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UNDERSTANDING THE IMPLICATIONS OF AUGMENTED REALITY OUT OF CONTEXT IN ENGINEERING EDUCATION

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Abstract: Educating building design and construction students about sustainability is critical to the development of a future workforce that is capable of making a positive impact on future sustainable buildings. Prior research has leveraged emerging computing technologies to remove some of the educational hurdles that are common among new engineering students, related to visualization and design assessment. In this prior work, an augmented reality (AR) based simulation game, called *ecoCampus*, was developed to allow students to design an exterior wall for an existing building on their campus to improve sustainable performance. After users created designs in *ecoCampus*, they were able to view a virtual mock-up of their design at full-scale with AR and then assess the performance of that concept using the basic simulation game interface. Using this technological approach to design, students were able to resist the tendency toward design fixation as compared to students who were not provided with the computerized *ecoCampus* interface. This paper further explores the AR component of *ecoCampus* to understand how students' learning is affected when the design activity is completed out of the context of the physical building. In this work, students who used *ecoCampus* to design a new exterior wall concept for an existing building did so in a lab space where they were not able to physically explore the existing building for which they were designing the concept. Instead, they could only view the existing building through a single photograph that was projected on a screen. Students completed the same assessments as prior student cohorts and were allotted the same amount of time. After analyzing the collected data it was observed that, while students still employed beneficial design behaviours as compared to prior cohorts using paper-based design strategies, the process that they employed to arrive at their final design concept included fewer considerations of different design alternatives than students who used *ecoCampus* in the existing building. This suggests that there may be additional value in using AR in the physical context of a space for building design and assessment learning tasks, especially when design creativity is advantageous.

1 INTRODUCTION

There has been a growing concern for the environmental impact of buildings, and subsequently, a shift in recent years to embrace more sustainable design and construction strategies. As the Architecture, Engineering, and Construction (AEC) Industry continues to adopt more aggressive sustainability standards, it becomes increasingly important for students pursuing AEC careers to understand the sustainability performance implications of the buildings they design and build. This paper extends prior research that explored how mobile computing technology can help to remove traditional barriers to sustainable building design education to allow newer students in AEC disciplines to develop, visualize, and assess the sustainable performance of different design concepts.

A prototype mobile computer application, called *ecoCampus*, was developed in prior work to challenge users to design a new exterior wall for an existing building in an attempt to make it perform more sustainably (Ayer et al. 2014a). Through an augmented reality (AR) based simulation game interface, *ecoCampus* allows users to: design an exterior wall concept; visualize their designs using augmented reality; and assess the performance of the designs with a basic simulation game interface. *ecoCampus* was implemented with students at The Pennsylvania State University enrolled in courses in Architecture, Civil Engineering, and Architectural Engineering. The prior work compared the behaviour and perceptions of students who completed the same sustainable design challenge using either *ecoCampus* or one of two paper-based versions of the design activity. One of the paper-based design activities included a purely open-ended design activity, where students were only supplied with blank sheets of paper on which to illustrate their design concepts (Ayer et al. 2014b). The other paper-based design activity included printed images of the existing building's exterior wall on which students would illustrate their design concepts to help provide them with a sense of scale and limitations on design requirements (Ayer et al. 2013a). From these prior implementations of different sustainable design activities, several beneficial learning behaviours were observed related to the students' design process when using *ecoCampus* (Ayer et al. 2013b).

One of the research questions that these prior implementations did not explore was related to the extent to which the augmented reality (AR) component of *ecoCampus* affected student behaviour. In prior implementations, students who completed the design activity, regardless of format, were physically located inside the existing building for which they were designing a new wall for improving sustainable performance. This placement of students in the actual, physical building for which they were designing was hypothesized to allow the AR component of *ecoCampus* to add value by letting students visualize their design concepts at full-scale and in the context of the physical space. This paper explores this hypothesis by implementing the same design activity out of the context of the physical building. Instead, students involved in this work used *ecoCampus* in a laboratory setting, which required them to visualize their design concepts from a projected still image of the physical building. This effectively eliminated their ability to view a full-scale mock-up of their design concept through AR and also eliminated their ability to physically explore the existing building to gather information that could influence their design. By removing this component of physical location in the targeted building, this implementation served to provide an understanding of the benefits and drawbacks of using AR out of the context of a physical space.

2 BACKGROUND

Situated learning theorists suggest that the best way to educate students about content that will eventually be applied to a particular context is to learn that content in its corresponding context (Lave and Wenger 1991). This can be especially relevant for students in engineering disciplines because of the problem-based nature of their work that requires them to apply mathematics and physics concepts to an engineering context to create viable solutions (Johri and Olds 2011). For new students learning about sustainable building design and construction, situated learning theory would suggest that the best way for students to learn these concepts is in the context of a design or construction scenario. This can be a challenging scenario to create for newer students because many new students have had little, if any, design experience in the early stages of their academic career. This challenge of creating a design scenario for new students is complicated further because the traditional means for communicating design and construction information relies on the use of 2D drawings. These can be challenging for students to understand and the mental models they create from their understanding of the drawings can be prone to errors (Johnson 1997).

The potential challenge with presenting this learning content in the context in which it will eventually be applied offers some synergies with AR visualization technology, which presents virtual content in its physical context. AR is a subset of the broader “mixed reality” which involves the merging of real and virtual components along a continuum ranging from completely virtual (computer models) to completely real (what can be seen by unaided eyes) (Milgram and Kishino 1994). AR allows users to see a predominantly real world view of a space with some virtual content superimposed to “augment" their view, similar to the yellow “first-down” line on televised American football games (Azuma 1997). This superimposition of content allows AR to present virtual content in the context of a physical space. In a building design context, AR allows hypothetical or planned design models to be visualized on top of an existing building or construction site, which allows users to visually compare planned versus existing building content.

In addition to the visualization capabilities that can be afforded through AR, simulation game technology further facilitates learning by situating students in a learning context where they may experiment in an engaging way (Gee 2005). 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 between individuals that move toward specific goals under sets of conditions and constraints that will sufficiently model a real-world situation (Gredler 1994; Jacobs and Dempsey 1993). Prior work using simulation games applied to construction engineering educational contexts have identified pedagogical benefits enabled through the use of the technology (Nikolic et al. 2010).

In prior work conducted by the authors of this paper, these educational approaches involving AR visualization, simulation games, and situated learning environments were applied through the development and implementation of *ecoCampus* (Ayer et al. 2013b). *ecoCampus* is a mobile computing application (or “app”) that was created to challenge users to create a more sustainable exterior wall design concept for an existing building on Penn State’s campus. The performance and behaviours of the students using *ecoCampus* was compared to other first-year students from prior semesters who completed the same design activity using non-computerized formats (Ayer et al. 2013a, 2014b). In these prior studies, all students completing the exterior wall design challenge, regardless of format, were physically present in the building for which they were designing wall concepts. This consistent educational setting allowed the researchers to vary the format of the design activity between paper-based and computerized activities, which allowed for direct comparison of findings, but also lead to additional research questions. Specifically, it was still not clear from the prior works the extent to which AR’s presentation of virtual content in its physical context affected student behaviour. This paper removes the “physical context” component of AR to specifically focus on this question.

3 METHODOLOGY

The research presented in this paper extends prior work that involved the implementation of *ecoCampus*. For this work, first-year engineering students enrolled in an architectural engineering course were tasked with creating an exterior wall retrofit design concept for an existing building on campus to make the building perform more sustainably. Unlike prior implementations, this implementation of *ecoCampus* tasked students with completing this activity in a lab space that was not in the same location. This eliminated the students’ ability to physically explore the existing building to gather additional information that could potentially affect their design process.

Students completed their design work in the Immersive Construction (ICon) Lab at the Pennsylvania State University, as shown in Figure 1. The ICon Lab features three, large (1.8m by 2.4m) projection screens. During implementation, an image of the building targeted in this design challenge was projected onto the center screen, which is also shown in Figure 1. This image was taken with a fiducial marker hung in the appropriate position on the wall to allow the tablet computer camera to track a user's position and display accurately positioned and scaled AR content. Therefore, in the ICon Lab setting, students could use *ecoCampus*'s AR interface to see their design concepts overlaid onto the projected image of the physical space.

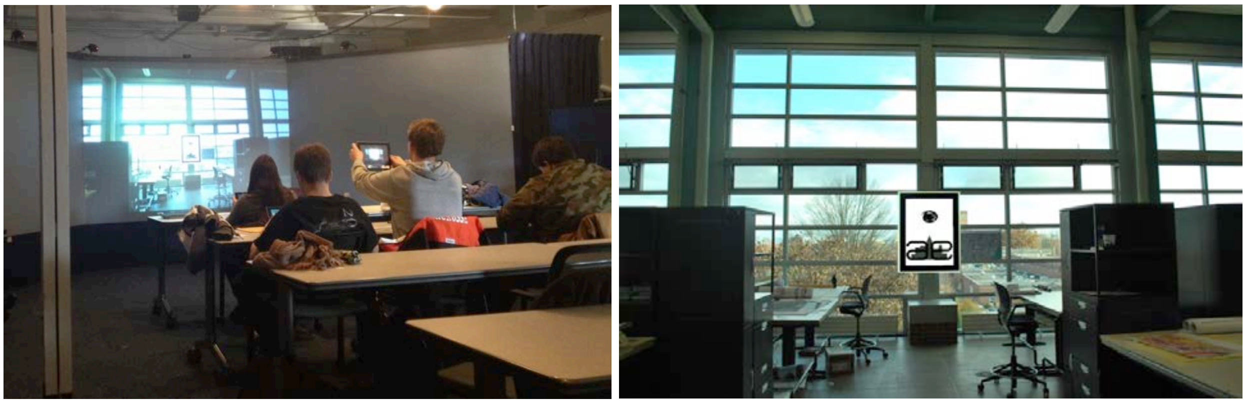

Figure 1: Students used *ecoCampus* in a lab (left)
where an image of the building wall was projected (right).

Other than the modified activity setting, the research steps completed by the students remained consistent with the different prior design activity implementations. Students were able to self-direct their work to determine for themselves how to approach the design challenge. Additionally, students completed the same assessment activities, before and after designing, to generate data that could later be analyzed to assess their performance.

3.1 Pre-tests

Before beginning the design activity, each student completed a pre-test assessment. This pre-test determined baseline knowledge of sustainability and building design concepts for each student. Additionally, the pre-test gathered responses from the students related to their levels of motivation, confidence in their building design abilities, basic demographic information, and familiarity with mobile computers and the technologies incorporated into *ecoCampus*. All responses to pre-tests were made anonymous using experimental identification (ID) numbers, which were not known to the course instructor or researchers, to encourage candid responses from the student participants.

3.2 Design Activity

After completing the pre-tests, students were given tablet computers equipped with *ecoCampus*. They were given a brief, five-minute, introduction to the application, which explained the workflow. The workflow involved three main user interfaces with which a student would interact as shown in Figure 2. These included: a touch-based design interface where students would develop wall design concepts; an AR interface where students would visualize their concepts in the context of the projected image of the physical space; and a basic simulation game interface where they would receive performance data for assessment of their design concept.

After students were introduced to the application, they were asked to input their experimental ID number to link their design work to the other assessments. At each of the main user interfaces, students took screen-captured images of their work to serve as a record of what they designed. These screen-captured images were also submitted as part of their assignment for research analysis as shown in Figure 2.

Students were given approximately 40 minutes to complete the design activity using *ecoCampus*. They were required to complete a minimum of one design concept. As with students who completed other formats of the activity, they were also allowed to create as many additional design iterations as they felt were necessary during the class time.

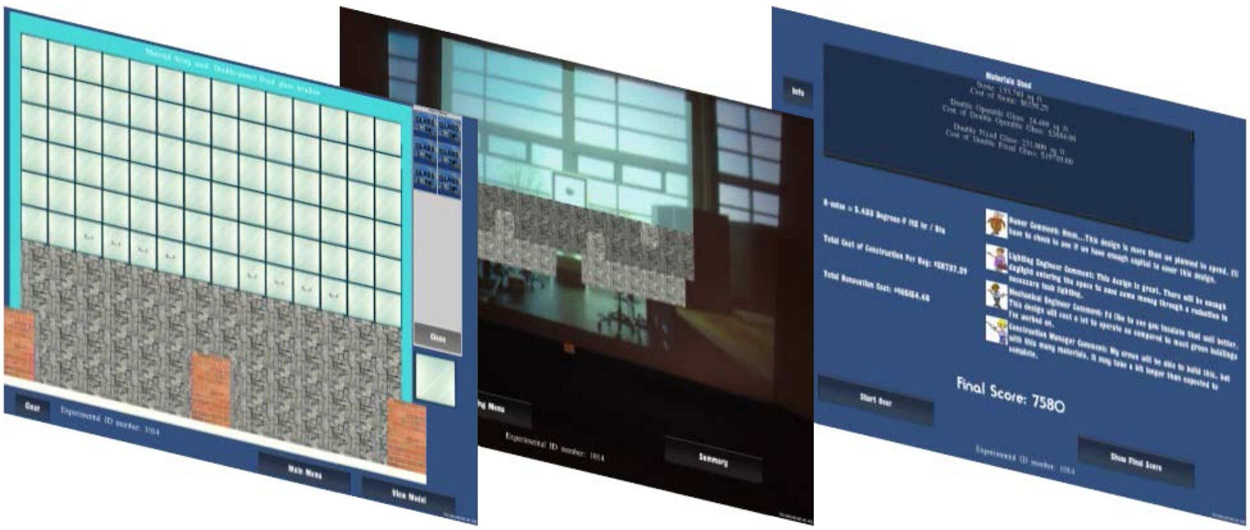

Figure 2: *ecoCampus* screen-captured images taken by student participants.

3.3 Post-tests

After completing the design activity, students were given a post-test assessment where they were asked similar sustainable design understanding questions to the pre-test assessment. Additionally, they were asked questions to elicit responses related to their perception about the activity. These questions sought to understand their perceptions related to the benefits of the activity to their education, the appropriateness of the amount of time allotted to this activity, the level of enjoyment they experienced while completing the activity, and the level of interest generated in building design and sustainability from completing the activity. Using the same approach as the pre-tests, the responses to the post-test were also made anonymous through the use of experimental ID numbers.

3.4 Analysis

After all design activity documentation was received, the documents were reviewed and analyzed. Specific attention was given to the design process that students completed to arrive at their final design. Additionally, students' perceptions about the value of this activity was also examined to understand if completing the *ecoCampus* design activity out of the context of the physical building had any observable differences from the data collected from students in prior semesters who were physically located inside the building.

4 RESULTS

ecoCampus was implemented in the Fall semester of 2013. During this implementation, 27 students completed all assessments and consented to allowing their responses and design submissions to be used in this research. All students who completed the design activity during this implementation were enrolled in the same first-year architectural engineering course (AE 124S), which was also the same course that was targeted in prior semesters' implementations.

4.1 Student Perception of Activity

The responses to the post-test assessments were collected and analyzed to understand the perception that students had about completing this format of *ecoCampus*. The responses collected were compared to prior semesters to identify similar trends or shifts in perceptions. In this comparison to prior semesters, only data from students enrolled in the same architectural engineering course were examined to allow for consistency in comparison. The responses to the different assessments were analyzed and compared to students who completed: the same version of *ecoCampus* where students were physically in the existing building; a paper-based approximation of *ecoCampus*, where students would illustrate design concepts on top of printed images of the actual building; and a purely open-ended activity where students were given the design challenge description and blank sheets of paper on which to illustrate their concepts. Table 1 shows a summary of the findings related to student perception of the activity.

Table 1: Students' self-reported perceptions about different design formats.

	ecoCampus in ICon Lab (27 Students)	*ecoCampus* in actual building (34 Students)	Paper-based, *ecoCampus* approximation (23 students)	Open-ended, paper-based format (65 Students)
Enjoyed completing activity (%)	92%	82%	76%	84%
Increased interest in building design (%)	80%	82%	80%	80%
Increased interest in sustainability (%)	76%	79%	55%	69%
Did not have enough time to complete the activity (%)	14%	9%	43%	43%

The findings from the implementation in the ICon Lab were generally consistent with the responses from prior semesters. Students generally enjoyed completing the activity and also generally felt that it increased their interest in building design and sustainability (see Table 1). The main difference observed between the computerized *ecoCampus* design activity formats and the paper-based versions related to the perception about the amount of time allotted to complete the design activity. Students who completed the paper-based format were more likely to feel that there was not sufficient time provided to them to complete design. This echoes the findings of prior *ecoCampus* versus paper-based design format comparisons (Ayer et al. 2014b).

4.2 Design Behaviour

In addition to exploring student perceptions regarding the activity, it was also of interest to study the process they employed while performing the design activity. The screen-captured images taken by the students were analyzed and their design behaviours were documented. In prior work, one of the most noteworthy findings related to the design process employed by the students was related to the number of design iterations and materials that were considered by students during the design session (Ayer et al. 2013b). This prior work showed statistically significant increases in the number of iterations as well as building materials that were considered by students during design.

The results from this implementation of *ecoCampus* in the ICon Lab also indicated significant increases in the number of iterations completed as compared to students who completed either of the paper-based design activity formats ($p<0.001$). Additionally, the design activities submitted by the students who used *ecoCampus* in the ICon Lab considered more building materials over the course of the design activity session as compared to the students who completed either of the paper-based design formats ($p<0.001$). This is consistent with findings from prior *ecoCampus* implementations.

Perhaps the most noteworthy finding related to this implementation of *ecoCampus* in the ICon Lab related to the students' design behaviour was in the comparison between the students who used *ecoCampus* in the ICon Lab (a virtual setting) and those who used it in the actual building. There was a statistically significant increase in the number of design iterations that students considered when they were physically located in the building ($p<0.001$). There was also a statistically significant increase at the 95% confidence level in the number of building materials that students considered when completing the activity in the actual building ($p=0.017$).

4.3 Discussion

Students who used *ecoCampus* in the ICon Lab to develop improved exterior wall retrofit design concepts for sustainability did so through the creation of more design iterations and considered more possible building materials than students from prior semesters who used paper-based approaches. This finding was not surprising as it echoed the findings of prior work (Ayer et al. 2013b). This behaviour of considering multiple design concepts before finalizing on a chosen concept suggests that students were successfully able to resist the tendency toward design fixation. Design fixation has been defined as adherence to a set of arbitrary rules or constraints that effectively limit creativity (Jansson and Smith 1991). Therefore, this research also reinforces this prior conclusion that an AR-based simulation game interface can help students to break the tendency toward design fixation.

The more noteworthy finding from this work relates to the finding that students used *ecoCampus* differently based on where they completed the activity, which affected the way that AR would function in *ecoCampus*. In other words, students enrolled in the same first-year seminar course, using the exact same version of *ecoCampus*, demonstrated a statistically significant difference in the number of design iterations and building materials that they considered in the same amount of time.

This finding was further explored to determine if there could be a separate factor that might have affected the students' behaviour. Pre-tests were compared between the different implementations of *ecoCampus* to determine if the different groups of students had differing levels of experience with mobile computing technology or different levels of motivation for completing the activity. Substantial differences in these metrics could potentially cause a change in students' design processes.

Table 2 shows the responses related to these topics from students who used *ecoCampus* in the lab and also those who used it in the actual building. The students in both implementations of *ecoCampus* responded with similar levels of motivation in the activity pre-tests. This does not suggest that their levels of motivation or experience using mobile computing technology affected their design behaviour.

Table 2: Perceptions between students using *ecoCampus* in different implementations.

	ecoCampus in ICon Lab (27 Students)	*ecoCampus* in actual building (34 Students)
Students looking forward to activity (%)	82%	85%
Students who anticipated putting "very much" effort into activity (%)	54%	47%
Students who had more than 20 prior experiences using mobile computers (%)	93%	91%

5 CONCLUSIONS

This work explored the use of an AR-based simulation game called *ecoCampus* that presents sustainable building design learning content to students through an interactive design challenge. From prior semesters, several beneficial learning behaviours were observed through the use of *ecoCampus*. This paper presents a follow-up study to further explore the prior semesters' implementations. In this work, students were tasked with completing the same exterior wall re-design activity, but they were not physically present in the building for which they were designing this wall. Instead students were tasked with completing this design challenge in front of a projected image of the physical space. This meant that the AR component of *ecoCampus* did not offer a virtual 1:1 sense of scale. It also meant that students were not able to physically explore the existing facility to gather additional information that could affect their design choices, such as what materials felt the most thermally insulated from the cold outdoor air or which materials worked best aesthetically based on the rest of the building's design.

The findings of this work generally backed up the findings of prior research that compared *ecoCampus* design behaviours to paper-based design format behaviours. In this work, it was observed that even when students were taken out of the physical building for which they were designing, *ecoCampus* was still able to help students to break the tendency toward design fixation by considering more possible design concepts and building material options than students who completed paper-based design activity formats. The perceptions of the activity among students were also largely similar between the different *ecoCampus* implementations, regardless of location, which further supports prior findings.

The findings related to this work differed in comparison to prior studies when the performance of students using *ecoCampus* in the physical building were compared to the students who completed their work in the ICon Lab. Students who completed their design work in the context of the ICon Lab did so through the creation of fewer design iterations as compared to the students who completed their design in the building. The group of students completing their design in the ICon Lab also completed their work by considering fewer different building material choices. Both of these findings suggest that using the AR component of *ecoCampus* in the actual building context can increase motivation to be creative and curious during design and analysis. While this conclusion is supported by empirical evidence related to the students' behaviour, it was not supported by their self-reported levels of motivation. The responses to these perception-based questions were not largely different between the two groups. This could potentially be due to the fact that students only completed one version of this activity. Had the experiment been conducted by offering students the opportunity to complete both formats of the activity and subsequently rate their perceptions of which one was more engaging, interesting, and valuable, a difference may have been observed.

Future work will explore how human behaviour may be influenced by augmented reality and simulation games in other contexts. This future work will explore how these technologies can influence student learning about building design and construction, but it will also be tested in industry use-cases. It is possible that the same beneficial behaviours that are exhibited by students learning these skills could be observed by industry practitioners when determining the best approach to an actual building design scenario. Finally, additional use-cases for this technology will be explored to study how tasks may be improved related to training professionals in the AEC disciplines.

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