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BIM AS A PEDAGOGICAL TOOL FOR TEACHING HVAC SYSTEMS TO ARCHITECTURE STUDENTS

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ABSTRACT

Understanding the basics of Environmental Control Systems including HVAC systems is required in architectural curricula. One of the challenges of learning this subject is the non-familiarity of the students with the components of these systems and how the selection and installation of these components can impact the architecture of the building and its spacial experience. Such difficult interrelationships can be clarified using various techniques. One technique that the author experimented with is the use of a BIM tool. Yet, using the tool to achieve this purpose had been a challenge in itself. The tool needs to be setup and its interface needs to be configured for a particular learning objective within a defined learning environment. This paper discusses the various techniques to achieving the learning of this required subject. It also shares the details of preparing and executing the experiment of using BIM hoping that other instructors make use of it and further build on it. A survey of the students who went through the experiment shows that a large majority believes that they learned the subject better through the BIM tool.

INTRODUCTION

HVAC systems are essential components of any modern building. Therefore, architectural curricula require that students to understand these systems to an adequate level. In general, it is reasonable to identify four different levels of such understanding:

- Recognize the terminology used in these systems. This enables the future architect to communicate with HVAC engineers and can tell - for example - what an AHU is.
- Understand - to a reasonable extent - the concern of an HVAC engineer when designing a system. For example, understanding the impact of changing a space function from a storage room to a computer server room and why such a change, which can be a simple space name in an architectural drawing, can have a significant impact on the HVAC needs of the space.
- Recognize the impact of the HVAC system components on the architecture. For example, the volume of the space needed to host these components. Even more important is the possibility that adding these components requires a change in the space arrangements in a building.
- Recognize the potential to use the HVAC components as architectural elements that enhance the aesthetic quality of the spaces. This is in contrast to trying to hide these elements above suspended ceilings or in locked rooms.

However, there are many difficulties that face instructors of systems courses in achieving these levels of understanding. These include:

- Students' recognition of the importance of the subject to their professional career. This - in the author's opinion – is the most difficult obstacle to learning. Particularly in architecture schools that tend to focus on the formal aspects of architectural design, students tend to think that it is the engineers' job to accommodate their designs and to achieve their needs. They tend to believe that they should not worry about an extra design constraint. As is commonly the case, studio instructors rarely ask for the inclusion of these systems except in the comprehensive studio experience. Even in that studio, such inclusion is commonly to the minimum and is often at the very end of the process. This results in leaving little room for a real integration of these systems with architectural design.
- The components of a typical central HVAC system are commonly hidden in a building. The large equipment are in closed rooms, above a suspended ceiling, or on the roof. Ducts, if not above a false ceiling, are usually colored to be with little visibility. Observant students may notice the existence of the grilles, registers, and diffusers in a space. Most students do not recognize any aspect other than the temperature controller (thermostat) from a central HVAC system. Such unfamiliarity makes it difficult to just talk and show photos about the system. This difficulty is not only about the functions of the different components, but more on the logic that relates these unfamiliar components with architectural design.
- Considering the above two challenges, one can imagine the difficulty that instructors of the systems courses face trying to make the architecture students like the subject. Liking the subject is certainly important when preparing future architects who must be able to further develop themselves and to become self-learners. As technology changes, they should not be afraid of that subject due to bad experiences they had when they first learned about it in university.

Having identified these challenges, instructors of the systems course can overcome them with a palette of tools. The author uses the following tools when teaching the course:

- Lectures that are enriched with photos and videos. Well-selected short YouTube videos proved to be an excellent resource for explaining important concepts and for illustrating different technologies.
- Field trips allow students to closely see and touch the different components. Hence, they recognize their size, their space conditions, and their installation techniques. They can also hear the noise, sense the heat, and feel the vibration when these issues exist. The instructor does a short field trip in the college, but asks groups of students to arrange for visits to large commercial buildings. They learn how to initiate a contact and to talk to maintenance engineers who reveal more issues about the function of the HVAC system. A class presentation is then required to link what they learned in class with what they experienced on site.
- Class exercises that are designed such that the instructor can discuss the logic for integrating the HVAC system components with the architectural design. The purpose is for the students to appreciate how having these components may result in some design changes. Students then apply what they learn on a small residential project provided by the instructor.

The last tool is the one addressed by this paper. The instructor experienced difficulties from a number of students in understanding the integration between the HVAC components and the architecture spaces. The difficulty was largely related to the students' ability to visualize these components when installed in the building. To overcome this difficulty, the instructor decided to try the use of BIM technology.

This paper starts with a literature review of the reported methods for teaching HVAC systems to architecture students. The review also covers the using of BIM technology for teaching various aspects of technology in architecture. The paper then discusses the traditional technique used by the instructor to explain the issue. An example illustrating this technique is followed by a discussion of the difficulties of using such a traditional technique. The paper then explains the experiment of using the BIM technology in the classroom. This includes the preparation of the appropriate working environment, the preparation of an illustrative example, and the deployment of the experiment. Finally, the paper discusses the result in terms of the students' feedback and the conclusion of the experiment.

REVIEW OF RELATED WORK

Very few research work is published regarding the teaching of the interrelationship between architecture and building systems. Brown (1980) discussed the different approaches to link the learning of Environmental Control Systems (ECS) with architecture design for architecture students. Such a link is very close to the intention of the author in presenting this paper. Brown presented an educational process that help students reach a problem resolution following a sequence of "progressively reduced scales: off-site, site, building, and component". Due to the time of writing his article, the use of technology was not part of the approaches discussed by Brown.

Fithian and Mccuen (2009) reported on the use of various BIM-based design tools in a charrette learning environment where Environmental Control Systems where part of the design. The tools were used to relate architecture decisions with other decisions, including the environmental control systems.

Vassigh at al. (2016) presented a technology to be used in a classroom where both BIM and virtual reality tools are integrated to allow students to show/hide different systems of a building and hence, visually study the interrelationship among the systems. No result was reported yet on the value of using such technologies.

Rader and Mahdavi (2016) developed "a building systems control schema that can be automatically generated based on a limited set of design input data". The main focus is their work is the logical distribution of the control system elements. It is intended for the use by both architecture and engineering students to help them better understand these systems.

There is clearly a gap in the research work that discuss better ways to help architecture students learn about the environmental control system.

Using BIM technology as an educational tool was investigated by several researchers. Holland et al. (2010) reported on an experiment for the use of BIM technology as a collaborative design tool in two multi-disciplinary studios at Penn State University. The experience involved students from Architecture, Architecture Engineering, and other disciplines. They reported a generally positive students' learning and also reported several challenges when BIM is used. These challenges include the need to have students with reasonably well-developed BIM program skills before taking the studios.

Gledson and Dawson (2016) used BIM tools to enhance design skills for architecture technology students. They reported positive results through measuring the perception of the student using a questionnaire survey. The students believed that they gained a greater depth of conceptual understanding and in subject-specific knowledge.

Mokhtar (2005) discussed the use of BIM as a tool to help architecture students learn about basic structure concepts. He also reported on doing the same regarding construction concepts (Mokhtar 2007).

Zhao et al. (2015) reported on the use of BIM process to help building construction students develop their collaboration skills. They used a survey of the students to investigate the value of BIM to students learning. One of the survey results is that the objection of using BIM tools came mainly from students who had no previous training in the tool.

Others reported on the use of BIM as a collaborative tool for construction management students including Peterson at al. (2011), Zhao at al. (2013), Ghosh et al. (2015) and Suwal and Singh (2017).

The literature review reveals that little is reported about the use of BIM as an educational tool for architecture students. This is particularly the case when it comes to integrating ECS with architectural design.

THE TRADITIONAL 2D APPROACH

As discussed in the introduction, one of the levels of understanding the HVAC systems by the architecture students is recognizing the impact of the system components on architecture. The author - as the course instructor - demonstrates this impact using all three tools mentioned above. Discussions during the lectures supported by many photos help reveal that impact. This is particularly the case when a coordination error affects the architecture design as shown in the example in Figure 1 where a duct is going through a stair well. Field trips reveal the size and location of the different equipment and their relations to architectural spaces and their potential impact on architectural zoning and spaces clear heights. Coordination examples are also shown and discussed as they pop up during the trip.

However, the above tools always relate to design decisions that are already done by others. It is critical that the student goes through the process of making these design decisions and determines the interrelationship between the HVAC components and the architectural elements of a building.

To achieve that, the learning process goes through two stages. The first stage is a demonstration by the instructor where he goes through the logic of deciding on the HVAC system components and their relation to the architectural elements in a small residential project. A desktop visualizer that is connected to a data projector is used to show the instructor sketching the different HVAC elements step-by-step in the class and in front of the students while discussing the rationale for locating each HVAC element. He also discusses the impact on architecture as these components are located.

The second stage is for the students to do the same for a different building, so they can make their own decisions. The success of the second stage certainly depends on the quality of the explanation at the first stage.

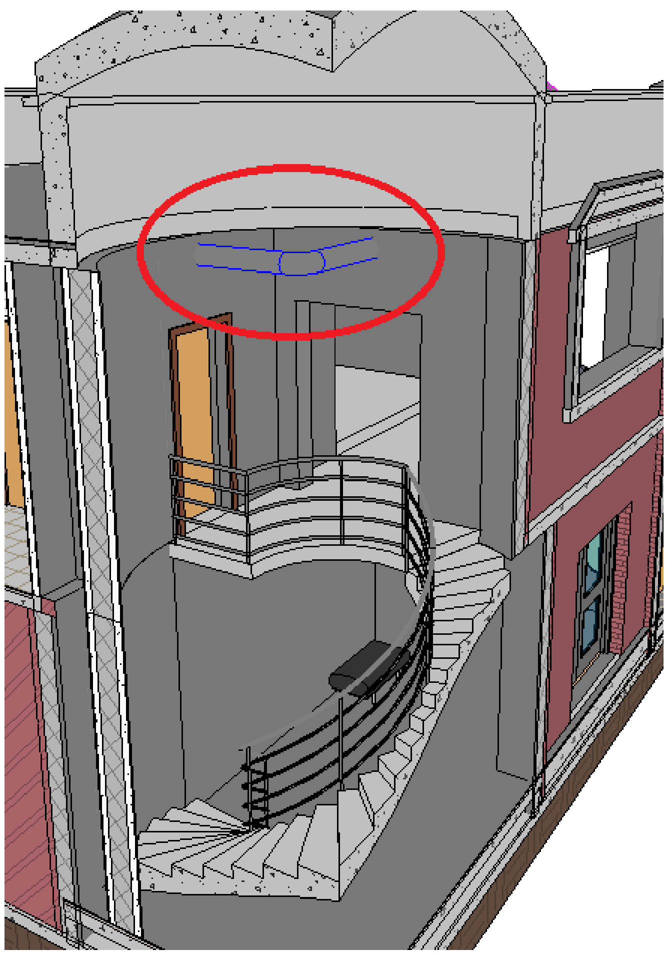


Figure 1. An example of a system decision that negatively impacts an architectural space.

CHALLENGES OF THE 2D APPROACH

After going through the above two stages, the instructor runs a quiz to test the students' ability to make the relevant design decisions. The results of the quiz typically show the following challenges:

- The relationship between the HVAC components and the elements that go through several floors (e.g. Stairs). Several students pass ducts that will cut these stairs or violate the needed clear head of a stair.
- The relationship between the suspended ceilings and the ducts. Several students pass ducts that are unintended to be visible in the living rooms or the bedrooms, which can impact the clear height of these spaces if suspended ceilings are used to cover these ducts.
- The relationship between the vertical ducts connecting the HVAC machines on the roof with the horizontal ducts in the plenum of the lower floor. Many students pass these vertical ducts in the middle of the living spaces of the above floor.
- The relationship between the return duct that goes to the roof, the plenum as the space used for return air, and the walls that cut that plenum. Many students do not provide a continuous path for the return air to return back to the cooling equipment on the roof.

It is easy to see that these challenges relate mainly to the students' inability to visualize the interrelationship between the HVAC components and the architectural elements. Therefore, it makes sense to use the 3D capability of BIM tools to overcome these challenges and provide a richer pedagogical environment.

THE EXPERIMENT OF USING BIM

It is indeed possible to use regular 3D software to acquire the needed visualization that helps achieve the needed pedagogical objective. However, using a BIM tool makes it much easier to digitally construct both of the architectural elements and the HVAC system elements and to show the interrelationship among these elements.

Nevertheless, using a BIM tool has its own set of challenges. These include:

- The non-familiarity of many students with the tool. Indeed, in the case of the author's school, most students never used a BIM tool before they took the ECS course. Even those who are familiar with the architectural BIM tool are not familiar with the use of a related HVAC BIM tool. Therefore, asking the students to experiment with the BIM tool does not seem to be a viable option. The literature review also revealed the same issue for most who use BIM tools in different courses.
- The limited time available in a lecture. Hence, any demonstration using a BIM tool needs to be very efficient in using the class time.

Therefore, the author - as the course instructor - developed a customized Revit file to overcome the above challenges. The purpose is to simplify the interface with Revit and to accelerate its use for the required purpose in class. Such customization is done after several trials and errors to achieve the best possible result. The author would like to share the experience so others may use, build upon, and assess its value for teaching architecture students about integrating HVAC components with architectural elements.

The Customization Process

The author uses Revit as the BIM tool. Hence the shown process depends on the structure of Revit. Nevertheless, the concepts should be very much the same for other BIM tools.

The process to customize and prepare a Revit-based class demonstration as done by the author is as follows:

Prepare a Sample Project:

1. Get or construct a Revit architectural model for a building that has a suitable design. The selected design should provide the instructor with the opportunity to demonstrate some key challenges as discussed above.
2. Simplify the architectural model by removing all the elements that have no impact on the demonstration of the HVAC system.
3. Start a new project using a Revit MEP template. Import the architecture project into this template. This makes all the rules used by Revit to build an HVAC system available in the file. It will not be the case if you continue to use the architecture template.
4. Identify the HVAC elements that you need for the demonstration. These include:
   - The cooling equipment (e.g. Rooftop AC unit, Fan Coil Unit, etc.)
   - Duct type and duct connection style (e.g. Rectangular Duct with Flanged Square Bend / Tee)
   - Air terminals for both supply and return.
5. Load the HVAC elements that you need and remove all extra elements that might be already loaded with the Revit MEP template. This reduces the confusion of selecting the appropriate element during the class demonstration.
6. Make sure that the selected HVAC elements work with one another using the built-in Revit rules.

Identify the key location in the project to support the discussion in class:

7. Identify where you want to show particular interrelationships between the architecture and HVAC system components. Create perspectives at these points as shown in Figure 2 and Figure 3.
8. Make three versions for each perspective. The first shows the normal views (Figure 3). The second shows the HVAC system components such as the duct as shaded elements while the architectural components as translucent elements (Figure 4). The third shows all components as translucent elements (Figure 5). These pre-arranged different configurations perspectives allow quick and clear illustration during class time.
9. Prepare a Revit sheet for each point of discussion. The sheet collects all the views needed to clarify a certain relationship between the HVAC components and the architectural elements. A sheet may include a plan, reflected ceiling plan, section, and several perspectives. Using Revit sheets simplifies class discussion without the need to navigate between different views for the same point of discussion. The instructor can also distribute print outs of these sheets to students.

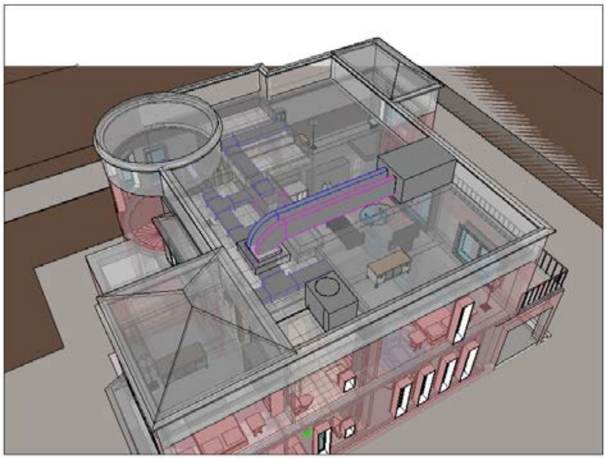


Figure 2. A pre-arranged view to allow seeing the equipment on the roof and its connection to ducts on the upper floor (transparency mode).

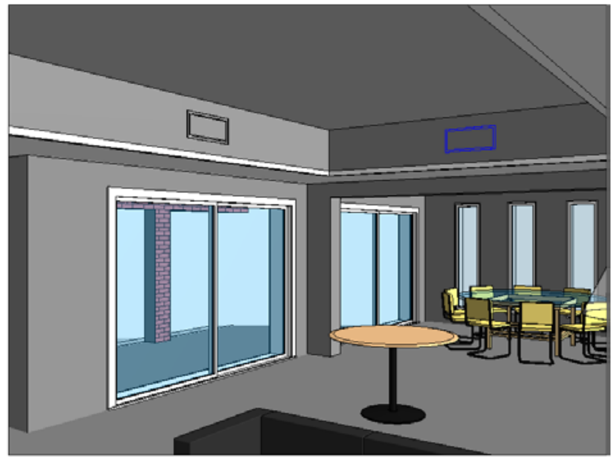


Figure 3. A pre-arranged view to allow seeing the HVAC grilles in the ceiling of the living room (normal mode).

Figure 4. A pre-arranged view to allow seeing the HVAC grilles in the ceiling of the living room (shaded HVAC elements mode).

Figure 5. A pre-arranged view to allow seeing the HVAC grilles in the ceiling of the living room (transparency mode).

Deployment of the Experiment

During class, the instructor explains the purpose of the demonstration and clarifies the reason to use a BIM tool. With the prepared file showing the architectural elements, the instructor explains the process of thinking about installing the different HVAC system components. He also discusses the rational and the concerns for making various decisions.

As the instructor models the different HVAC components in the different parts of the building, the perspectives as well as the sheets are used to illustrate the results of each design decision and its implication on the architecture of the building. The consequences of wrong decisions are easily exposed in the 3D views. Other solutions are easily explained and modeled.

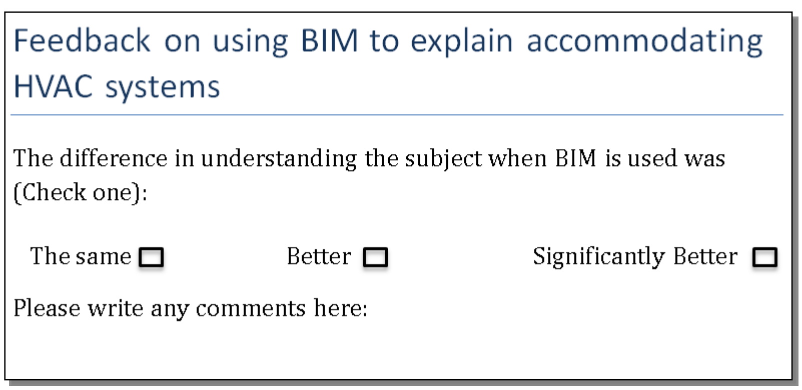
Finally, the instructor makes selected virtual reality renderings (called stereo panorama rendering) using the cloud service of Autodesk. Students can download and see these renderings on their mobile phones at their convenience. This helps them understand the role of the different HVAC components and explore further the relationship between these components and the architectural elements.

Students Feedback

To test the impact of using BIM on the students' learning of the subject, it would be ideal if the students are divided into two groups. One group is exposed to the traditional 2D explanation only and the other group is exposed to the BIM explanation only. Then the instructor compares the performance of each group in the second stage of the process when the students make their own design decisions for another project.

However, this was not possible due to the time limitation and because it would have disadvantaged one group of students over the other. Therefore, another approach is used. The instructor completed the 2D exercise as explained above and in another day did the same exercise using BIM. He then surveyed the students and asked for their feedback using the form shown in Figure 6. As shown, the survey asked one question with three possible answers.

The survey was done twice in two different semesters. During the first semester, 41 students were in the class and in the second semester there were 26 students. Both the Revit customized template and the instructor's experience were better in the second semester. Figure 7 shows the percentages of the students' replies to the question on the provided form. The figure illustrates that more than 90% of the students believe that using BIM made them understand the subject "Better" or "Significantly Better". Percentage wise, more students in the second semester believed that using BIM was significantly better in understanding the subject.


Feedback on using BIM to explain accommodating HVAC systems

The difference in understanding the subject when BIM is used was (Check one):

The same ☐ Better ☐ Significantly Better ☐

Please write any comments here:

Figure 6. The form used to survey the students and get their feedback.

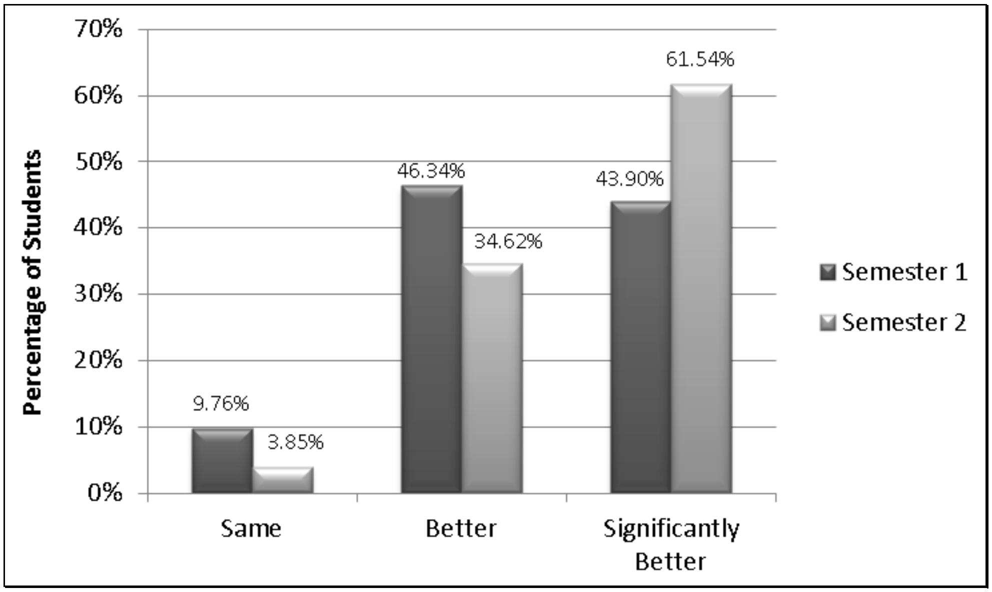


Figure 7. Shows the percentage of students and their assessment for the use of BIM approach to explain the subject relative to the 2D approach.

The students also made comments that are generally positive. The comments can be grouped in the following:

- It was helpful to see all the system components in 3D instead of only imagining them, which is much clearer.
- We need to know BIM.
- Using the two approaches together is also useful.

SUMMARY AND CONCLUSION

This paper presents an experiment to use a BIM tool to explain the interrelationships between HVAC system components and architecture elements to architecture students. This is part of the standard course in the architectural curricula on Environmental Control Systems. The purpose is to share the experience so other instructors of such a standard course can evaluate it and build on it. The paper explains both the rational-for and the challenges-of using BIM for this purpose. It also addresses how to overcome these challenges. The result of the experiment shows that a very high percentage of the architecture students involved understood the subject through the BIM tool better than through the traditional 2D drawings. Despite the challenges of using the BIM technology in class, the pedagogical value seems to be worth the investment needed to prepare a suitable BIM environment that fits the pedagogical purpose.

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