TEACHING BUILDING INFORMATION MODELING (BIM) FROM A SUSTAINABILTY DESIGN PERSPECTIVE

FLORIAN TECHEL, KHALED NASSAR
Department of Architectural Engineering, University of Sharjah, Sharjah, United Arab Emirates
techel@sharjah.ac.ae , *knassar@sharjah.ac.ae*

Abstract. Building Information Modeling has recently gained significant attention both in academia and practice. BIM presents immense opportunities for increased efficiencies, coordination and quality of architectural design. One of the reasons that BIM offers a more comprehensive design approach is the fact that all aspect of the building are considered during the modeling phase. Rather than drawing the building using lines and circles actual object are used to model the building, which results in a more comprehensive underlying database model of the entire edifice being designed. The approach obviously has tremendous benefits in terms of coordination and systems integration, as well as, project control and management during the design and construction phases. Nevertheless BIM offers its own unique challenges vis-à-vis its introduction to students of architecture. The students in Architecture programs are usually introduced to BIM in two ways, either through a specialized course in CAD or via a shadow introduction in design studios and related courses. Careful positioning of the course within the architecture curriculum is crucial in order to gain maximum benefit in the synthesis of other course content. The reason being that students of architecture in earlier years of the design curriculum may not yet have developed the ability to synthesize and coordinate multiple systems required for complete BIM. This is an important consideration the design and pedagogy of introducing BIM to Architecture students. This paper argues for a new approach in teaching BIM for Architecture students. Instead of designing a course specifically for BIM/CAAD we present a paradigm whereas BIM can be presented within a larger more rigorous context. The experience of teaching BIM within a sustainable design framework is presented in this paper. Issues relating to the design of basic residential buildings were integrated into the course presenting BIM. A simplified set of design rules and guidelines under banner of sustainability were taught to the students in pre-defined doses and sequence throughout the course.

The careful placement of these concepts permitted for BIM to be introduced in a more interesting and comprehensive manner than in the traditional CAD-course setting. Samples of student work are presented and critiqued in order to come up with recommendations and guidelines for incorporating BIM into a comprehensive and comprehensible course. The pedagogical advantages of and disadvantages of the approach are discussed within the paper, as well as, a detailed description of the course content and structure. Results from and outcome-based assessment of the objectives of the course are also illuminated which provided suggestions for future offerings of the course.

1 Ramifications of CAD-use on the professional practice of architects

1.1 CONTEXTUAL BACKGROUND

The concept of digitally modeling building design in architecture is still new compared to other industries such as automobile, aeronautical, aerospace. While it is perfectly normal for automobile designers to test the aerodynamics or the crash behavior of future cars on their digital models, the building industry still lags behind these digital developments. The design of buildings is unfortunately still primarily evaluated along solely aesthetic criteria such as form, color and texture. As a result many faculty embraced digital modeling primarily under formal aspects, consequently favored form modelers such as 3D-Studio, Maya or Form•Z. These modeling applications, however, do not grasp the holistic nature of the building that is being conceptualized. Different construction elements, such as walls, slabs, beams and roofs, have differing material properties, requiring different consideration in the design and construction process. A primarily form-driven architectural education tends to lack in both spatial experience, as well as, material and structural properties of construction. Physical model building used to address some of these topics in the past. Problems arose from the time and space consuming nature of workshops and building models and their subsequent specialized and limited usability. Usually models were good either for urban evaluation, or for lighting simulation, or for structural analysis but hardly ever for all these tests at the same time.

In a particularly visual industry such as architecture, non-visual issues appear to be negated despite their prominent impact on residents, microclimate and the world as a whole. Slowly professional organizations appear to come around and realize their responsibility, as well as, call for a change in education. BIM appears to be the vehicle of bringing all these digital tools together in and feeding of the same digital model.

1.2 INTEGRATION OF BIM INTO THE ARCHITECTURE CURRICULUM (OR LACK THEREOF)

"The most recent changes, in 2004, concerned studio culture –to promote a positive, constructive learning environment– and included two new criteria, requiring an understanding of sustainability and the client role in architecture"(American Institute of Architects White Paper). The AIA, in collaboration with the US General Service Administration, has engaged in series of activities to evaluate and promote BIM and its possible use for building design. One recent (26. Oct. 2006) symposium hosted by the AIA Center for Building Science and Performance undertook the effort to "explore and further the use of BIM (building information modeling) technology for designing energy efficient and high performing buildings."

The AIA accepts BIM as a given. "Each school of architecture has to balance between providing future architects with an incubator for their self-development and as a workshop to gain skills of collaboration and integration resulting of the benefits of BIM"(AIA Seminars).

While the industry appears to be slowly awakening to the needs of the marketplace and calling for a change in education, few architecture programs in the world have yet changed to making CAD a mandatory part of the program. Lachmi Khemlani finds little evidence of the use of BIM to fundamentally change the design approach in education (Khemlani, 2007).

Building Information Modeling is even less integrated into the curriculum. Established programs find it difficult to sacrifice other courses in order to free credits for the introduction to digital media. This frequently results in the somewhat imprecise statement that students should be introduced to the subject during and along with the design studio structure. While this inclusive approach sounds sympathetic, the underlying problem is that design faculty rarely are at the forefront of the CAD/BIM development, consequently expose biases and lack of ability that jeopardize the ability of the student body to leave the academy at the forefront of knowledge in the field. Instead frequently fancy renderings are used as anecdotal evidence for educational CAD outcomes that are difficult to assess as the targets were rarely formulated in the first place.

1.3 INTEGRATION OF BUILDING INFORMATION MODELING AT THE UNIVERSITY OF SHARJAH

In the Department of Architectural Engineering we found that students learn matters best in a segregated-integrative approach in which the learning material or topics are still split into separate courses that try to cooperate with each other as much as possible. The separate courses ensure that certain topics are handled while the commitment towards cooperation ensures that the respective subjects do not entirely isolate themselves into their own ivory tower. While cooperation among faculty is –of course– not warranted, this approach appears better than trusting one faculty to somehow handle it all in the design studio.

BIM should therefore be either taught in cooperation with a studio or handle its own small design challenge. This is important, as students are not only to learn how to draw lines, arcs, circles, etc. but to comprehend the procedural nature of the building design process and how BIM tools are structured to assist in the process. Students cannot fully comprehend these very specific structures for as long as they do not understand the design process itself. BIM instruction should include the

- Technical skills in handling the respective application
- Basic knowledge of aesthetic, functional and structural aspects of design
- Ability to synthesize these skills and knowledge into the shaping of more complex objects
- Ability to formulate a spatial hypothesis
- Skills to generate respective views of the design as a basis for criticism
- Ability to criticize the respective design hypothesis
- Ability to repeat these steps in an iterative process

At the beginning of the semester students were asked to design a chair in 3D as a first finger stretching exercise to become familiar with generic CAD. Students learn basic orientation in three dimensions, as well as, basic object creation and manipulation commands.

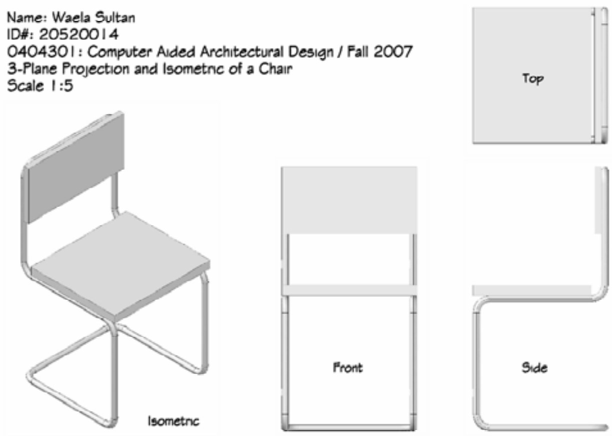

Figure 1. Fist exercise: Basic orientation in 3D; Waela Sultan, 3rd Year, Fall 2007

As a next assignment students were presented with a room and asked to design a shading device with which to manipulate the light in the interior space. The assigned room had dimensions of 8m deep, 5m wide, and 3.5m tall. Over this assignment students were introduced to the differences between CAD and BIM, as well as, confront a quantifiable building design issue. This was different from previous designs in that the outcome was measurable (does the sun shine into the space on a given date, say 21. March, noon). They could evaluate themselves how well the shading device worked. They could use the various projections of the software, such as section, axonometric, (rendered) perspectives, as well as, the two rendering engines built in to ArchiCAD 10 (ArchiCAD’s own, as well as, LightWorks). In the future another rendering tool, Maxwell, that is based on true light may permit to produce even more realistic simulation conditions.

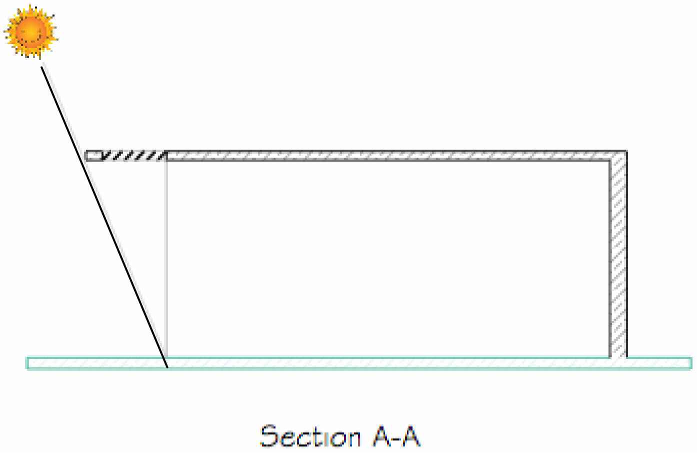

Figure 2. Second exercise: Designing a Shading Device; Waela Sultan, Fall 2007 (drawing edited for better visibility)

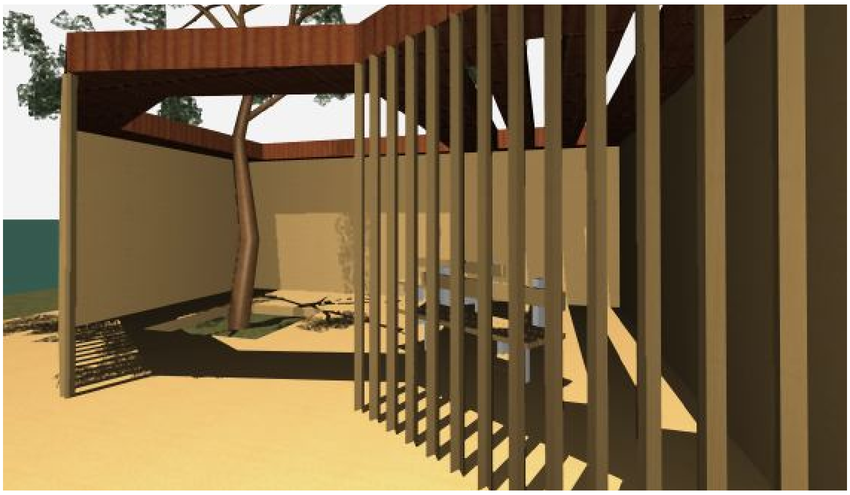

Figure 3: Second exercise: Designing a Shading Device; Maha Aljarrah, Spring 2007

Figure 4. Second exercise: Designing a Shading Device; Maha Aljarrah, Spring 2007

The final assignment of the semester was the re-design of a standard house for the Emirate of Sharjah. Such houses are two-story villas with five to six bedroom containing approximately 400m2 of usable floor space. The dwellings are executed by the governmental Department of Housing and Public Works of the Emirate for residents that cannot or want not build their own houses.

With the use of the BIM software, students of the course found these buildings left substantial space for improvement. One focus of this course was on raising efficiencies over the status quo through optimization in design. It was left to the students where to set priorities but their decisions were continuously questioned by the instructor from a functional, budgetary and ecological aspect. Students used the standard house as a point of departure for modifications.

For example the standard Sharjah house contains six different bathrooms with a maximum of two carrying common piping. A discussion ensued in which the expense of the additional piping was explained both during construction and during the lifecycle of the building, and the software was used to demonstrate that slight geometric and spatial adjustments could cut the number of vertical piping shafts in half thus drastically reducing the construction costs of the building. Students would use the abilities of the software to superimpose the current story with the one below in order to see if wet cells are vertically registered. Simultaneous checks in the model sections would verify this undertaking. Simple measurements in plan and section led to a summation of piping and an approximation of costs and possible savings in construction costs. The saved money could be used for adding insulation on the façade, as well as, better windows and doors.

Issues of surface-to-enclosed-volume were discussed using the automatic calculation features within the software. Students learned to use the “Zone Stamp” tool in order to automatically generate the floor space of each room, as well as, the entire floor, and the total enclosed volume of the house. This is a tool to divide the complex entity of a building into subsections of ones own choice.

The entire educational program is just three years old and still lacks some key support infrastructure. For example, a comprehensive wood workshop could not yet be acquired. The lack of abilities to build sturdy wood models for exploring solar geometry (K.P. Cheung, 1997) and its impact on the design of buildings thus enhanced the need to simulate these issues digitally. Students were encouraged to investigate the path of the sun throughout the day, as well as, throughout the year. Items of investigation were, e.g. the winter and summer solstice and spring/fall equinox. At the beginning of the course not a single students (all third year) had a correct understanding of these terms. Solar simulations, however, permitted the students to investigate the impact of the solar geometry on the building and thus comprehend the meaning of these terms. Several students reported that the possibility to make changes in the sun settings (date and time) and to visualize the results in the shadows cast on and within the building did help them in their understanding of the solar geometry. Students designed various shading elements, either designed into the geometry of the building itself or added as shading devices in front and above openings. Subsequently the rendering function of the software permits the students to verify the basic working and the efficiency of the design assumption.

Several of the designs incorporate multiple instances of the same shading element. This permitted the students to learn the concept of CAD/BIM symbols (called “blocks” in AutoCAD or “Library Elements” in ArchiCAD) and the efficiency of “change once, effect many!”

The following images display some of the investigations the students conducted regarding shading devices.

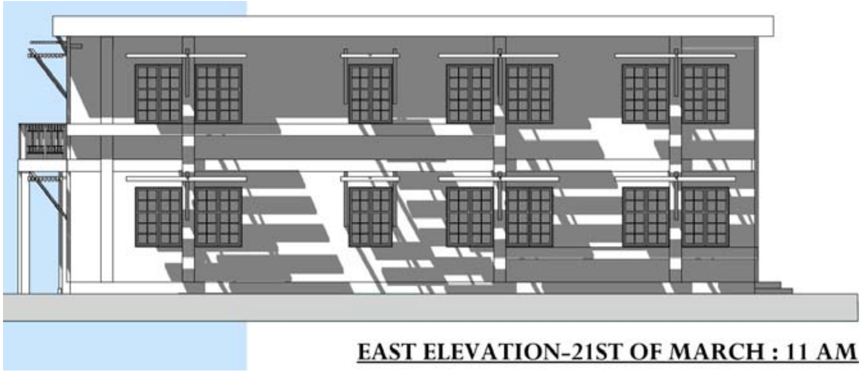

Figure 5. Simulation of Shading Devices as add-ons to the façade, elevation;
Maha Aljarrah, Spring 2007

Figure 6. Simulation of Shading Devices as add-ons to the façade, perspective;
Maha Aljarrah, Spring 2007

Figure 7. Simulation of Shading Devices as add-ons to the façade, perspective; Meera Al-Qassimi, Spring 2007

Figure 8. Simulation of Shading Devices as add-ons to the façade, overall perspective; Moza Alsuwaidi, Spring 2007

The ability to visualize the building design in every possible projection (plan, section, elevation, axonometric, perspective) permitted the students to choose the respective best view to analyze the impact of their design. For example, the merit of few wet pipe shafts can be best analyzed in plan and section on the other hand, the impact of shading devices can be better analyzed in an axonometric view. Students response at the end of the semester was that of a more "holistic" experience of the design process.

1.4 IFC

Fostered largely by the construction industry the development of IFC (International Foundation Classes), has led to a BIM data format independent from private corporate interests and overseen by an public standardizing organization, which will spawn the free and uninhibited flow of 3D building data between various specialized software applications.
The Industrial Alliance for Interoperability (IAI) recently conducted the seminar "buildingSmart 2007 'Building Data Model as a Basis for Cost Management, Energy Simulation and Construction…" in Berlin on 26. Sept. 2007 (BuildingSmart Seminar Berlin, 2007).

In the future this may prove as a vehicle to emancipate the software users from the manufacturers and enable them to select and assemble software solutions to their own needs. The free scalability of hardware would then be followed by free scalability of software applications and creation of individual solutions "off the shelf".

This approach is, of course, diametrically opposed to the application centric approach that has dominated Computer Aided Design since its inception. For many years the industry argued that the processing power of computer was insufficient to handle anything but the application centric model. This effectively hid the fact that the industry was primarily protecting its own corporate interests. With every additional project created in an application following the traditional application centric model, the dependency between the user and the software grows and it becomes increasingly difficult to change towards a possibly better solution.

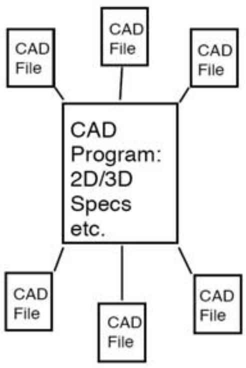

Figure 9. In an application-centric model the exchange of data is limited to a specific software, at times even a specific version of the software (F. Techel, 1991)

On the other hand, the task of joining different highly specialized software applications into workflow of simulating complex buildings requires strict standardizing of the BIM data. Ideally this data should not be exported/imported from one application to another resulting in changing interfaces, different metaphors and a new learning curve. This leads to a complete reversal of the traditional application-data-relationship as shown in figure 8. Efforts in this direction reach as far back as the mid 1990s when Apple Computer launched the ill-fated OpenDoc format. Perhaps the most successful and widely applied reversal of original application-centric concept is the World Wide Web. It is based on the assumption that standardized data can be read by many different applications.

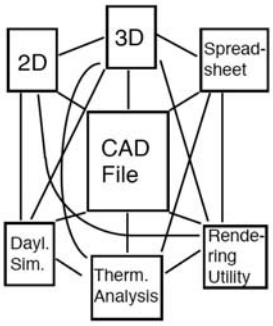

Figure 10. Free exchange of information in a modular, data-centric model (F. Techel, 1991)

All of the specialized building data simulators work on the concept of visualizing certain behavior of building elements or entire buildings. Just as the stress inside a beam could be made visible under polarized light, the energy consumption of a building, or its generation of CO2 and other greenhouse gases can be visualized through clouds of colors. This ability to visualize and consequently realize becomes vital in a time that it becomes obvious that buildings of the future need to change radically in their consumption of energy, throughout the world but particularly in the Gulf region.

2 Outlook / Next Steps within the Department

2.1 INTEGRATION OF DIGITAL DAYLIGHTING

The department has recently acquired Maxwell Renderer, the first rendering engine that uses real light algorithms, and plans to apply it during the Fall 2007 semester. Maxwell's real-light approach makes the results not only quite realistic looking, its also enables students to make early predictions about the real world illuminative effects of their designs. It thus makes the software extremely instructive and thus effective for lighting investigation purposes. Students comprehend the reflection and transmission of materials relatively quickly once they see the effects. Compared to other rendering engines, Maxwell is still rather slow, but for as long as the scene is not overwhelmed with too many details a current laptop computer (Intel Core2Duo Processor) can produce viewable results within 30min. The unique new rendering approach of Maxwell should also be noted. While current applications usually render the scene line for line, Maxwell displays the first calculation iteration relatively quickly, but extremely grainy, like in an old-high-ISO-film. Longer rendering times decrease the amount of grain, increase the sharpness and detail. This process practically never stops. It is at the discretion of the user to terminate the process at any time when he/she finds the results pleasing enough. Thus quick evaluations about the general correctness of the approach may be made within a few minutes. Maxwell thus may be a step in the direction of replacing physical lighting models with digital models, thus saving the student/architect time and increasing the quality of the overall design. Finally Maxwell permits the inclusion of up to 100 different light sources and their integration into the calculation. Obviously more lights elongate the rendering times, but once the software has calculated the entire scene it is possible to change the individual lights and within a few seconds Maxwell will re-render the scene under the different lighting conditions.

Figure 11. Simulation of Light Shovel as add-ons to the façade, interior perspective

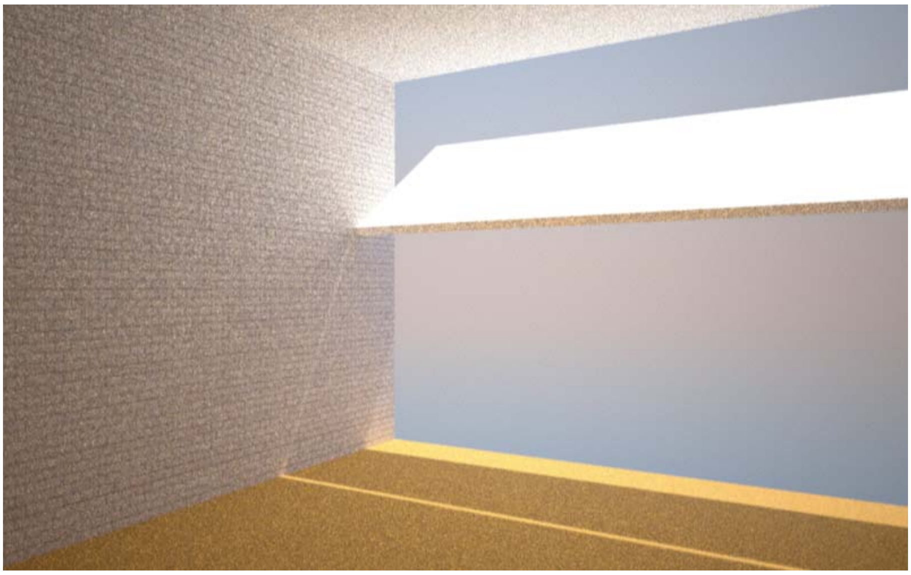

Figure 12. Simulation of Light Shovel as add-ons to the façade, interior perspective

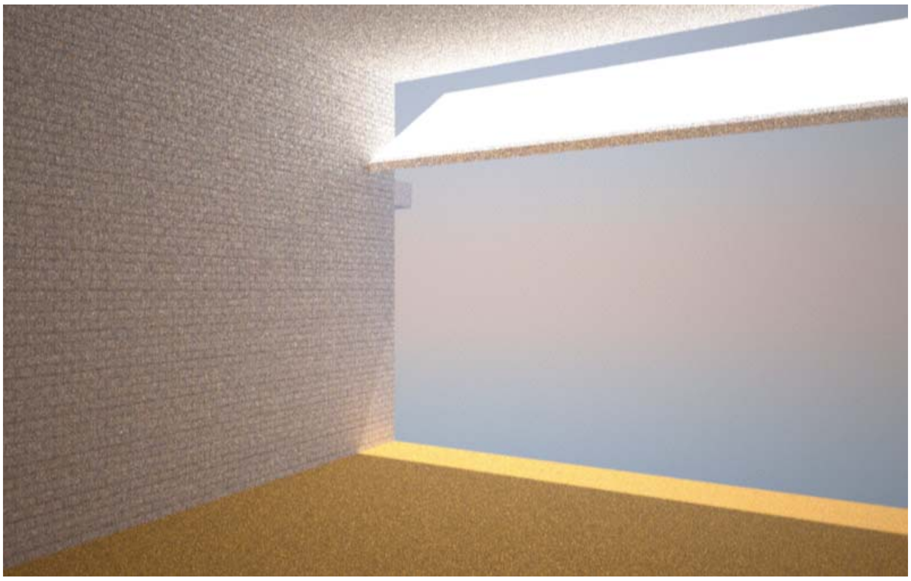

Figure 13. Simulation of Light Shovel as add-ons to the façade, interior perspective

The digital model for the renderings in figures 9 through 11 was created in ArchiCAD. It comprises a simple box 5m wide and 7m deep, with an interior height of 4m. The box is enclosed on five sides (floor and roof slab, three walls) while one wall is left open. Material settings are set inside ArchiCAD (although they could be finer manipulated inside Maxwell). A light shovel is added. The whole model is then rendered in Maxwell Renderer. Each one of the renderings did not take more than three minutes and already produces an understandable effect of the conducted manipulations of the light shovel (change of incline, manipulation of horizontal and vertical position of device).

Note: The instructor conducted this experiment in front of the students soliciting their input. Unfortunately the rendering software was received so late during the Spring Semester 2007 that students could no longer conduct their own work in this rendering software. This will be on the agenda for the Fall 2007 semester.

2.2 SIMULATION OF THERMAL BEHAVIOR OF BUILDING

An additional step could be made in the direction of thermal simulation by using tools such as Ecotect or EnergyPlus and gain insights into the thermal performance of the building designs already at an early stage. These simulations will be added at a later stage, as will be acoustic simulation software.

3 Conclusion

This paper should have demonstrated the effectiveness of using BIM for proper architectural design education. Buildings differ fundamentally from industrial design objects, primarily in their spatial complexity and wide array of used materials. More than simply oversized teacups, buildings require their own set of specific design tools. Given the enormous capital expense of buildings construction prototypes is still out of the question in most instances. All the more it should be clear that the lifecycle behavior of a design should be properly tested through digital simulation. Therefore seamless interfaces to various simulation tools should be provided and properly standardized. To date, IFC is the most comprehensive standard in this area. Simulation applications for structural, thermal and lighting behavior are only the most prominent tools to date, but other simulators can be envisioned. Close integration of these tools with the design software via neutral interfaces will both level the playing field for all applications while at the same time increase the market for these tools. Their increased use together with improved visualization capabilities will permit for a better understanding of the yet not built structures and resulting in the inclusion of various, previously unseen and therefore little considered issues into the design process. More comprehensive and consequently better designs should be result from these advances.

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