ecoCampus: A NEW APPROACH TO SUSTAINABLE DESIGN EDUCATION

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ABSTRACT: *Civil and architectural engineering education programs strive to prepare students to design built environments that will be used by society. Some of these built systems can be challenging for laypeople to visualize while learning the design process. This research focuses on improving the way that students visualize and engage with building design content through the creation of a novel educational tool for designing sustainable building elements. The tool prototype, called ecoCampus, is an educational game that uses augmented reality technology on a mobile computing platform. It allows users to visualize a possible building retrofit design in the context of an existing built space and also receive tailored feedback about their design. The prototype application was tested with 47 first-year architectural engineering students to better understand the benefit of this tool. The results of this implementation were analyzed and compared to the results of prior semesters' students who were tasked with completing a similar retrofit design activity without the use of ecoCampus or a mobile computing device. This comparison suggests that students who completed the ecoCampus activity were more likely to complete multiple design iterations as well as experiment with materials other than those present in the existing wall, suggesting that ecoCampus may help to break the tendency toward design fixation. Additionally, students generally rated the experience as highly enjoyable, suggesting engagement with this teaching tool. Future work will implement the ecoCampus experience with students in several building-related majors to identify possible additional benefits that can be observed.*

KEYWORDS: *ecoCampus, Simulation Game, Augmented Reality, Engineering Education, Situated Learning Theory*

1. INTRODUCTION

Educators strive to prepare students to solve challenging design problems with creativity and sound reasoning. In the context of the built environment, the engineering process requires an ability of an engineer to visualize a possible building design as well as to assess the implications of the given design to understand how the building will perform and also how it will interface with its physical surroundings. This ability to visualize building geometry and analyze a design's performance can be challenging for new engineering students to perform (Dede et al. 1999). It requires a background in the fundamental engineering principles necessary for accurate assessment of performance as well as a developed ability to envision how a particular building design might look in a given setting. Despite the potential challenges associated with completing engineering design processes for new engineering students, the expectations for what the future cohort of engineers is expected to comprehend continues to grow (National Academy of Engineering 2004). This research aims to leverage emerging computing technologies to reduce or eliminate some of the visualization and analytical understanding barriers that can inhibit newer engineering students' abilities to effectively solve design challenges. This can allow students to take a learn-through-doing approach, which has been suggested to offer educational benefit in gaining knowledge that will eventually be applied to a given task as in building design (Lave & Wenger 1991). This may also offer the potential for students to gain an understanding of concepts that they might not otherwise learn until later in their academic careers because of the challenges with presenting this content early in the academic process.

Visualization plays a critical role in the engineering problem solving process, but it is not frequently stressed in education (Finke 1990; Finke et al. 1996). New technologies may be able to offer some help to students to allow them to more easily visualize building designs. This work specifically examines the benefits of augmented reality (AR) for helping students to visualize building designs in the context of an existing physical space. In addition to helping students visualize building design content, a basic simulation game has also been incorporated into the experience to provide instantaneous feedback to students to help them analyze design ideas.

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Mixed reality involves the merging of the physical and virtual worlds (Milgram & Kishino 1994). As a subset of mixed reality, augmented reality allows a user to experience a predominantly real view of a physical space with certain virtual information overlaid on top of his or her view of the space. In the building context, AR technology can allow a designer to view full scale virtual representations of building design content in the context of an existing space or project site. This may help to reduce some of the challenges and errors that can be present when new engineering students attempt to create mental models to envision complex building geometry.

In addition to the potential for AR to improve visualization, simulation games may be able to offer benefit in helping with design analysis. Simulations are models that attempt to approximate a situation, environment, or set of events to predict, teach, or entertain (Prensky 2004). Games, on the other hand, are defined as: having rules; having variable and quantifiable outcomes; having value assigned to possible outcomes; requiring player effort; requiring a player to become attached to the outcome; and having negotiable consequences (Juul 2003). Simulation games are, therefore, defined as contests where users move toward specific goals under sets of conditions and constraints that will sufficiently model a real world situation (Gredler 1994; Jacobs & Dempsey 1993). Properly used simulation games may be able to help engage students with course content and let students experiment with different design options, while providing feedback to help students analyze the pros and cons of each design idea.

This research examines the potential of using these technologies in tandem to improve certain aspects of the design process for new engineering students. To understand the benefits and challenges of these technologies, an educational game called ecoCampus was developed. ecoCampus uses AR technology in a simulation game to test students' abilities to redesign a building element in an existing building to attempt to make it perform even more sustainably. The topic of sustainability was targeted as a core design goal for this activity because of the prevalence of sustainability in the building industry (Bernstein 2010) as well as the wide variety of building design challenges that relate, in some way, to a building's overall sustainable performance. Eventually, ecoCampus is envisioned to offer several different design modules that will test students' abilities to design a variety of different building elements for existing areas on a given campus, which will broaden the possible impact of the ecoCampus design experience. By focusing on sustainability for all design modules, students will not only be able to design a variety of individual building systems, but also see how the decisions made for one system may affect others with regard to sustainability. For this initial prototype, one focused design module has been created. The findings from this first implementation will help to shape the development of future design modules.

2. METHODOLOGY

This research presents an application, called ecoCampus, which has been developed to enhance sustainable building design education through the use of augmented reality in conjunction with a simulation game. ecoCampus was designed to help students: Brainstorm different "what if" design scenarios to determine what they believe to be the best possible design solution to the given design challenge; Visualize virtual full-scale prototypes of their design ideas through augmented reality; Receive tailored feedback through a basic simulation game to shape subsequent design iteration thought processes; And, ultimately, learn sustainable design concepts through these actions.

First-year engineering students were tasked with redesigning a particular building component in an existing facility to attempt to make it perform more sustainably. While students were primarily challenged to create a sustainable design, they were also challenged to consider other design concerns such as aesthetics, cost, and constructability. For this work, students were asked to redesign a component on an existing building on campus. Because of the variety of impacts that an exterior wall design can have on sustainable building performance, students were tasked with redesigning the exterior wall on the LEED rated Stuckeman Family Building on campus. Prior to the design activity, the first-year engineering students had been presented with a basic overview of the LEED rating system in class as well as an out of class tour of the Stuckeman Building that discussed applied sustainable design and construction strategies. During the ecoCampus design activity, students would not only be required to tap into their existing knowledge of sustainable concepts from class and the building tour, but also to gather pertinent information from the simulation feedback provided in ecoCampus.

To assess the outcomes of the ecoCampus design activity, students were given pre- and post-tests before and after completing the activity to identify areas where their thought processes or understanding of sustainability may have been influenced by the format of this design activity. These pre- and post-activity assessments were designed to elicit feedback about students' understanding of sustainability and their impression of the design activity, as well as basic demographic information about the students. The assessments included multiple choice and Likert-scale questions as well as open ended questions for students to complete, which helped to generate qualitative and quantitative data for evaluation. As a point of comparison, this design activity had been completed by first-year engineering students in prior semesters using more traditional, paper-based, methods of design instead of the computerized ecoCampus format. These prior implementations had been completed by 65 students with only blank sheets of paper with no suggestions on how to perform a sustainable redesign (Ayer et al. 2013b) and another 23 students with printed images of the existing space on which to illustrate design ideas with suggestions of possible building materials to consider in their designs (Ayer et al. 2013b). In both of these prior efforts, the design goal of creating a new exterior wall, the time involved to complete the task, and the self-directed nature of the activity remained constant. Only the format of the activity was changed. These prior works help to isolate the variable of the augmented reality and simulation game technologies on a mobile computing platform from the act of completing a specific building redesign problem. Other than the differences in the format of the activities, all students who completed any design activity completed the same class activities. Fig. 1 shows the process that the students followed. The only change between the different formats would be what form of the activity was completed where "ecoCampus design activity" is currently listed. After the students completed the activities associated with this work, the responses to the pre- and post-test assessments, in addition to the data that was collected during the design activity, were analyzed to determine the aspects that may have been affected by the ecoCampus design experience.

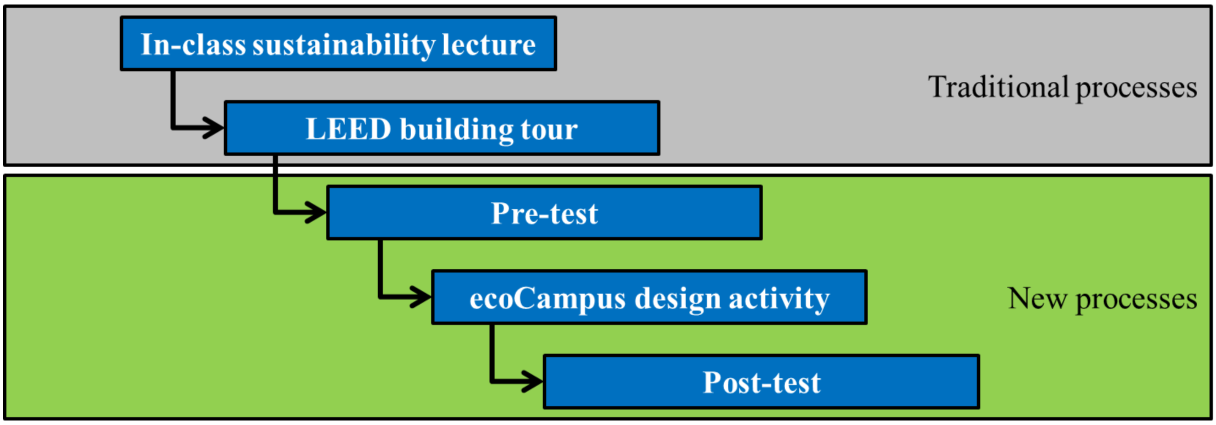

Fig. 1: Students completed several activities related to sustainability during research.

2.1 Design Activity

Students were given a 50-minute class session to complete the sustainable design activity. Students were physically present in the Stuckeman Family Building space shown in Fig. 2. This building has a predominant

Fig. 2: The Stuckeman Family Building's curtain wall can be seen with the rectangular "ae" fiducial marker.

exterior curtain wall with typical bays on the 4th floor of the building for most of the architecture students' studio space. Students were asked to redesign the typical curtain wall bay where the rectangular "ae" sign visible. This printed sign served as a fiducial marker for ecoCampus to allow students to view their design at full scale in the context of the existing space. At the beginning of the design session, students were given a brief, five minute overview of the ecoCampus workflow so they would understand how to use the application. After this overview, students were each given a mobile computing device on which to work for the class session. Students were given approximately 40 minutes to complete the design activity with ecoCampus. They were told that they must complete a minimum of one design idea, but were free to create more as time would permit. As they would complete different designs using ecoCampus, they would take screen captures on the provided iPad so that they could later reexamine their work to recall what they had done in a given design iteration and what they had learned. In the last five to ten minutes of class, students were asked to stop their design work and reflect on their ecoCampus designs. They were asked to review each design iteration along with the feedback generated and indicate whether or not they agreed with the provided feedback.

2.2 ecoCampus Workflow

The ecoCampus experience consists of three steps that students followed during design. Users would first create a design idea in the ecoCampus design interface. Fig. 3 shows the design interface with an example curtain wall bay design already created. The right side of the screen included a variety of possible building materials that students could select in their wall design. After a user would touch a particular material, it would become active and they could touch predefined, blank squares on the curtain wall template. After they touched a blank square, it would be assigned the active material and rendered accordingly. As students experimented with designs, they could select alternate materials and override the materials selected in prior design iterations with the new desired materials.


Material being used: Triple-paned fixed glass window

Experimental ID number: 548

Fig. 3: The ecoCampus design interface allows for touch-based design of possible building components.

After a student was satisfied with his or her design, he or she could view the model in the context of the existing space. When a user selected “View Model”, the screen would change from the ecoCampus design interface to a live camera view of the physical building space. A user would then hold the computing device so the camera would point toward the printed fiducial marker placed on the existing wall and a virtual representation of their design would be displayed over top of the existing wall at full scale. Fig. 4 shows the design from Fig. 3 overlaid on top of the existing wall. In this AR mode, a user could physically navigate around the space and the virtual wall would reorient its position in real-time to provide the illusion that it was already constructed. The only constraint related to a user’s physical position was that the printed fiducial marker would need to remain entirely in view at all times for scaling and orienting the virtual content. If the marker would go out of view, the model content would disappear until the marker came back into view.

Fig. 4: ecoCampus users can view full-scale, virtual mockups of their designs with AR.

After a user visualized his or her virtual design in the AR interface, he or she could proceed to the summary interface to receive tailored performance feedback about the design from ecoCampus. Feedback is generated about the upfront cost of a design on the whole as well as the cost for each individual building material that was selected for the design. The R-value of the building assembly is also provided to the user for a given design. Lastly, users receive design critiques from 3 virtual project participants. The first virtual project participant was a building owner concerned with initial project cost. This critic would generate comments about a design based on the total calculated upfront cost of the design. Based on different threshold values, the owner’s comments would range from greatly satisfied to greatly dissatisfied. The second project critic was a lighting engineer concerned with the amount of daylight that would be allowed to enter the built space with a given exterior wall design. This critic’s comments would be generated based on threshold values for the exterior wall design’s window to wall ratio. If little or no glass would be used in a design, the lighting engineer would be strongly dissatisfied. As students would incorporate additional glazing into their design, the lighting engineer would become more satisfied in their comments. After a certain window to wall ratio threshold was reached, the marginal benefit from additional glass diminished and the lighting engineer’s comments would begin to decline. The third virtual critic was a mechanical engineer who was concerned with lifecycle cost of heating and cooling a space with a particular design based on the R-value of a particular design concept. This critic’s comments would range from highly satisfied to highly dissatisfied based on where the design’s calculated R-value fell in a range of threshold values.

After examining the generated feedback about a particular design, students were able to view a numerical score for their design. The score they received was based on cost, R-value, and the positive or negative comments received from the three project critics. The lower the initial cost, the higher the calculated R-value, and the more positive the comments received by the virtual critics, the higher their final score would be. This numerical scoring mechanism was developed to help students recognize the importance of weighing different project participants' desires in quantifying design performance and also for quickly comparing different design iterations. Fig. 5 shows the ecoCampus simulation game interface with all of the performance values and design critiques.

Materials Used

Therm Copper: 165.960 sq ft
Cost of Therm Copper: $5252.63

Double Operable Glass: 30.500 sq ft
Cost of Double Operable Glass: $3355.00

Triple Fixed Glass: 213.500 sq ft
Cost of Triple Fixed Glass: $32025.00

R-value = 8.375 Degrees-F ft2 hr / Btu

Total Cost of Construction Per Bay: $40632.63

Total Renovation Cost: $1279828.87

Owner Comment: Hmm...This design is more than we planned to spend. I'll have to check to see if we have enough capital to cover this design.

Lighting Engineer Comment: This design will let in a lot of light. We can probably reduce our intended number of interior light fixtures

Mechanical Engineer Comment: This design should perform fairly well. It will not cost too much to heat and cool the building with this design.

Final Score: 11223

Experimental ID number: 548

Fig. 5: The simulation game in ecoCampus allows for tailored feedback to be generated for a user based on a specific design's performance characteristics.

2.3 ecoCampus Technical Specifications

ecoCampus was developed on a mobile computing platform to allow users to design building components in a simple drawing interface, view and physically explore a full-scale virtual prototype in the context of the existing building, and receive tailored feedback about their designs. The Apple iPad (3rd generation) was selected as the mobile computer interface to use for this initial version of ecoCampus because of the built in cameras and the simple touch screen interface on iOS devices. Unity game engine was strategically chosen for development of the ecoCampus graphical user interface (GUI) because it allows for the application to be exported to both iOS and Android platforms as well as other console game system formats. From a development perspective, this provided freedom for future versions to be easily adapted to include additional content for a variety of mobile computing and smartphone platforms. In addition to the exporting benefits that Unity offered for development, there are also several external parties who develop plug-ins for Unity. For this work, String provided an easy method for creating custom fiducial markers with pre-defined scripts to allow Unity cameras to track the custom markers. This allowed for real-time physical navigation of a space to see augmented content. The simulation game component of ecoCampus was developed within Unity using construction cost data and typical R-values for different building materials to automate performance feedback for ecoCampus users.

3. RESULTS

During this ecoCampus implementation, 47 students participated in the study. Of these 47 students, 30 were male and 17 were female. All but one of the participants was a college freshman. Students were also surveyed to find out their intended majors. In this semester, 67% of the students indicated that they were interested in pursuing architectural engineering as their major. After analyzing the submitted files from all of the students, several interesting findings were observed.

The screen captured images of the students' designs were examined to identify how many design iterations students explored during the activity. For each student who used ecoCampus, the number of different design iterations that they completed was documented. It was found that students completed between 5 and 19 different design iterations with a mean of 9.3 design iterations during the class session. The number of design iterations created by the students who used ecoCampus was compared to the number of iterations created by students who completed the activity with the purely open-ended version where they were only supplied with blank sheets of paper (Ayer et al. 2013b) and also the image-based version where students were supplied with images of the existing building and a basic materials list to help them illustrate their designs (Ayer et al. 2013a). The number of iterations with ecoCampus was significantly higher than both prior activity formats (p<0.001). Fig. 6 shows the percentage of students in each treatment that explored a given number of design iterations in the same time period.

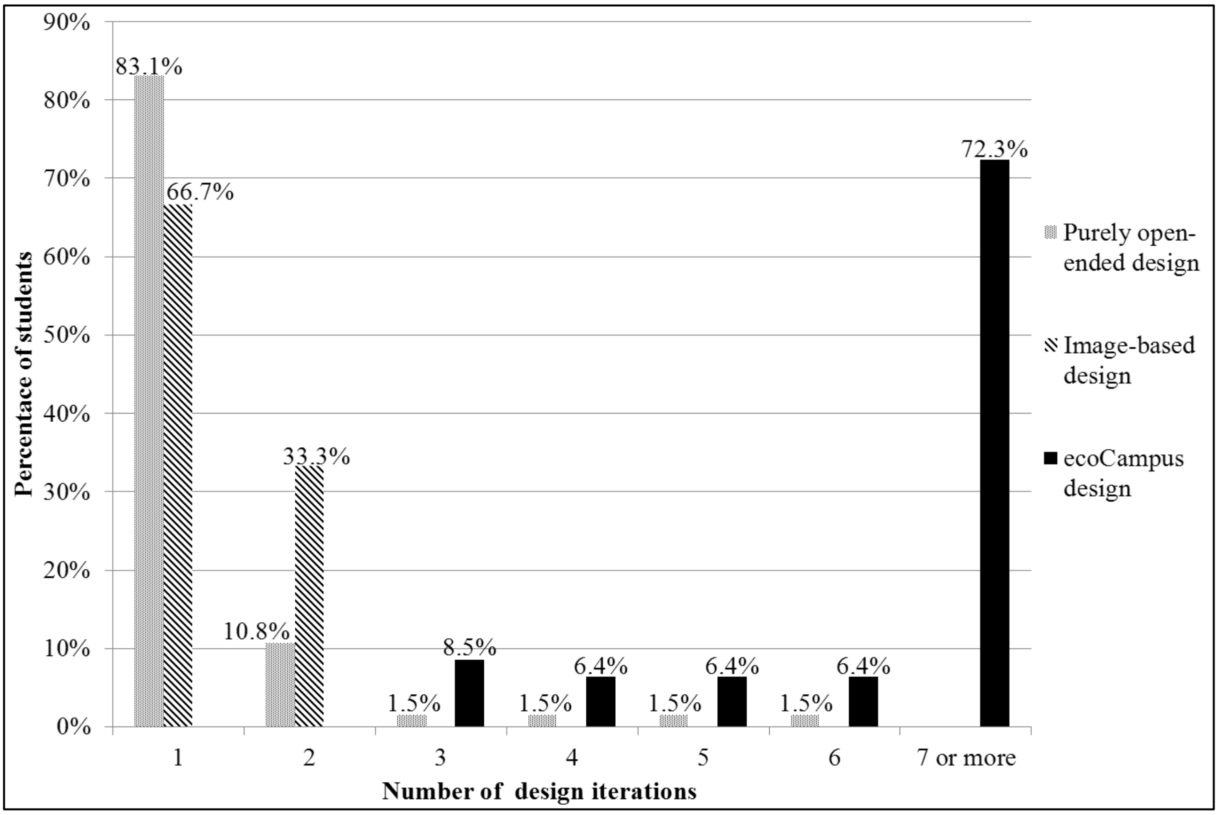

Fig. 6: Graph showing the number of design iterations for each of the experimental treatments.

In addition to examining the number of design iterations that were explored by students during this design activity, it was also of interest to examine how many different building materials students considered during their design process. It was noted in prior implementations that students generally did not deviate from the existing building design with regard to material selection and geometric layout when attempting to create their more sustainable design idea (Ayer et al. 2013b). On average, students who used ecoCampus used 9.2 different materials throughout their design creation process, which is substantially more than the 3 main materials currently used on the existing section of curtain wall. This was also significantly more than the number of materials that students used in prior semesters with paper-based formats (p<0.001). The numbers of materials that students experimented with in their design processes from the different activity formats can be seen in Fig. 7.

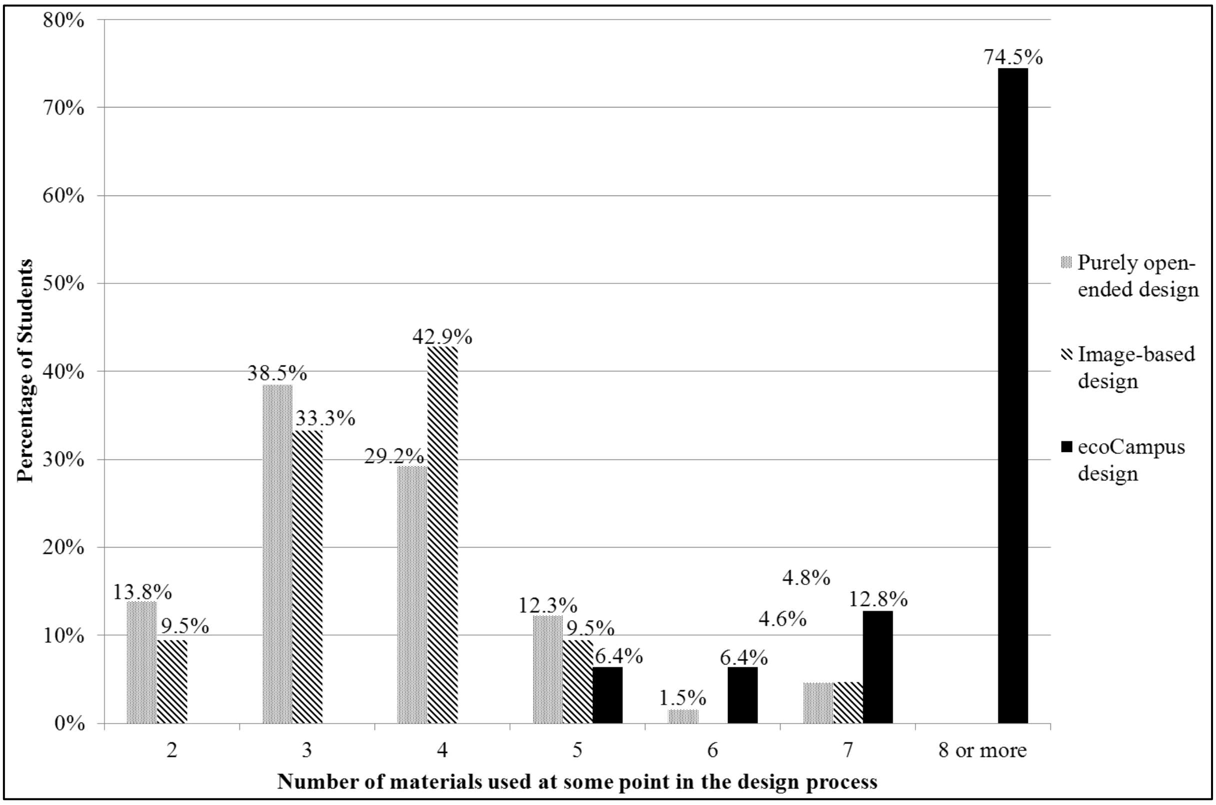

Fig. 7: Graph showing the percentage of students who experimented with certain number of materials throughout the design process.

In addition to analyzing the designs that were submitted, the responses to pre- and post-test questions from this work were examined to understand the learning and perception that the activity made on the students. Students generally felt that the format of ecoCampus was effective, with only 6.4% of students reporting it as either "not very effective" or "not effective at all." Students generally also found the activity to be interesting. For example, 63% of the students felt that it specifically increased their interest in sustainability and 70% indicated that it made them more interested in the building design process.

After completing this initial study some unintended learning outcomes were also observed. For example, as students were designing in ecoCampus, they frequently tried to achieve the highest score possible. While this might initially sound like a good approach, in this initial ecoCampus version, the only factors that affected the score were initial cost, daylight usage, and thermal efficiency. While these are certainly important considerations when designing an exterior wall for this project, it excluded other important design considerations, such as constructability and aesthetics of the design. In striving to achieve the highest score possible, students could overlook impacts from aesthetics or constructability. This is not to say that every student overlooked these other design considerations. One student mentioned, "I liked the activity. It was challenging using good insulating materials and keeping the interior aesthetically pleasing at the same time." This may be an area where further development will help to encourage all users to consider other design considerations while developing their wall concepts.

4. CONCLUSIONS AND FUTURE WORK

This work has examined the educational benefits of using augmented reality in conjunction with a simulation game to educate students about sustainable design practices in the built environment. In this paper, ecoCampus has been presented as a new application that allows students to experiment with several "what if" scenarios, visualize full-scale virtual mock-ups of their design, and receive tailored feedback about their design ideas. To test ecoCampus, students were given a hypothetical design scenario where they were asked to redesign an exterior wall on an existing LEED rated building to attempt to make it perform even more sustainably. After analyzing the submitted design files, several noteworthy findings were observed.

Students completed this activity through the creation of several different designs. Students who used ecoCampus to create their sustainable building created between 5 and 19 different design ideas over the course of the 40-minute design period, which is significantly more than prior semesters where students were not provided with the ecoCampus platform in which to design. This suggests that this type of mobile game environment can serve as a catalyst to encourage students to brainstorm different design possibilities without the need to explicitly instruct students to complete a given number of alternate design ideas. This may be beneficial because students frequently fixate on a particular idea, which can limit their ability to consider other, possibly better design ideas (Jansson & Smith 1991; Linsey et al. 2010).

The students who used ecoCampus also considered more possible building materials in their design process as compared to prior semesters' students where the application was not used. This could be due in part to the fact that some first-year students are not yet aware of possible different building materials that could be used in a design. The provided options eliminate the need for students to identify possible choices on their own. While this finding may not necessarily suggest that students are more *willing* to experiment with different building materials with ecoCampus, it does suggest that they are more *able* to experiment with different materials. For future educational game development, this may be especially beneficial for design modules where laypeople cannot realistically be expected to know all possible design options that might be relevant to a given design challenge.

This research has identified benefits that were observed through the use of ecoCampus with in a first-year architectural engineering class. Future work will also explore possible benefits that can be obtained by introducing this learning tool to students in other, building-related disciplines, including Architecture and Civil Engineering. Additionally, the ecoCampus prototype will be further developed to include more virtual design critics to the simulation game interface to encourage every student to consider even more design considerations in their process. This will likely make the application more challenging, but also more realistic in complexity. Finally, it will be of interest to test the students who used ecoCampus later in their academic careers to see if the brainstorming behaviors they displayed in ecoCampus are translated to other courses and design projects as well or if, without the use of ecoCampus, students are prone to design fixation. This future study could examine students' design processes in other courses and compare the number of ideas generated between those who had completed the ecoCampus design activity and those who had not.

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