www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

INTELLIGENT DESIGN IN AEC EDUCATION

PUBLISHED: June 2010 at http://www.itcon.org/2010/23
EDITORS: Obonyo E A and Issa R R A

Nawari O. Nawari
School of Architecture, University of Florida, Gainesville, FL 32611
nnawari@ufl.edu

SUMMARY: *The Architecture, Engineering, and Construction (AEC) students must possess skills such as engineering dexterity, a bit of vision, and an ability to communicate with a variety of professionals. This requires a solid knowledge of basic design principles, a firm understanding of how buildings behave, and a sound understanding of how a building is pieced together. Additionally, the designers of tomorrow must look outward; beyond the confines or comfort zone of their specialization. AEC education will continue to emphasize the basics of building design fundamentals, but there is also a critical need to expose students to those facets of the profession that enable them to bridge gaps between different disciplines. This paper reviews the concept of Intelligent Design and examines its development and current use in AEC educational activities. It also reviews the gap between education and practice can be bridged through the Intelligent Design-Based Learning (IDBL) approach. Intelligent design is presented in this paper as a knowledge-based model, or ontology that provides an environment where virtual prototyping of the whole building or parts of structures prior to their construction, can be examined against code specifications and requirements digitally in an efficient manner.*

KEYWORDS: *Intelligent Design, AEC Education, Knowledge-based Model*

REFERENCE: *Nawari N O (2010) Intelligent design in AEC education, Special Issue Advanced Digital Technologies for Built Environment Education and Learning, Journal of Information Technology in Construction (ITcon), Vol. 15, pg. 306-317, http://www.itcon.org/2010/23*

1. INTRODUCTION

Evolution of technology has continuously engaged the design profession over the past several centuries. From the wood covered lead pencil, which was first mass-produced in 1662 to the recently surfaced Building Information Technology (BIM) all note down the revolutionary impact of technology on AEC practice. In the ancient days of Rome, the master designers created their structures on paper, and then had them built to see if they would stand. Bad designs fell down; good designs are still around today (to some extent). This methodology of trial and error has come a long way over the past couple of thousand years, and our industry continues to seek tools that improve design before construction begins. Combining BIM with Smart Codes is crucial step in that evolution.

Computer, automobile, and aircraft manufacturers have taken the lead in improving the integration of design and manufacturing, harnessing automation technology, and using electronic standards to replace paper for many types of documents. Unfortunately, the construction industry has not yet used information technologies as effectively to integrate its design, construction, and operational processes.

The process of detailed design of a building system made of a large number of components is quite involved. Further, since design is an open-ended problem, i.e. in general there are a large number of design alternatives satisfying functional requirements and the selection of the optimum design becomes an extremely challenging problem. The key approach to this problem is by simplifying the design process utilizing ontology. Ontology is derived from Greek words *ontos*, meaning to be, and *logos* mean word. Generally, ontology is the science or study of being. However, in Information Systems, ontology is a representation of a certain part of world in a machine-readable manner. Ontology is a knowledge-based model that represents a domain, and it is used to reason about the object in that domain, as well as the relations between them (Gruber, 1994, Fensel, 2003). Ontology plays a major role in facilitating Intelligent Design-Based Learning (IDBL) in AEC education.

The IDBL process includes how accurately and efficiently can complex Code specifications be translated into a flexible and actionable format using ontology that would allow simple interoperability within different digital design environments to facilitate automation in AEC design activities. This work addresses these issues, introducing the concept of Information Management Systems in engineering design and Building Information Modeling and their implications in design education. Intelligent design is a term used here to describe the integration, interoperability and adaptability for evolution of Code specifications, information management systems, and the Building Information Modeling in a coherent digital framework.

2. BACKGROUND

Engineering ontology is defined as a process that focuses on knowledge related activities to facilitate knowledge creation, capture, transformation and use, with the ultimate goal of leveraging automation in engineering design and analysis decision to achieve optimum solutions. In building design, there has been much research in the area of design knowledge reuse. Very little has focused on handling complexity of Code provision and integration of different digital design tools to achieve automation. Most of the research in the past was focused on area of design knowledge reuse in building design, with most of the approaches previously tested originating from Artificial Intelligence (AI). In the 1970s and '80s a large number of rule-based expert systems were developed for the purpose of knowledge reuse. However, these systems were not entirely successful because of the difficulties in producing a formal representation of the knowledge (Brandon 1990, Pu 1993, Davenport et al., 1998). The knowledge had first to be acquired from experienced designers and then generalized and transformed into rules. Using cases for design knowledge reuse is commonly termed Case-Based Design (CBD) (Johansson (2000)). Although many of these systems are useful in solving the specific problem they are intended for, CBD systems are seldom used in practice. One of the main reasons is that the representations used in these systems are system specific and differ considerably from representations used by the ordinary designer when documenting design information. This makes it difficult to achieve an automatic translation. Classification systems, such as OmniClass and UniClass, provide taxonomies of building concepts and elements. The e-Cognos project is a comprehensive ontology-based portal for knowledge management in construction, developed by a set of web services supporting following activities: acquisition, transformation, indexing, updating, refreshing, searching, and sharing (Katanuschkov et al., 2002; Staub-French et al. 2003, Lima et al., 2005). The approach of e-Cognos classifies construction knowledge into three main groups (Lima et al., 2005): domain knowledge, such as administrative information, standards, technical rules, product databases; corporate knowledge or the intellectual capital of the company; and the project knowledge. The e-Cognos represents the backbone components of the Intelligent Design-Based Learning (IDBL) by supporting: Capturing and reusing knowledge, management of formal organizational knowledge, knowledge sharing and Assessment, creation and synthesis of new solutions, and knowledge maintenance (Lima et al., 2005).

Recently, researchers start to work on engineering information systems to provide an efficient means for data storage, retrieval, data transfer, indexing, exchange and utilization to enhance and simplify design and construction process (Nawari, 2007). Good examples are the efforts made by many state and federal agencies in the United States to develop such information management systems. For instance, state DOT (Department of Transportation) geotechnical specialists (Lefchik et.al. 2006) are pursuing means to better manage geotechnical data (e.g., boring logs, lab test data), geologic hazards (e.g., landslides, rockfalls, mine subsidence), and assets (e.g., walls, reinforced slopes). Several states have instituted electronic data management systems to manage geotechnical data for large projects. Some states have hazard management systems in place. And some states are beginning to develop geotechnical asset management systems for elements such as piling or retaining walls. In the precast construction industry, Stefan Peterson et al. (2009) investigate the critical aspects of information management system as related to industrialized house design and construction and their impact on the overall growth in production and reduction on the design effort invested. All of these efforts have showed that potential efficiency gains can be achieved through the utilization of effective, interoperable information management systems.

In design education, many researchers reported the need for consideration of new and innovative pedagogical approaches employing emerging technologies (Maher, 1999, Kvan et al., 2000, Kvan et al., 2004, Gu et al., 2007, Gül et al., 2007). These resulted in the establishment of virtual design studios globally varying from the early approach of digital design data sharing to the more recent 3D virtual world approach where the designs as well as the educators and the learners, are simulated and represented in the virtual worlds allowing "design and learning within the design". Gül et al., (2008) showed that integration of communication and information technologies into design curricula offers significant potentials for design education, through their capacity to facilitate designing in new learning environments, advancing research and development in learning theories. They showed that 3D virtual worlds have the potential to make a major contribution to design education as constructivist learning environments.

As cited above, several research efforts have capitalized on the wealth of construction classification systems and product models (namely IFC, e-Cognos and BIM) to establish domain taxonomies/ontologies and interoperable information management systems. Based on these efforts, the paper seeks to establish a roadmap that can be utilized to architect an Intelligent Design-Based Learning (IDBL) system in the EAC education. The main enabling technologies of this IDBL system include information management technologies, building information modeling (BIM), Smart Codes, and the ASCE Body of Knowledge (BOK policy 465).

3. INFORMATION MANAGEMENT TECHNOLOGIES

Building materials and construction has been continuously growing over the past thousands of years. This trend will also continue in the future. Consequently, it is necessary to develop a comprehensive management system of an ever-growing construction industry. This problem is made more complex given the accelerating rate of scientific and technical discovery, typified by the ever-shortening time period for the doubling of information (currently estimated at 18 months). With limited resources, engineers, contractors, developers, and builders are striving to improve the efficiency of their operations and better manage their staff time, funds, design and construction by delivering critical information in a timely fashion. Information Management systems can provide means to assist in managing their construction and structural systems data while improving decision-making and performance. These systems provide an efficient means for data storage, retrieval, data transfer, exchange and utilization to enhance design and construction of structures.

Information management systems for different construction materials are the core of the automation process of any AEC design. Development of Information management system for concrete structure (CIMS, Concrete Information Management System), steel structures (SIMS, Steel Information Management System), and Wood structures Information Management Systems (WIMS) similar to Masonry Information Management System (MIMS) and Geotechnical Information Management System (GISM) in the near future is crucial for achieving intelligent building design. Figure 1 depicts the architectural concept of intelligent design. The architecture describes an adaptable system that can intelligently provide the design data needed as per the profile of the incoming building model.

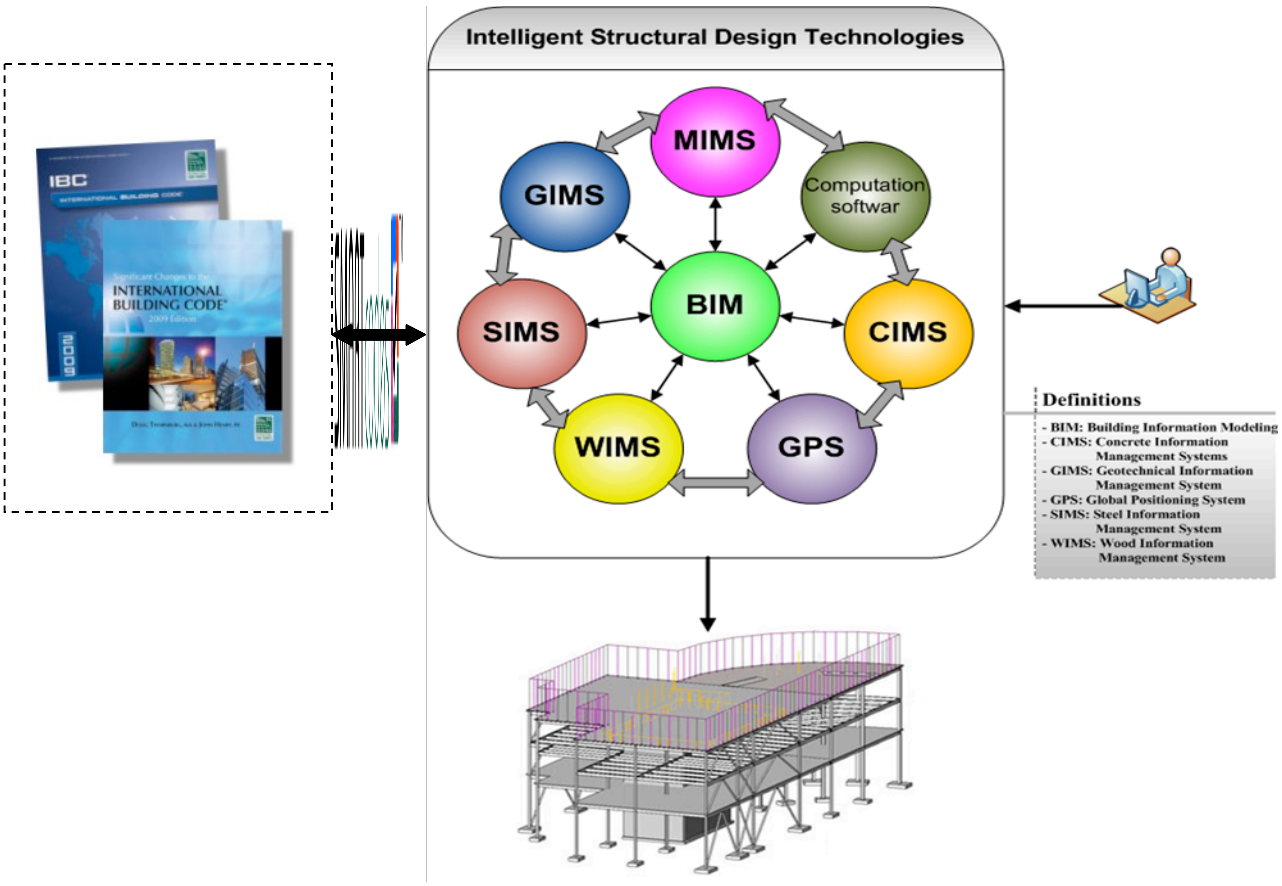

FIG 1: Intelligent Design of Building Systems

Furthermore, it is flexible enough to accommodate any future information system that might be needed in the future. Interoperability, adaptability and extensibility are key features of this architecture.

The integration between the advancement of information management systems and the AEC design process, the tendency toward a migration path, the development of scalable, interoperable, flexible, and open design systems are instrumental in developing Intelligent Design-Based Learning (IDBL) system in the EAC education. An example of a design software tool that is implementing some of these fundamentals is SolidThinking Inspired (2009). In architectural design, the ability to engage in a highly exploratory ideation process to generate as many different conceptual designs to a problem as possible is vital. The software utilizes information technology and morphogenesis algorithms that mimic biological processes like bone growth can generate highly organic forms that are often surprising and occasionally counter-intuitive. This results in creating designs that react automatically to forces such as gravity, live, dead loads, and other to environmental stimuli, making efficient use of space and materials. Designers can quickly alter their design and keep track of any changes in a detailed manner.

Key benefits for architectural students include:

- Being able to create aesthetically interesting, unique, often unexpected designs.
- Understanding relationship between architectural forms and structural requirements, since design results are well-adapted to their intended structural functions.
- Learn about form efficiency, because resulting architectural forms are generally efficient, because they economize the use of material.
- Understanding material optimizations through the capabilities of the tool to distinguish conduciveness to manufacturing processes like extrusion, casting, and stamping.

4. BUILDING INFORMATION MODELING

Building information modeling (BIM) broadly encompasses a series of technologies that are transforming design and construction. In essence, BIM uses information rich databases to characterize virtually all relevant aspects of a building or system. In a BIM system, drawings, specifications, take-offs, and even construction details are not separate documents, but specific manifestations of the model. Because all aspects of a project are driven from a single database or related databases, issues of drawing coordination and conflict errors are greatly diminished. Integration of information from multiple disciplines also supports project visualization, simulation, and optimization.

The building Information Model (BIM) provides the 3-D objects library of the physical building. According to the National Institute of Building Sciences (NIBS), the BIM is defined as: Building Information Model, or BIM, utilizes cutting-edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and is intended to be a repository of information for the facility owner/operator to use and maintain throughout the lifetime of the structure.

5. SMART CODES

A crucial component of the Intelligent Design-Based Learning (IDBL) system is the Smart Codes and their role in the design automation process. IDBL is not merely a matter of teaching automation of building design; it has to do with accurately translating the complex specifications and complaints in Codes and Standards into a simple process that student can learn and understand effectively. As technology advances, new constructions and computations techniques emerge, code specifications grow and client expectations are in turn extremely higher. All these suggest pressing needs for IDBL environment to prepare future AEC professionals.

The automated code compliance check takes the building plan as represented by a BIM model, and instantly checks for code compliance via model checking software. The user can choose several options to output the results, printing out the sections of the code that apply, an inspection checklist of things to look for, or viewing the building in 3D as a virtual walkthrough that shows the building components that don't comply with code and why. The International Code Council (ICC) introduced Smart Codes project concept as shown in figure 2 below.

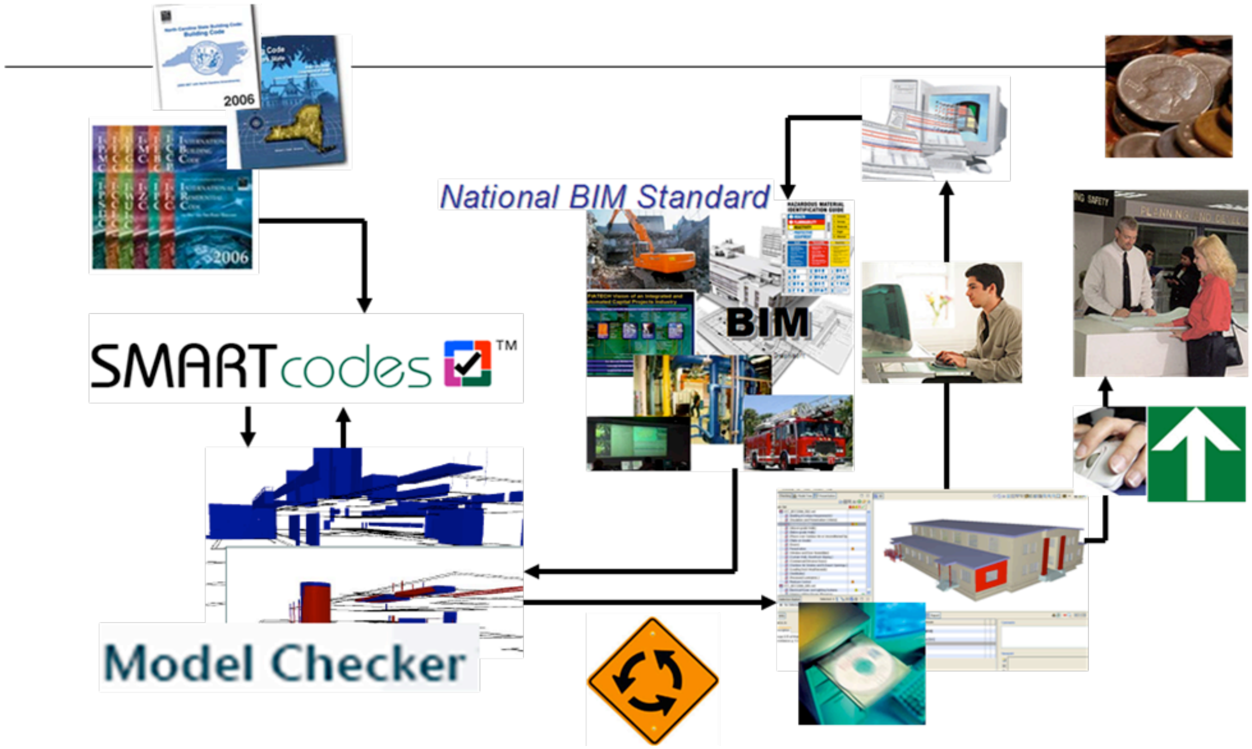

FIG 2: Smart Codes Concept (ICC)

Integration, interoperability and adaptability for evolution of the enabling technologies such as architectural design tools, structural computational software, Engineering Information Systems, Smart Codes and the building information modeling (BIM) characterize the foundation of IDBL environment in building design education (see figure 3).

6. AEC DESIGN EDUCATION

The AEC design profession has undergone dramatic changes over the past years. With computer-Aided Design, complex building codes, fast-track construction, and many younger engineers taking on more responsibility earlier in their career, the need for well educated AEC professionals has never been greater. Young engineers spent several years learning about the code and specifications under the guidance of experienced designer before more responsibilities can be delegated. Furthermore the design review process is taking more time as our code provisions grow in complexity and frequent updates along with rapid construction technology advancements. All this suggest the need for new learning environment where explorations of new design ideas, cross- and inter-disciplinary knowledge, and awareness of code provisions can be achieved effectively within undergraduate and graduate curricula making full utilization of the parametric modeling. At the same time, the environment should satisfy the customary requirements in AEC education by addressing critical thinking and cognitive skills.

In that regard, it is noteworthy to cite Lonergan (1978) when he addressed learning. He reported that humans seek, legitimately gain, and properly apply knowledge by means of four conscious operations:

(i)- Experience - Being attentive in examining the data presented.

(ii)- Understanding - Being intelligent in envisaging possible explanations.

(iii)- Judgment - Being reasonable in evaluating which is most likely.

(iv)- Decision - Being rational in electing how to proceed accordingly.

In AEC education becoming familiar with these Transcendal Precepts (Schmidt, 2009) and then following them with greater concern helps students to grasp insight that may be classified into several progressive categories:

Conjectural – Postulating a plausible account of a given state of affairs.

Conditional- Ascertaining the circumstances under which it would obtain.

Confirming – Determining whether those exigencies are indeed satisfied.

Contextual – Identifying next step that are compatible with the actual situation.

To prepare students properly in AEC education, a faithful adherence to the Transcendal Percepts is required for pursuing, acquiring, and employing knowledge. Thus, guard against laps into uncritical approaches, including the extremes of dogmatism and relativism.

Recently, the academic community has embraced the ASCE Policy 465 "Body of Knowledge" (BOK and BOK2) as a cornerstone for training and preparing young engineers for the future. The premise or objectives stated in the BOK meets the premise of Transcendal Percepts, but the underlying problem is not the material but the delivery. For the most part, AEC curriculum has not changed, but the way in which engineers practice has. This has led to a "disconnect" between training/academia and practice. Current AEC curriculum requires students to be trained or exposed to allied disciplines associated with their major. As an example, architectural engineering students are required to be "competent" in three of the following concentrations: architecture, construction management, structures, mechanical systems, or electrical systems. The idea of being "competent" in these areas is a valid objective, but the level of competency is at question. A similar problem exists in traditional AEC programs where students are required to be competent in geotechnical, structural, transportation, and construction engineering. But in today's information epoch, it is very difficult to achieve the BOK2 objectives using our traditional teaching tools. For example, a medium-sized building includes more than one millions parts, at construction level of detail that require code compliance. No traditional teaching or training courses will be able to address 50% of that level of details. The time required would be prohibitive. However, introducing intelligent design in the AEC curriculum would solve many of these hurdles.

Students need to know how each discipline is related to the other and how one discipline impacts the other. This implies the teaching model should emphasize breadth rather than depth for allied disciplines, but also require breadth and depth in the student's concentration. In "support" type courses, typically numerical problems and engineering theories are the primary focus, but the focus should be spent on interesting problems that emphasize design concepts and that allow students to understand how topics relate to their discipline. The goal of education should be to create students who understand the inter-relationships of allied disciplines and be well equipped with the recent advancements necessarily for the professional practice. To help meet these challenges, the educational model for AEC students needs constant and careful revisions and modifications. Educators cannot afford to stay behind in their understanding and application of new technologies and organizational forms, especially in the preparation of students who upon graduation - or even before it, through internships, assistantships and co-op programs - join the industry and research communities.

Innovation in educational innovation starts at the point when a critical mass of people is sufficiently motivated to initiate change that the inertia of not changing is overcome. When the motivation is sufficient to overturn a complete curriculum a complex process of change is put into action, and the outcome would drive a higher AEC education values. The introduction of Intelligent Design-Based Learning (IDBL) in AEC education will play a major role in creating the future education and training for AEC students (see figure 3).

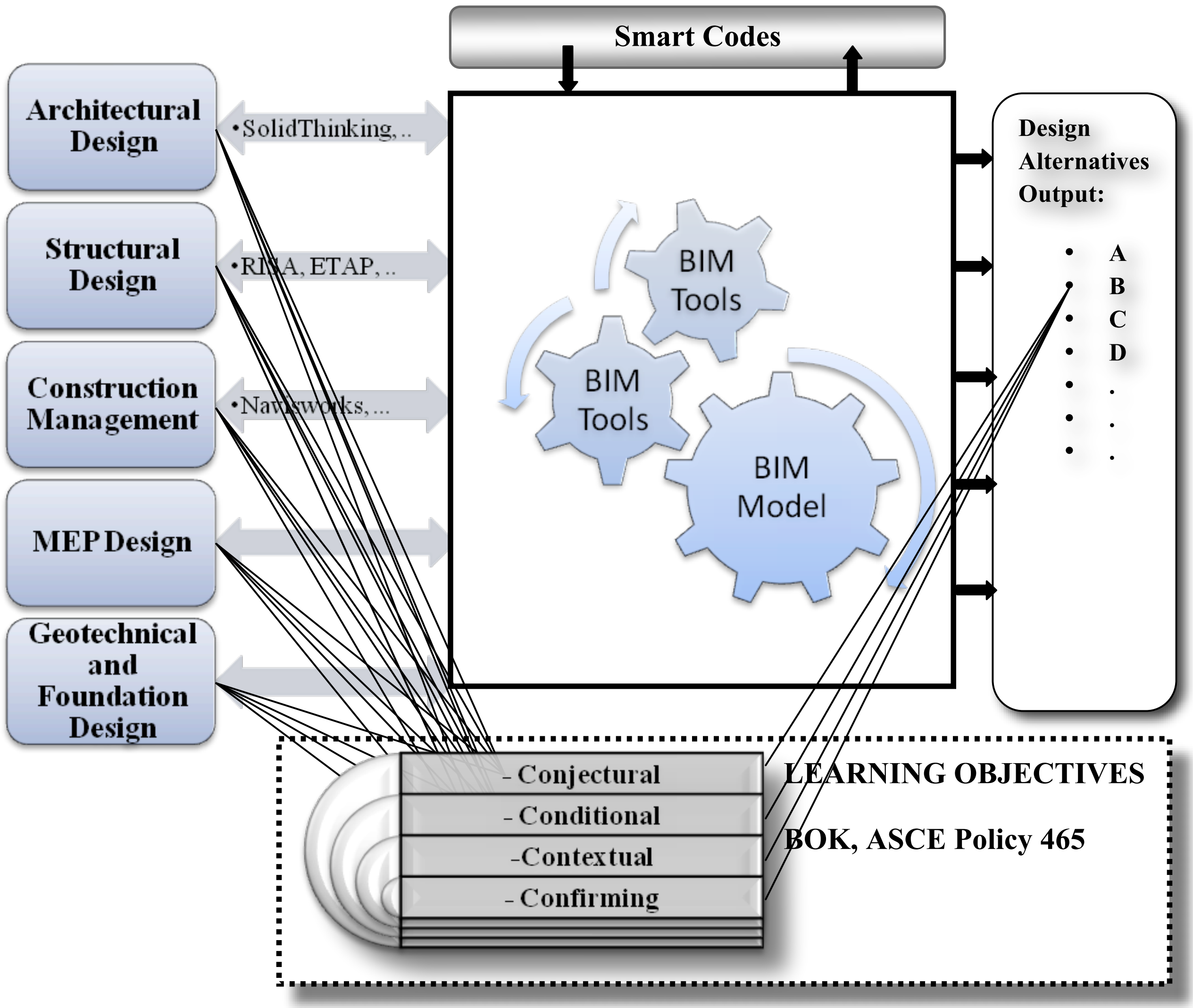

*FIG 3: Intelligent Design-Based Learning (**IDBL**)*

Examples below show some cases of the IDBL process. The Screen shot shown in figure 4a illustrate a BIM model loaded into Smart Code software. Figures 4b to 4d depict the model after performing code compliance checking. The different code provisions are listed on the left side of the screen as a rule set or limiting constraints. There are icons indicating areas of non-compliance and a row indicating each specific code criterion. Clicking on the first row in areas of non-compliance, a "problem icon" makes the building object that is not in compliance i.e. that is the problem show in red. On the bottom left of the screen, the reason for non-compliance is stated. In this case the wall design is R=0, but the code requires R=13.

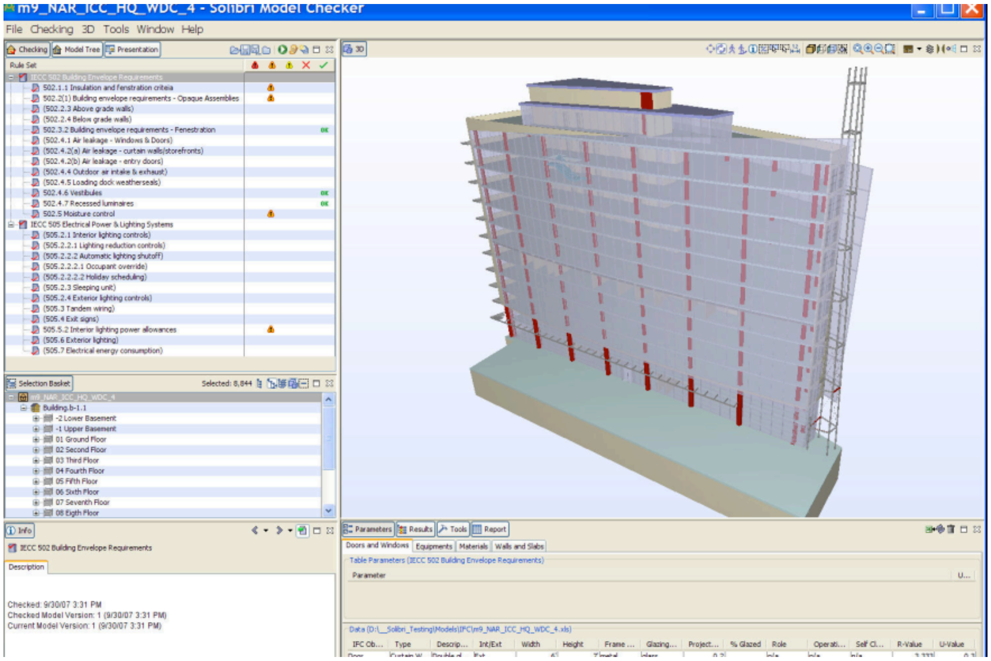

FIG 4a: BIM Model in SmartCode software (Solibri)

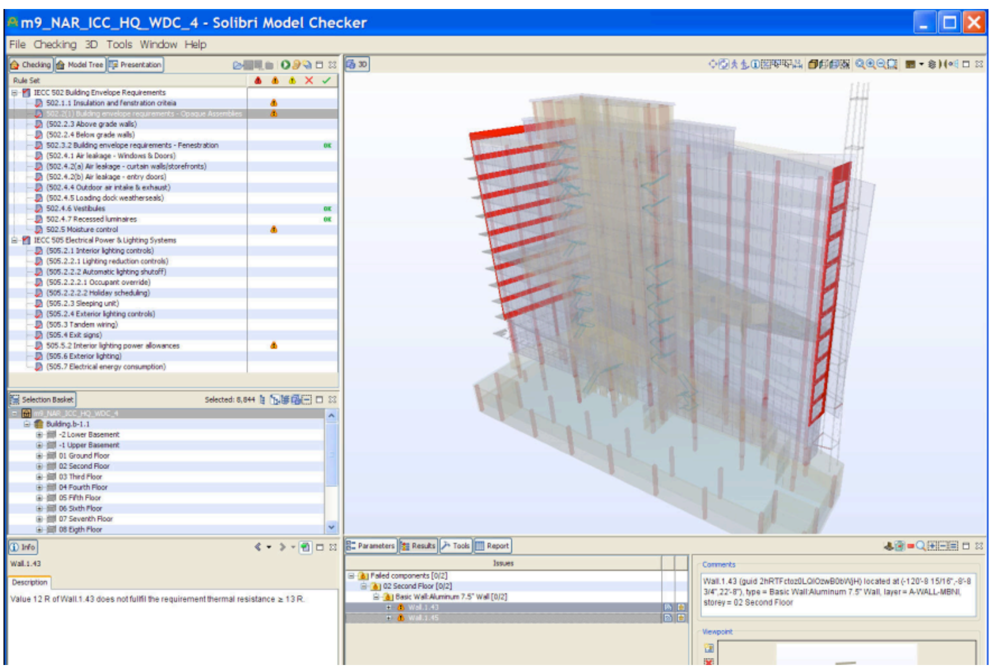

FIG 4b: BIM Model in SmartCode software (Solibri)

Moving down the list other non-compliance icons are seen and clicking on each of them would result in the building model changing so the problem area is in red, and the reason is stated in the bottom left (see figure 4c and 4d). All of these can be saved and at the end a report outlining each is then printed out or saved.

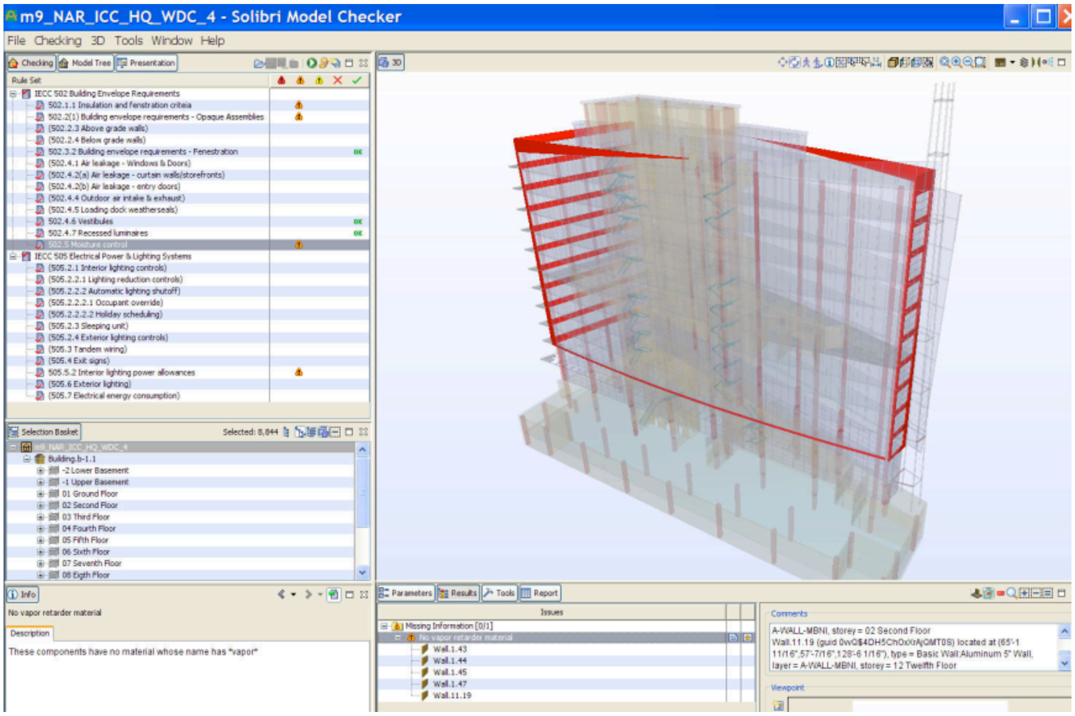

FIG 4c: BIM Model in SmartCode software (Solibri)

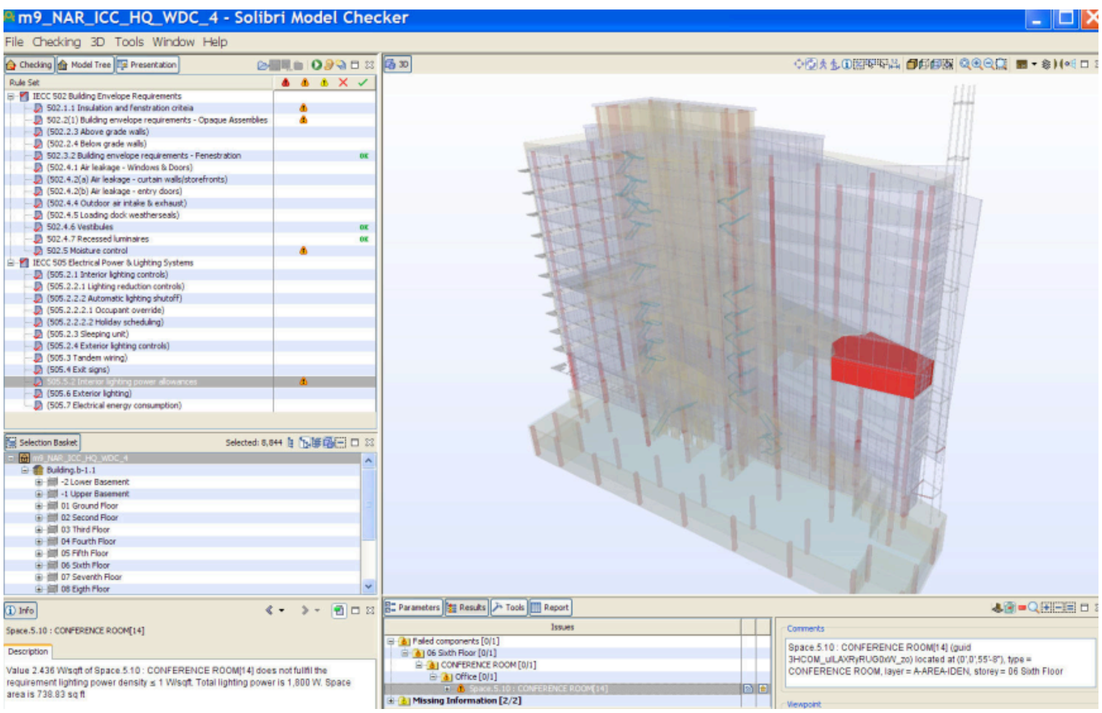

FIG 4d: BIM Model in SmartCode software (Solibri)

The Intelligent Design-Based Learning (IDBL) offers the following global benefits in AEC education:

- Students will have access to the full information on building design and construction.
- Development of an integrated view and better understanding of the building and its components and of the design and construction process eventually generating new ways to reason about the building, design and construction.
- Improved collaboration, communication and coordination among multidisciplinary design teams.
- Advanced skill acquisition for the students, thus creating better job opportunities and stronger alliance with the industry through projects, thesis, independent studies and internships.

7. CONCLUSIONS

Presently, AEC students are faced with increasing emerging technologies, globalization, complexity of codes and specifications, and crossing boundaries of traditional disciplines as we delve deeper in the information era that make conformity, and adherence to the Body of Knowledge (BOK policy 465) prerequisite for professional practice cumbersome process. The introduction of Intelligent Design-Based Learning (IDBL) in AEC education will play a major role in achieving the BOK objectives and creating the future education and training for AEC students.

The paper provided an overview concerning the definition, features, technologies, functionalities, and implementation advantages of Intelligent Design-Based Learning (IDBL) environment in AEC education. The information era shows that a proper information infrastructure offers many benefits that help produce and share high quality engineering data and decision management systems more cost-effectively and more efficiently. The concept of Intelligent Design described in this work focuses on the relationship among the various Engineering Information Management Systems, the Building Information Modeling (BIM), Smart Codes, and the ASCE Body of Knowledge (BOK2) capitalizing on developed taxonomies/ontologies such as IFC, e-Cognos and BIM. By providing more accurate information across AEC disciplines in an integrated dynamic digital environment, Intelligent Design-Based Learning (IDBL) system proffers students the ability to investigate a large number of design alternatives, learn effectively about design methodologies across disciplines, understand provisions of codes and standards and practicing a number of new skills as advancing forward blurring boundaries between education and practice in the 21st. century.

REFERENCES

ASCE Body of Knowledge (BOK2) (2008). “Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future”. Second Edition, American Society of Civil Engineers, 2008. www.asce.org/bookstore/book.cfm?book=8241

Brandon P.S., (1990). “Expert Systems: After the Hype is Over”, Proceedings of CIB90-Design Economics and Expert Systems, Building Economics and Construction Management, Vol. 2, 1990, University of Technology, Sydney.

Davenport T. H., De Long D., Beers M. (1998). “Successful Knowledge Management Projects”, Sloan Management Review, Vol. 39, No. 2, 1998, 43-57.

Johansson P. (2000). “Case-Based Structural Design –using weakly structured product and process information”, PhD. Thesis, Chalmers University of Technology, Division of Steel and Timber Structures, Publ. S 00:7, 2000, Göteborg, Sweden.

Fensel, D. (2003). “Ontologies: Silver Bullet for Knowledge Management and Electronic Commerce”. Springer-Verlag,

Gruber, T. (1994). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. IJHCS, 43 (5/6): 907-928.

Gu N., Gül L.F. and Maher M.L. (2007). Designing and learning within the design: A case study of principles for designing and teaching 3D virtual worlds, CAADRIA 2007: *Proceedings of the 12th International Conference on Computer-Aided Architectural Design Research in Asia*, Nanjing, China, 127-132.

Gül L.F., Gu N. and Maher M.L. (2007). Designing virtual worlds: A case study of design education in and of 3D virtual worlds, Robert Z. and Cart R. (Eds), *2007 Proceedings of ConnectED 2007, International Conference on Design Education*, The University of New South Wales, Sydney, 9-12 July, CD Proceeding, ISBN 978-0-646-48147-0

Gül L.F., Gu N. and Williams A. (2008). Virtual Worlds as a Constructivist Learning Platform: Evaluation of 3D Virtual Words on Design Teaching and Learning. ITcon, Vol. 13, 2008, pp. 578-593

Katanuschkov, P., Gehre, A., and Scherer, R. J. (2002). “An engineering Ontology framework as advanced user gateway to IFC model data.” Proc. of the European Conference on Product and Process Modeling, Prortoroz, Slovenia 9-11 September 2002.

Kvan T., Schmitt G.N., Maher M.L. and Cheng N.Y.-W. (2000). Teaching architectural design in virtual studios, (Fruchter R., Pena-Mona F. and Roddis W.M.K. editors), *Computing in civil and building engineering,* Stanford, 162-169.

Lefchik , T. E. and Beach, K. “Development of National Geotechnical Management System Standards for Transportation Applications”. Proceeding of GeoCongress 2006, Atlanta, Georgia.

Lima, C., El-Diraby, T., and Stephens, J., (2005). “Ontology-Based Optimization of Knowledge Management in e-Construction.” Electronic Journal of Information Technology in Construction, Vol. 10, 2005, pp. 305-327.

Lonergan, B. (1978), “A Study of Human Understanding”, Harpercollins, May 1978, ISBN-13: 978-0060652692.

Pu P. (1993). “Introduction: Issues in Case-Based Design Systems”, AI-EDAM, Vol. 7, No. 2, 1993, 79-85.

Maher M.L. (1999). Variations on a virtual design studio, *the 4th international Workshop on CSCW in Design*, Universite de Technologie de Compiegne, 159-165.

Nawari, N. O. (2007). “Masonry Information Management Systems (MIMS)”. Proceeding of the Tenth North American Masonry Conference, June 3-6, 2007, St.Louis Missori, 2007, 216-225.

NBIMS (National Building Information Modeling Standard), Version 1, Part 1 (2007). “Overview, Principles, and Methodologies”, National Institute of Building Sciences. 12/2007. http://www.nationalcadstandard.org/

Petersson, S., Malmgren, L., Johnsson, H. (2009): “Information Management in Industial Housing Design and Manufacture”. Journal of Information Technology in Construction **-** ISSN 1874-4753, June, 2009.

Schmidt, J. A. (2009). “How We Know and What It Means”. Structure Magazine, A Joint Publication of NCSEA, CASE, SEI, September 2009.

Staub-French, S., Fischer, M., Kunz, and Paulson. (2003) “An ontology for relating features with activities to calculate costs.” J. of Computing in Civil Engineering, ASCE. Vol. 17 (4).

SolidThinking, Inc. (2009). www.solidthinking.com, 1820 E. Big Beaver Rd., Troy MI 48083-2031 USA