Autodesk® Revit® Building 9*. Avatech is a certified distributor and educator of Autodesk products. The workshop is titled "Revit: Core Concepts."[16] Access to the Avatech workshop is gained through enrollment and payment. The workshop is open to the general public for a fee, yet typical respondents are design professionals.

The data is the experiential descriptions in the form of raw field notes and drawings created during the participation in the workshop. The notes represent context and actions while engaging the BIM software and the conversations with the instructors and other attendees. The workshop provided two volumes of course manuals in support of the BIM software. The data is analyzed to discover relationships, make interpretations, develop explanations, and generate theories. The process involves an eight step interpretive analysis that leads to the findings.[17]

Findings

The findings represent the author's selected interpretations of the relationship between the BIM experience and the learner activities. The focus is on the elements described in the cognitive paradigm: required prerequisite knowledge of what the learners should know, learner activities at the moment they encounter new information, and the consequences of deficient prerequisite knowledge. The storied knowledge from a BIM exercise or application is described in a chronological format.

Change One Change All

The workshop commenced with a description of the fundamental elements of BIM.[18] The intent of BIM is to incorporate live building elements in a comprehensive and interactive manner. The building elements carry the individual properties of construction materials and assemblies and their particular relationship with other modeled elements. Assembly of the elements provides the singular 3D building model database, what Autodesk terms 'bidirectional associativity.' This represents "the ability of the building information modeler to coordinate changes made in any view with the database and out to all other views. Bidirectional associativity is applied automatically to every component, and annotation."[19] The automatic change management system allows the user to 'change one change all' of the elements instantaneously. Change is reliant on the parametric relationships, or the boundary conditions associated with the individual elements. The coupling of the bidirectional associativity and the parametric relationships is where 'shifting the curve to the left' originates.

Although the starting point of 'what the users already know and how their knowledge is structured' may be different for each user, the learners are receiving new information whether one is a licensed professional or a student. New information is exhibited by the existence of the BIM database. Accelerated information is the forward shift of the later design phases. The 'learner activities as they receive new and accelerated information' require them to create the actual 3D building model database, rather than the 2D abstraction. This necessitates the retrieval of a substantial amount of DD and CD knowledge at the outset of schematic design.

The performance of the change engine raises two concerns. First, a positive change that creates elements does not allow for an opportunity to become familiar with all the drawings individually. The designer must have the presence of mind to instantaneously comprehend in 3D all the data being generated. In essence, the 'discovery' aspect of learning has been altered.[20] Second, a negative change that adjusts existing elements will perform the modifications on a grand scale. If a door is moved two feet north, it is adjusted on every applicable drawing. The change engine requires that students understand all design phases leading up to and including construction documents.

Conceptual Design

Conceptual design is the genesis of a building. The Autodesk building maker module tool allows the user to produce and assemble massing elements as an initial step of building form studies.[21] The massing elements are available in a variety of shapes from the Autodesk palette, or the user may create new shapes. The massing may be an arrangement of function blocks to make distinctions between occupancy groups, public and private spaces, etc. BIM has the capacity to work in the positive or negative where additive or subtractive transformations of form are performed for the individual or collective massing elements.[22] During this process, BIM is actively functioning within the bidirectional associativity and parametric relationships. BIM tabulates the floor area, volume, and surface area of the conceptual design. BIM contrasts the CAD 2D abstractions where the conceptual model has the capacity for converting the massing elements into exterior building envelope elements and interior floors.

The first exercise recreated the textbook conceptual design by creating the basic mass, mass detailing, and converting mass to building elements. The exercise requires prerequisite knowledge that extends beyond understanding the conventional architectural principles of form, space, and order.[23] Two simple and diverse conditions from an Autodesk conceptual design were associated with the building envelope and building codes. The first condition applied a 10 ft (3.28 m) floor-to-floor dimension. This was convenient for the exercise, but is not appropriate for an actual construction assembly. A student learner is rarely exposed to the inherent errors of designing a structure with an extremely low floor-to-floor height. The activity of incorporating this dimension has the consequence of creating an impractical building when converting the mass to the building elements. The second condition implemented extrusions or subtractions of the mass to create exterior balconies. The extrusions began at 3'-6" (1.15 m) and ended at 8'-0" (2.62 m) at each floor. This may be appropriate for construction purposes, but produces inconsistencies for the constructability of BIM exercises.

A False Sense of Security

Detail views are enlarged illustrations that inform the builder how the construction materials are assembled. In previous exercises, BIM requires that the designer acknowledge the materials through wall, floor, and roof assemblies. This assimilates the materials in the 3D database. The detail view exercise captures the most appropriate locations to identify the construction assemblies.[24] The 3D views are instantly generated from the database. The student does not have to create a 2D abstraction.

New and accelerated information is represented by the instantaneously completed detail. As learners receive this information, they must identify which elements within the

BIM-generated detail are deficient. This necessitates a substantial amount of previous construction detailing knowledge. The BIM automation provides a false sense of security that the detail is correct. BIM did not generate flashing material for the detail views which cut through the window locations. The consequence of omitting flashing is having a wall assembly that is susceptible to water intrusion at all window locations.

Style over Substance

Two exercises concentrated on creating and modifying 3D views and rendering.[25] BIM captures pictures of the building through the use of a camera operation. The camera location, height, focal point, and axis allow for the adjustable positioning and target points for any vantage point from inside or outside of the building. The rendering capabilities implement the interior and exterior luminous environments. BIM has interior artificial lighting controls and acknowledges solar positioning for any geographic location and time. The final rendering is a realistic image that includes the brightness, transparency, and reflectivity. BIM recognizes distinctions between the deciduous and coniferous trees in winter by the treatment of foliage. The deciduous trees drop their leaves in winter and change their color in autumn.

The accelerated information is represented by the completed 3D view and rendering module, which displays spectacular and realistic 3D graphics. The learner is confronted with an inappropriate desire to respond to the instantaneous gratification by capturing the most aesthetic representation rather than exhibiting sound environmental stewardship. Historically, the design community has been slow in providing a localized response to global warming. "Most alarming is the fact that even after 100 years our industries, professionals, and technical specialists have shown little ability in making necessary changes in design and construction methodologies."[26] This is about to change if the users take advantage of the BIM environmental package to maximize daylighting strategies.

Discussion

Meaningful learning occurs with the successful construct of a conceptual framework that makes the mental connections between existing knowledge and new knowledge. [27] The current state of existing architectural design knowledge allows for a discovery aspect associated with manual design coordination required for creating 2D abstractions. A mental bridge is created by that coordination and allows knowledge to cross the bridge that spans between new and existing knowledge. BIM disrupts the discovery process by removing the bridge supported by the foundation of manual design coordination. Therefore, this gap of knowledge and its consequence justifies identifying the appropriate context of where, when, and how BIM should be launched in the classroom.

Considerable prerequisite architectural knowledge is required to fully utilize the principles of bidirectional associativity and parametric relationships. The National Architectural Accreditation Board (NAAB) student performance criteria are applied to distinguish the knowledge and its associated skill level in architecture education. NAAB criterion 'comprehensive design' parallels the required prerequisite knowledge. The definition of comprehensive design employs the "ability to produce a comprehensive architectural project based on a building and site that includes development of programmed spaces demonstrating an understanding of structural and environmental systems, building envelope systems, life-safety provisions, wall sections, and building assemblies and the principles of sustainability."[28] The 'ability to produce' establishes the highest level of accomplishment set forth by NAAB and highlights the criterion's importance. The 'comprehensive architectural project' implies a large scope of work inclusive of internal building systems spaces and external site development. Therefore, using BIM as a design tool should not occur prior to the department's response to the comprehensive design criterion. A common solution is the comprehensive design studio (CDS).

The comprehensive design studio is typically situated in the advanced years of a program and takes on several different forms.

Common CDS attributes include a singular studio that may act as a capstone course or a technology adjunct lecture course in support of a design studio. The prerequisite knowledge is considerable and includes all design phases, materials and assemblies, construction detailing, and environmental forces (Table 1). Therefore, full BIM applications should be relegated to the upper-class academic years for the present time.

BIM implementation has far reaching implications to the overall curriculum. BIM applications require the support of the prerequisite and subsequent design courses and their adjunct courses. Since BIM does not require any previous CAD knowledge for proficiency, design faculty are likely to attempt introducing BIM into foundation courses. Early BIM entry into a design studio sequence requires the appropriate academic support structure to hasten the acquisition of the required prerequisite knowledge. Once BIM is introduced CAD will disappear academically and professionally. Therefore, BIM implementation necessitates a collaborative faculty effort in a similar manner as the integrated practice exhibited by the design community.

One limitation of this study is the autobiographical methodology. The procedure does not have the same popularity as other narrative strategies.[29] A combined narrative research design may enhance the results where the autobiographical study is united with personal experience stories from other participants. This would follow more closely the ideal epistemological perspective of a constructivist. Hatch suggests the researcher and participants co-construct the reality.[30]

In conclusion, BIM will overturn current beliefs that CAD is the most appropriate method for design communications. The implementation of BIM is inevitable and is an enhancement to the infrastructure of the design profession and architectural education. This study intentionally brought awareness to some of the academic issues that surround 'shifting the curve to the left.' The awareness may provide direction in how architectural education may respond as BIM is introduced in the classroom.

Table 1. BIM exercise impressions and the cognitive paradigm.

Impressions	Prerequisite knowledge	Learner activities	Consequences of deficient prerequisite knowledge
Change one change all	Schematic design, design development, and construction documents	Assembling a 3D model database with bidirectional associativity	Changes in the database alter the discovery aspect and hinder the construct of a bridge between existing and new knowledge
Conceptual design	Fundamentals of building construction materials and assemblies	Creating a constructible and code compliant building configuration	Creating an impractical building form may lead to incorrect preliminary cost estimates
A false sense of security	Construction detailing	Selecting an appropriate view to inform builder of construction details	Reliance on BIM-generated detail may lead to cosmetic or structural failures
Style over substance	Environmental stewardship	Utilize the BIM interior and exterior luminous environment for energy conscious design	Focusing on aesthetics may neglect larger issues such as global warming

Endnotes

[1] Phillip G. Bernstein, FAIA, supplies evidence that BIM will supplant CAD due to economic necessity. Bernstein teaches professional practice at the Yale School of Architecture, serves as the vice president of Building Solutions for Autodesk, is a current chair of the AIA Contract Documents Committee, and is a member of the AIA's Integrated Practice Strategy Working Group. Phillip Bernstein, "Integrated Practice: It's Not Just About Technology," *AIArchitect Best Practices*, 3 October 2005 [article on-line]; available from http://www.aia.org/aiarchitect/thisweek05/tw0930/tw0930bp_notjusttech.cfm; internet; accessed 16 June 2006.

[2] The principal of Ayers/Saint/Gross illustrates the comparison between project manpower for pre-BIM and post-BIM projects for his firm. Glenn W. Birx, "BIM Evokes Revolutionary Changes to Architecture Practice at Ayers/Saint/Gross," *AIArchitect Best Practices*, 9 December 2005 [article on-line]; available from http://www.aia.org/aiarchitect/thisweek05/tw1209/tw1209changeisnow.cfm; internet; accessed June 16, 2006.

[3] The statement was made during the Building Information Modeling Panel Discussion at the 2005 AIA national convention in Las Vegas. Thom Mayne, FAIA, is the 2005 Pritzker Prize Winner and principal of Morphosis. Norman Strong, FAIA, is the 2006 AIA National Vice President and partner of The Miller/Hull Partnership LLP. Norman Strong, "Change is Now," AIArchitect Best Practices, 12 September 2005 [article on-line]; available from http://www.aia.org/aiarchitect/thisweek05/tw0909/tw0909bp_bim.cfm; internet; accessed 1 March 2006.

[4] Autodesk is an eminent supplier of BIM and CAD products. Their consolidated statements of income are located in their press release *Autodesk Reports Record Revenues of $373 Million*, 18 August 2005 [article on-line]; available from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=5813271&linkID=1977925; internet; accessed 16 June 2006.

[5] The data was provided by the workshop presenter pursuant to the author's inquiry of the purchasing differences between the new units of CAD and BIM. Daniel D. Bayer, *Revit: Core Concepts,* Avatech Solutions, Inc., Englewood, Colorado, 7-9 June 2006.

[6] The AIA endorses BIM as a legitimate design tool by furnishing national recognition of BIM projects. AIA, "TAP Announces BIM Awards Recipients" [website on-line]; available from http://www.aia.org/tap_bimawardlisting; internet; accessed 16 June 2006.

[7] Diamond endorses a call for curriculum reform based on the efforts of Ernest Boyer, Lion Gardiner, and Roy Romer. Robert M. Diamond, "Curricula and Courses: Administrative Issues" in *Field Guide to Academic Leadership*, ed. R. M. Diamond (San Francisco: Jossey-Bass, 2002), 135-156.

[8] Ibid., 135.

[9] Bruning identifies the perspective of scientific psychology and the context of the learning in the A-B and the cognitive paradigms. Roger H. Bruning, "The College Classroom from the Perspective of Cognitive Psychology," in *Handbook of College Teaching: Theory and Applications*, ed. Keith W. Prichard and R. McLaran Sawyer (Westport, Connecticut: Greenwood Press, 1994), 3-22.

[10] Ibid., 8.

[11] Components of Figure 1 relate to the plot 'Shifting the Curve to the Left.' The original plot was designed to track the costs associated with making design changes at different points in time for BIM and traditional methods of design communications. The author made modifications by removing the cost aspect, including a Birx representation of straight-line activities across design phases, and including images that represent the perspective of scientific psychology. Patrick MacLearney, "Shifting the Curve to the Left" in Norman Strong, *Change is Now*, 12 September 2005, [graphic on-line]; available from http://www.aia.org/aiarchitect/thisweek05/tw0909/tw0909bp_graph_b.gif; internet; accessed 1 March 2006.

[12] Autodesk, "Autodesk Reports Record Revenues of $373 Million" (18 August 2005) [press release on-line]; available from http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=5813271&linkID=1977925; internet; accessed 16 June 2006.

[13] The ratio of the time spent at Ayers/Saint/Gross to the traditional time associated with the schematic design phase. Glenn W. Birx, "BIM Evokes Revolutionary Changes to Architecture Practice at Ayers/Saint/Gross," *AIArchitect Best Practices*, 9 December 2005 [article on-line]; available from

http://www.aia.org/aiarchitect/thisweek05/tw1209/tw1209changeisnow.cfm; internet; accessed 1 March 2006.

14 Roger H. Bruning, "The College Classroom from the Perspective of Cognitive Psychology" in *Handbook of College Teaching: Theory and Applications*, ed. Keith W. Prichard and R. McLaran Sawyer, (Westport, Connecticut: Greenwood Press, 1994), 3-22.

15 Hatch provides selection methods from the five frameworks for research paradigms (positivist, postpositivist, constructivist, critical/feminist, and poststructuralist) based upon the notions of ontology, epistemology, methodology, and products. J. Amos Hatch, "Doing Qualitative Research in Education Settings" (Albany, NY: State University of New York Press, 2002), 15.

16 Daniel D. Bayer, *Revit: Core Concepts,* Avatech Solutions, Inc., Englewood, Colorado, 7-9 June 2006.

17 The eight modified steps are: (1) Read the field notes and study the drawings for an initial sense of the central phenomenon; (2) Review impressions of previously recorded BIM articles and record these in memos; (3) Reread the field notes and drawings, identify impressions, and record impressions in memos; (4) Study literature memos and impression memos for salient interpretations; (5) Reread impression memos, coding places where interpretations are supported or challenged; (6) Write a draft summary; (7) Review experiential data (impression memos) to verify interpretations of phenomenon; and (8) Write a revised summary and identify excerpts that support interpretations. J. Amos Hatch, *Doing Qualitative Research in Education Settings* (Albany, NY: State University of New York Press, 2002), 181.

18 The fundamental elements of BIM are described in Autodesk. *Autodesk® Official Training Courseware (AOTC): Autodesk® Revit® Building 9,* vol. 1. (Autodesk, 2006), 2-10.

19 Ibid., 6.

20 Leonard implies that the learning method consistent with the nature of science is that of a 'discovery' process. Laboratory instruction in higher education does not always allow for the elements of discovery. He contends that scientific concepts are verified rather than discovered. Designers should be cautious that even in a studio environment BIM has the capability of altering discovery. One suggestion by Leonard is to allow students to make basic mistakes along the way where they can build a conceptual framework to make the mental connections. William H. Leonard, "The Laboratory Classroom" in *Handbook of College Teaching: Theory and Applications*, ed. Keith W. Pritchard and R. McLaran Sawyer (Westport, Connecticut: Greenwood Press, 1994), 155.

21 Autodesk. Autodesk® Official Training Courseware (AOTC): Autodesk® Revit® Building 9, vol. 1. (Autodesk, 2006), 56-70.

22 Additive and subtractive transformations from Francis D. K. Ching, *Architecture: Form, Space, and Order*, 2d ed. (New York: John Wiley and Sons, Inc., 2004), 52-57.

23 Ibid., 1-400.

24 The detail view exercise is described in Autodesk. *Autodesk® Official Training Courseware (AOTC): Autodesk® Revit® Building 9,* vol. 2. (Autodesk, 2006), 69-82.

25 3D views and rendering are described in Autodesk. *Autodesk® Official Training Courseware (AOTC): Autodesk® Revit® Building 9,* vol. 2. (Autodesk, 2006), 106-128.

26 Laura C. Zeiher, *The Ecology of Architecture: A Complete Guide to Creating the Environmentally Conscious Building* (New York: Whitney Library of Design, 1996), 10.

27 For further discussion on meaningful learning see Roger H. Bruning, "The College Classroom from the Perspective of Cognitive Psychology" in *Handbook of College Teaching: Theory and Applications*, ed. Keith W. Prichard and R. McLaran Sawyer (Westport, Connecticut: Greenwood Press, 1994), 3-22.

28 National Architectural Accreditation Board, *NAAB Conditions for Accreditation: For Professional Degree Programs in Architecture*, 2004 ed. (Washington, D.C.: NAAB, 2004), 15.

29 John W. Creswell, *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research* (Upper Saddle River, NJ: Pearson Merrill Prentice Hall, 2005), 476.

30 J. Amos Hatch, *Doing Qualitative Research in Education Settings* (Albany, NY: State University of New York Press, 2002), 13.

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