
AC 2012-5045: USING BIM TO TEACH DESIGN AND CONSTRUCTION OF SUSTAINABLE BUILDINGS

Dr. Zhigang Shen, University of Nebraska, Lincoln

Zhigang Shen is an Assistant Professor of Durham School of Architectural Engineering and Construction at the University of Nebraska, Lincoln. He received his Ph.D. in construction from the University of Florida. Shen received more than \$1.7 million in federal research grants on energy efficient buildings and innovative engineering education, from NSF, U.S. EPA, and DOE. Shen authored and co-authored more than 30 journal and conference papers in construction, energy efficient buildings, sustainable built environment, BIM applications, and innovative engineering education.

Dr. Wayne G. Jensen, University of Nebraska, Lincoln

Mr. Bruce Allen Fischer

Prof. Timothy G. Wentz, University of Nebraska, Lincoln

Associate Professor, Construction Management

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Abstract

Building information modeling (BIM) has been integrated into many architectural and engineering curriculums over the past five years. It is now being introduced into sustainability education because of its building energy analysis and simulation applications. Preliminary evaluation of the sustainability of buildings is becoming easier, faster, and more accessible to the academic community. This new accessibility to powerful modeling software is an innovative teaching and learning tool for both instructors and students in building design and construction. The BIM modeling platform allows users to quickly identify and evaluate the impact of design and construction changes on a building's sustainability. A review of the literature revealed a very limited number of publications that addressed how this critical development can be effectively utilized in higher education.

The objectives of this paper are: 1) to introduce an integrated, BIM-based building design and construction course; and 2) to demonstrate some of the teaching and learning methods, case studies, and projects used to teach sustainability in this context. The key research goal of this paper is to identify and document some methods of using BIM as an effective tool to teach sustainable building design and construction.

A building design and construction class integrating BIM was developed and its initial offering was used as a case study for this paper. One feature of this class was the introduction of three different BIM software packages during a single semester, which enabled students to use BIM tools to conduct "what-if" sustainability analyses during design and construction scenarios. A residential and a commercial building were used as class projects to allow students to demonstrate the knowledge they had learned in class. Project results and student feedback were collected for an analysis of learning effectiveness.

By incorporating case studies into the course, the authors were able to develop procedures and content appropriate for BIM-based instruction of building sustainability in a new and creative way. The preliminary results demonstrated that BIM can be used as an effective tool for teaching sustainability in a construction curriculum. The authors hope the described work will promote more discussion and additional sharing of knowledge on this important topic.

Key words: BIM; Revit; Ecotect®; Sustainability, Building Construction; Education

Introduction

Sustainability education has gained increased attention in higher education in response to societal need for sustainable development [1, 2]. In many engineering disciplines, course contents were modified or new curriculums were developed to incorporate sustainability content [3]. Buildings, which consume approximately 40 percent of the total generated energy in the United States, have

the greatest potential for lowering our country's energy consumption. In architecture, engineering and construction (AEC) education, which arguably has the most significant impact on sustainable development, great effort has been made to implement sustainability education into existing or new courses [4]. Despite a general consensus that sustainability should be an important topic in AEC education, only a few articles were found on innovative pedagogical tools that could be used to teach sustainability in AEC curriculums.

Building information modeling (BIM) [5], as a 3D information repository, has been gradually integrated into AEC education at many institutions. However, the use of BIM for building energy analysis and simulation applications was mentioned in only a few research papers [6, 7, 8]. Newly developed BIM-based energy analysis tools [9] make a preliminary evaluation of a building's energy use easier, faster, and more accessible to the academic community. The range of powerful energy analysis software available which interacts with BIM provides great opportunity for both instructors and students in the AEC community to identify the impact of design and construction practices on a building's sustainability. However, despite the wide spread acceptance and usage of BIM as a teaching tool for general construction and building design courses[4], few publications [4, 10] were found which discussed how to utilize a BIM-based platform in a formal classroom setting to teach sustainable construction.

The overall goal of this paper is to share the authors' experiences of using BIM as a pedagogical and technical tool to teach sustainability in construction education. The intent is to promote further discussion and research on this important topic. This paper has four objectives: 1) to introduce an integrated BIM-based building sustainability course; 2) to identify applicable BIM-based techniques useful in sustainable building education; 3) to discuss the pedagogical methods used in this case-study course; and 4) to present the results of and discuss some conclusions of a student survey administered in this course.

A newly developed BIM course served as the laboratory for this paper. One of the course requirements was for students to gain familiarity with three different BIM software packages (Revit Architecture, Revit MEP, and Autodesk Ecotect®) [11] in order to use the software to conduct "what-if" sustainability analyses during building design and construction later in the course. Typical functions of Ecotect®, a BIM based sustainability analysis software, were analyzed in relation to their applicability to classroom teaching. A residential and a commercial building were used as term projects to measure the knowledge students had acquired during the class. Feedback from the students was collected in the form of a survey to determine the changes in both student knowledge and perceptions, if any.

Related works

Most BIM and sustainability related software use models to conduct energy analysis [6, 7] and lifecycle analysis of building cost [8]. The recent, significant improvement in data interoperability among BIM platforms [12] has made BIM-based energy analysis feasible in a classroom setting. Sustainability has been identified as an important aspect of construction education [13]. A recent survey by Becerik-Gerber et al. [4] revealed that about 60% of all AEC programs in the United States currently incorporate BIM into their curriculum. The survey also revealed that nearly 40% of all construction programs are using BIM to teach at least some

aspects of sustainability courses. Many of the schools that do not currently use BIM have plans to introduce BIM into their sustainability courses. Given the results of the survey, academicians agree that BIM has significant value in the teaching sustainability within the AEC curriculum. Research on BIM uses in AEC education has become more prolific in recent years as a reflection of the 60% software adoption rate [4]. There is an ongoing discussion regarding the pros and cons of offering stand-alone BIM courses versus incorporating BIM in existing courses [14, 15]. It appears that most AEC programs are using BIM in a variety of classes after some basic skills are acquired by students through a stand-alone course. Other academicians question whether BIM should be offered as an upper level (third or fourth year) class or at the freshman level [16].

The literature review identified a significant gap in the methods of teaching and learning sustainability using BIM. No literature was found addressing various techniques of teaching and/or learning sustainable design and construction in a BIM-based classroom.

The course

The BIM course developed by the authors was offered as a mixed graduate/undergraduate technical elective in a Construction Management curriculum. This course was designed for undergraduate seniors with the primary goal of exposing them to BIM related analysis in a sustainable environment. The course was also designed for graduate students with the primary goal of helping them to find BIM-based research projects related to sustainability. One important outcome for the students completing the course was being able to perform preliminary energy load calculations using 3D BIM models. This outcome required the students to have a basic understanding of a building's structure, envelope, and its Mechanical-Electrical-Plumbing (MEP) systems.

A total of 12 students enrolled in this class including seven senior undergraduate students and five graduate students. The undergraduate students were required to complete mechanical/plumbing and electrical (MEP) courses before enrolling. All of the five graduate students had at least limited knowledge of building MEP, structural and envelope systems.

The course content was divided into three major parts: 1) how to create BIM models, including architectural and MEP models; 2) how to use the created models to perform building energy analysis; and 3) develop a quantitative understand concerning how the building design (shape and size of spaces, building materials, etc.) and construction affect the energy performance of the completed structure. Gaining an understanding of the relationship between design, construction and energy consumption is especially important if students are to think critically about how a building's design and construction impacts the building's sustainability.

Course assignments were organized into three major parts, as shown in Figure 1: Project 1 took eight weeks and required students to learn how to use Revit Architecture and MEP to design a simple ranch-style, single family residence, which included architectural design, mechanical, electrical, and plumbing design and building layout.

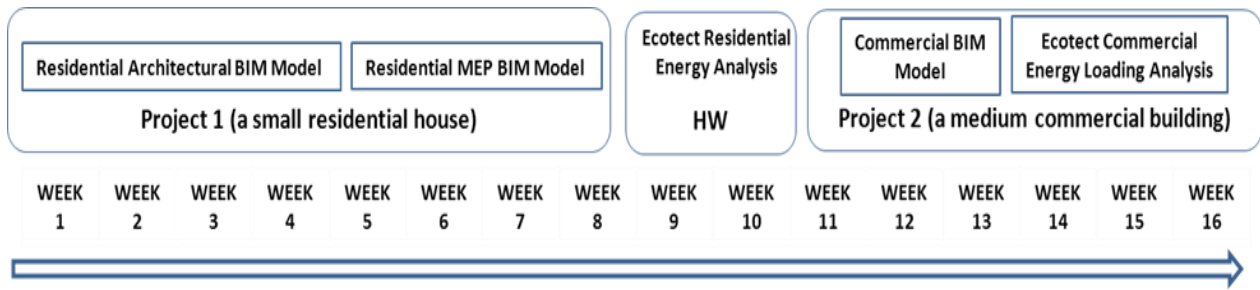


Figure 1. The major assignments and time line of the BIM sustainability course

The technical details of how to use the software were taught using in-class tutorials, exercises, assignments, and short tutorials on YouTube. Tutorials on YouTube proved to be a good resource which enabled students to become familiar with the technical details of Revit. However, it was necessary for the instructor to provide the big picture before students were able to use YouTube effectively. For example, the instructor explained the concept of stack walls before allowing students search YouTube for instructions on how to incorporate a stack wall into the model.

Students learned the basic skills of model creation for architectural and MEP components in the simpler residential project. The residential project was followed by an energy analysis assignment, which used the model created during the residential project. After completing the residential project and the energy analysis homework, students possessed basic knowledge and skills concerning how to create a BIM model and how to use that model to calculate the energy load of a building.

In project 2, which took five weeks to complete, students created an architectural and space model of an existing institutional building. Energy consumption over a 4-year period was provided to students so they could compare the energy usage calculated for the model to the energy consumed by the actual building. As a critical part of this project, students were asked to analyze any discrepancies between their modeled results and the actual energy consumption. This analysis was included as part of student's final report and presentation. Students were encouraged to develop critical thinking skills by relating their class assignments, whose scope was well-defined, to realistic scenarios involving an actual project where the scope was more complex and ill-defined. The contrast between the models completed in class and actual energy use was expected to increase students' awareness of the complexity and ambiguities associated with working on real-world projects.

Quizzes, assignments, graded homework and presentations were used to provide frequent assessment of the students' learning. Figure 2a illustrates some samples of students' typical submissions for the residential project. Figure 2b illustrates typical results for the commercial project.

As a part of their commercial project analysis, students were required to develop suggestions to reduce the energy consumption of their original models by 30%. Ecotect® provides convenient functions which allow student to try many alternatives, such as use of different building materials, layouts, number of occupants, and other similar variables. Using these functions,

almost all students achieved the 30% energy reduction goal by substituting different building configurations or materials. To complete this part of the exercise, students were required to model different alternatives based upon a number of ‘what-if’ scenarios.

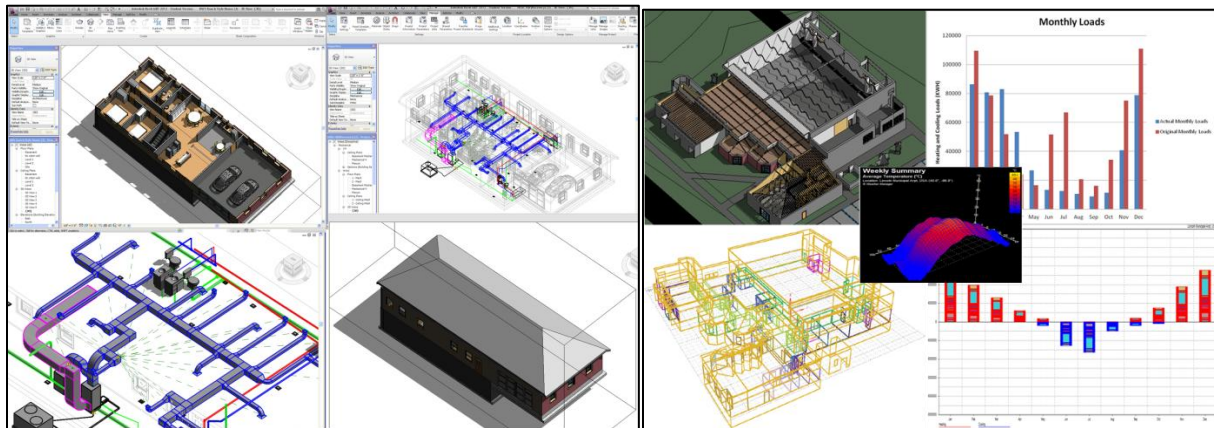


Figure 2a. Architectural and MEP modeling

Figure 2b. BIM building energy analysis

Methodology

To answer the question of whether or not BIM was an effective teaching tool in teaching project-based sustainable building and construction techniques, the researchers analyzed learning results from the two projects and a student survey. Considering the small survey sample size (12), the conclusions of this paper are preliminary and subject to modification based upon research with larger populations. The findings of this research will hopefully be helpful to those conducting research in this area in the future.

The data generated by this research was a mix of qualitative and quantitative information that the authors analyzed to form preliminary findings. Quantitative data from the survey was obtained as feedback from the students regarding the overall effectiveness of the BIM tools used in this class. The complete survey is attached to this paper as Appendix A.

Qualitative measurements were used to describe the performance of the students in the commercial project due to difficulties of quantifying student solutions in the complex, open-ended ‘what-if’ scenarios. Even though the data is in a qualitative format, it provides useful information for evaluating student understanding of basic concepts and design parameters that affect building energy consumption. Considering the preliminary nature and limited size of this study, the authors employed simple descriptive statistics to evaluate the quantitative data. The measured parameters, values, and the descriptive statistics are discussed in the following section.

Results and discussions

Table 1 and 2 demonstrate partial results from the commercial project reports. One part of the commercial project was to compare the simulated annual energy consumption to four years of actual energy consumption, and to analyze the results for any discrepancies between the actual

and estimated quantities. Most students' simulated energy consumption was 30-50% higher than the annual energy consumption of the actual building. Table 1 lists possible causes identified by the students for this discrepancy. Through this exercise, students were introduced to the complexity and limitations of building energy simulations.

Table 1. Identified typical factors, which might cause the difference between the simulated and actual energy consumptions

ID	Factors	Remark
1	Operation hours	Simulated hours may not match the actual hours
2	Office equipment	Simulated office equipment may be different from actual
3	Number of occupants	Not sure what are the actual number of occupants
4	Zone	Identified zoning issue during site visit
5	Indoor temperatures	Actual indoor temperature might be different from the simulated one
6	Air Infiltrations	Identified issue during the site visit
7	Weather data	Annual degree days might vary
8	Building's age	Roof, wall, window and door conditions cannot be set in simulation
9	Building category	Difficult to find a good match of predefined building category in Ecotect

Table 2 is a summary of the students' proposed solutions during a what-if exercise, in which students were asked to devise solutions to reduce the building's energy consumption by 30%. The proposed solutions were based on multiple what-if simulations. Simulations represent a significant departure from the way sustainability is taught in traditional lecture based courses. The most significant change is that students receive immediate feedback from their design changes while using the Ecotect® software, and can then explore other options. In a traditional setting, feedback is received through written evaluation of homework, which may be returned days or weeks later.

Table 2. Typical solutions proposed by students to reduce 30% of original energy consumptions through what-if simulations

1	Change insulations on walls and roofs
2	Reduce infiltration rate
3	Adding more zones to have better control of indoor temperatures
4	Use better windows and doors
5*	Reduce operation hours

* May not be an appropriate solution.

At the end of the class, a survey was administered to obtain student feedback about the BIM sustainability course. The full version of the survey is attached as Appendix A at the end of the paper. Table 3 summarizes the relevant questions (Question 1-3 and 8-15). Survey results (as shown in Figure 3) for Question 1-3 and 8-9 indicated that students were overwhelmingly positive on the effectiveness of using BIM energy simulation tools to learn building sustainability. The survey result for Question 10 indicated that not all students perceived the value of using an actual building as their term project, which was a surprising feedback for the instructor. Survey results for Question 11-12 were designed to gain better understanding of students' perceptions regarding the value of a BIM-based course compared to more traditionally taught sustainability courses. Although the overall feedback was still positive, a broader

spectrum of opinions was evident. It was also surprising to see that students appeared to be comfortable using BIM to evaluate architectural systems versus using BIM to evaluate MEP systems.

Table 3. The survey questions used in this paper (full version is attached as Appendix A)

ID	Survey questions
1	Creating BIM models (Architectural) helped you to better understand architectural systems (wall, foundation, floor, roof, etc .)?
2	Creating BIM models (MEP) helped you to better understand MEP system (air terminals, duct, AHU, condenser, plumbing, drainage systems, etc .)?
3	Ecotect® helped you to better understand how building systems affect energy consumptions?
8	Modeling MEP help me to better understand the whole building system including architecture design.
9	Ecotect® thermal analysis using 3D BIM model helped me to better understand how heating/cooling loads are calculated.
10	Using an actual building and energy consumption data in project give me more motivation to do the project.
11	Without doing the architectural BIM modeling I feel I can learn similar knowledge in other classes
12	Without doing the MEP BIM modeling I feel I can learn similar knowledge in other classes
13	Which of the following is an accurate description of your prior knowledge in Arch?
14	Which of the following is an accurate description of your prior knowledge in MEP?
15	Which of the following is an accurate description of your prior knowledge in energy consumption?

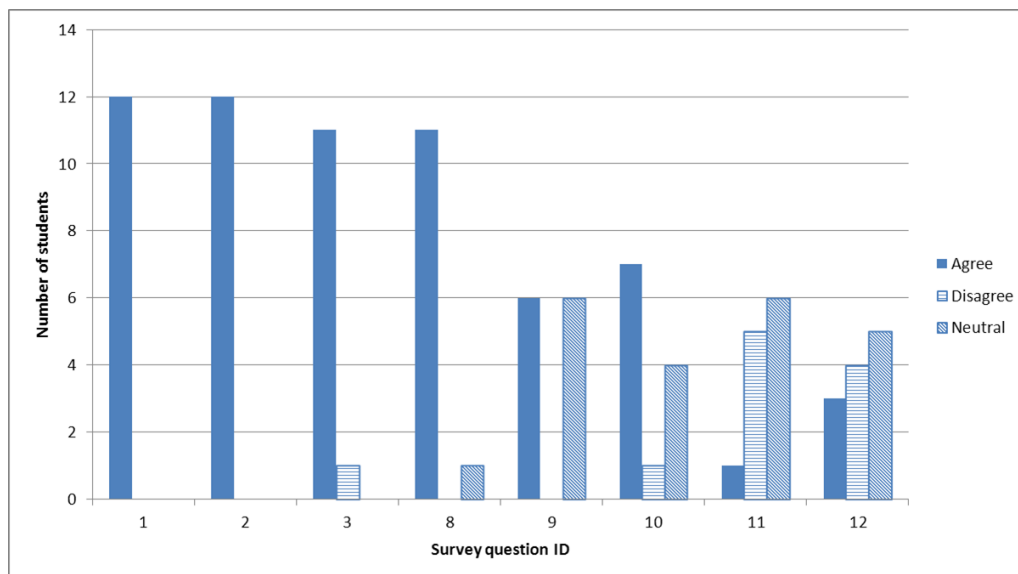


Figure 3. Survey results of Question 1-3, and Question 8-12 from the total 12 students

Figure 4, which contains the survey results of students' self-perception concerning their previous knowledge of three major sustainability areas, corresponds to Question 13-15 on the survey. Figure 4 illustrates that the majority of the students appeared confident concerning their background knowledge of architectural and MEP systems, while the majority were less confident of their background knowledge in building energy consumption. While students appeared slightly less confident of their MEP systems knowledge versus their architectural systems knowledge, most still rated their MEP knowledge as at least average.

Putting this background knowledge in context, the survey results for Question 11 and 12 are even more interesting. Students believed they had more background knowledge of and were more proficient working with BIM in relation to architectural systems versus BIM in relation to MEP systems. BIM-based instruction appeared to provide more opportunities to gain additional knowledge concerning architectural systems versus BIM-based instruction with MEP systems.

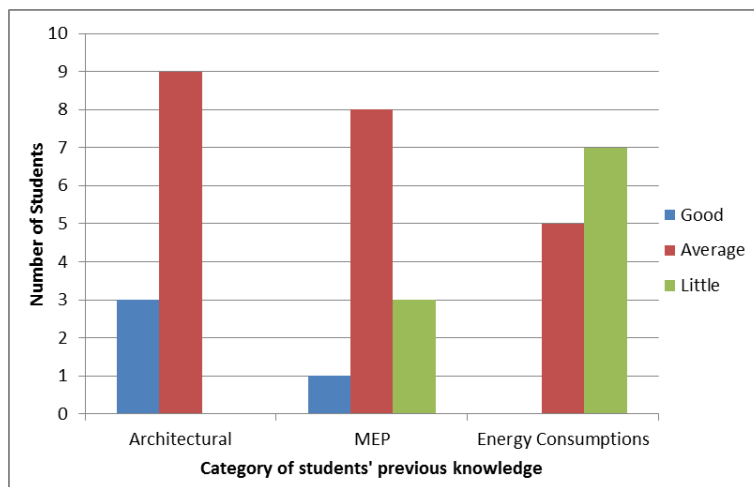


Figure 4. Self-determined level of previous knowledge background (corresponding to survey Question 13-15)

Conclusions and future study

Preliminary results indicated that BIM, when used as an instructional tool, provided a good pedagogical as well as a suitable technical platform for teaching sustainability in construction education. Many additional aspects of sustainability in addition to energy consumption could be taught using this platform. This conclusion is, however, limited due to the small size of the class in this study.

The results from the students' commercial project and the results of the survey provide very positive evidence of the effectiveness of using BIM tools as a platform for building systems instruction while simultaneously learning concepts relevant to sustainability. Students in this study did not, however, indicate a pronounced preference for this type of course versus the more traditional types of sustainability courses.

A majority of students believed they entered the BIM course with a stronger previous knowledge base concerning architectural systems than MEP systems. A surprising finding was that students

believed the Architectural BIM was more effective in learning architectural systems than MEP BIM was in learning MEP systems. This finding, though tentative, is subject to many different interpretations. One possible interpretation is that students learn more from BIM-based instruction when they possess additional prior knowledge about the subject material. If this interpretation is true, it provides strong support for the argument that BIM should be taught as a senior level course (maybe a technical elective) versus as an introductory class [15, 16].

The authors plan to continue to conduct this research on larger scale in order to gain better understanding on what and how BIM tools affect students' learning of building systems in the context of sustainability.

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Appendix A - Survey: What you learn from BIM

1. Creating BIM models (Architectural) helped you to better understand architectural systems (wall, foundation, floor, roof, etc .)?
 - a. agree
 - b. disagree
 - c. neutral
2. Creating BIM models (MEP) helped you to better understand MEP system (air terminals, duct, AHU, condenser, plumbing, drainage systems, etc .)?
 - a. agree
 - b. disagree
 - c. neutral
3. Ecotect helped you to better understand how building systems affect energy consumptions?
 - a. agree
 - b. disagree
 - c. neutral
4. By 3D Architectural modeling in BIM, you gained better understanding or new knowledge in which particular architectural systems (you can select multiple answers as applied)?
 - a. Wall system
 - b. structural system
 - c. floor system
 - d. roof system
 - e. overall building system
 - f. none
5. By 3D MEP modeling in BIM, you gained better understanding or new knowledge in which particular MEP systems (you can select multiple answers as applied)?
 - a. AHU
 - b. Duct work
 - c. drainage system
 - d. vent system
 - e. cold water supply
 - f. hot water supply
 - g. Supply air
 - h. return air
 - i. exhaust air
 - j. fresh air
 - k. condenser
 - l. none
6. By 3D architectural modeling in BIM, you gained better understanding or new knowledge in which particular knowledge areas (you can select multiple answers as applied)?
 - a. The structure/layout of the arch. Systems
 - b. the functions of the arch. Systems
 - c. the behaviors of the systems
 - d. none
7. By 3D MEP modeling in BIM, you gained better understanding or new knowledge in which particular knowledge areas (you can select multiple answers as applied)?
 - a. The structure/layout of the arch. Systems
 - b. the functions of the arch. Systems
 - c. the behaviors of the systems
 - d. none
8. Modeling MEP help me to better understand the whole building system including architecture design.
 - a. Agree
 - b. disagree
 - c. neutral
9. Ecotect thermal analysis using 3D BIM model helped me to better understand how heating/cooling loads are calculated.
 - a. Agree
 - b. disagree
 - c. neutral
10. Using an actual building and energy consumption data in project give me more motivation to do the project.
 - a. Agree
 - b. disagree
 - c. neutral
11. Without doing the architectural BIM modeling I feel I can learn similar knowledge in other classes
 - a. Agree
 - b. disagree
 - c. neutral
12. Without doing the MEP BIM modeling I feel I can learn similar knowledge in other classes
 - a. Agree
 - b. disagree
 - c. neutral
13. Which of the following is an accurate description of your prior knowledge in Arch?
 - a. I already had good knowledge of Arch. Systems
 - b. I had average knowledge of Arch. Systems
 - c. I had little knowledge of Arch. Systems
14. Which of the following is an accurate description of your prior knowledge in MEP?
 - a. I already had good knowledge of MEP
 - b. I had average knowledge of MEP
 - c. I had little knowledge of MEP
15. Which of the following is an accurate description of your prior knowledge in energy consumption?
 - a. I already had good knowledge of energy consumption
 - b. I had average knowledge of energy consumption
 - c. I had little knowledge of energy consumption