Enhancing Spatial and Temporal Cognitive Ability in Construction Education Through Augmented Reality and Artificial Visualizations

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ABSTRACT

It is essential to provide the future industry workforce to fully develop the learning abilities to effectively solve construction problems. The Construction Management (CM) students' ability to solve problems is hindered by the lack of exposure to construction processes on the job-site, which results in the students' lack of understanding of the dynamic complex spatial constraints (e.g., how construction products are related to one another in particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). As the spatial-temporal-constraint problems pervade projects during the construction phase, their full understating to solve CM problems will significantly enable students to improve productivity levels.

This research uses Augmented Reality Technology (ART) and a layer of artificial visualizations to simulate the environmental context and spatial temporal constraints. The superimposition of images serves as an instructional mechanism to virtually incorporate jobsite experiences. The assumption is that the enhancement of spatial-temporal constraints enables learners to visualize context and hidden processes. Therefore, this research expects to demonstrate a significant improvement of the perception of the reality through the combination of two layers (the real environment and the computer-generated information) including the learners' ability to understand the complexity of construction products (e.g., assemblies) and associated process in the jobsite.

INTRODUCTION

Nowadays, construction projects are becoming increasingly more complex due to the integration of the engineering systems required to meet the growing demand for a more sustainable, flexible built environment. For contractors and engineers, this trend requires systematic coordination and comprehensive understanding of the complex relationships, e.g., interdependencies, interactions and constraints, among these engineering systems. The understanding of these relationships is a significant challenge to master construction management practices in-situ. In addition, the globalization of the construction industry demands a highly qualified workforce to respond to the coordination and comprehension for understanding these relationships.

The lack of exposure to construction processes on the job-site results in students' lack of understanding of the dynamic complex spatial constraints (e.g., how construction products are related to one another in a particular contextual space) and the temporal constraints (e.g., the dependencies for coordinating subcontractors' processes). In fact, the deficiencies in understanding construction products and processes is widely acknowledged by construction program graduates, including a lack of experience in applying construction-related concepts to real-world problems (McCabe, et al. 2008) and the exclusion of important contextual constraints typical found on jobsites (Sawhney, et al. 2000). Even though these constrains commonly exist in the management activates of the projects, there is yet a lack of appropriate pedagogical materials and media to enable instructors effectively bring those job experiences (Jestrab, et al. 2009) into the classrooms that reflect what has been learned of the dynamic and complexity of such constraints.

Revealing the spatial temporal relationship of construction processes is a challenging task for educators, in particular, when using traditional instructional media in a classroom environment. The research question, therefore, is to determine how educators can bring the experiences of the dynamic complex spatial and temporal constraints found on the jobsites into the classroom. In response to this question, this research uses a pedagogical material in a way that leads the students' understanding of the complex dynamic and spatial-temporal constraints by using Augmented Reality Technology (ART).

INSTRUCTIONAL STRATEGY AND MEDIA LIMITATIONS

Knowledge gaps and deficiencies in mastering spatial and temporal skills are consequences of the instructional strategies and media limitations. The limitations prevent the successful demonstration of critical construction product and processes in different context and at different levels of complexity. As these gaps are broadened in higher-level courses, they become a major bottleneck to more efficiently and effectively learn the reasoning skills needed to understand and master spatial-temporal complexities. Construction Management courses should equip students to connect concepts for better reasoning and problem-solving skills. For instance, training on reasoning on problems regarding management of space on the jobsite (an spatial-temporal constraint problem) should better enable student to respond to unexpected situations though improvisation. Thus, instructors should situate students in a learning environments suited to engage students in real-world life situations including unexpected situations to better reasoning to accomplish construction activities within the project practices.

Typically, many existing CM curricula offer field trips or internships to remedy the instructional media limitations on instructing spatial-temporal and context conditions. This instructional strategy is an institutional sponsored experiential learning (Kolb and Kolb 2005). It involves a direct encounter with complex situations in the construction project under the assumption that the direct experience will lead to genuine meaningful learning. Students are exposed to the real-world environments within the projects of the construction firms they intern with. The challenge, however, is to expose the students to the context that add value to the learning experiences and to involve the student in relevant experiences that significantly impact learning (McClam, et al. 2008). As instructors do not accompany students on the project job-site during the internships, they do not embrace coaching and debriefing, reflection, scaffolding and judging, among other teaching strategies. Students are left in a self-learning environment, which might not lead to the development of the required skills defined by learning outcomes of the CM courses.

Their internship experience success requires a self-reflective active learning participation and intrinsic motivation (Levesque-Bristol, et al. 2010). These conditions demand an active participation to create a context of problems and site-settings at hand by observing and reacting on the jobsite. The demand for learners' active participation problematically approaches the successful internship practice, as the conditions for participation are not suitable for many students. The intrinsic motivated students might navigate through situations on the jobsite within more reflective enriching activities by opening themselves to changes in their understanding of the observed project practices, other internship participating students cannot sustain such practices with the same motivational level.

Furthermore, additional socio-cultural and economical related issues arise for the CM student population for their field trip participations. For instance, their successful internship engagement on jobsites when universities or institutions are located at considerable long distances from the practice site. Fitting academic work in tight schedules and restricted mobility to the jobsite (e.g., students may be residents at geographical distant locations and from areas with difficult access to the chosen jobsite) are some examples. These issues result in critical barriers that prevent certain students' from taking internships, which leads to disparity conditions among students. It is implied, therefore, that opportunities for learning on field trips are difficult to include within all the courses in the CM curriculum that benefit all CM student population. Although it seems plausible that the resulting differences should be avoided or overcome, this research values such differences as they emerge as a resource for learning. Specifically, this research uses such differences to better design a pedagogical material.

ART USE AS A PEDAGOGICAL MATERIAL

This research uses Augmented Reality Technology (ART) as an instructional mechanism to virtually incorporate jobsite visits through the perception of augmented reality. ART enhances the physical, real-world environment through a computer-generated sensory input. For example, ART enables CM students to enhance their perception of the jobsite and, more importantly, have unlimited access to otherwise limited opportunities to participate in jobsite experiences.

ART is a technology-based tool that enables to have layers of computer-generated information (Azuma, et al. 2001, Haller, et al. 2007), including a combination of both the real environment and the computer-generated information (Bimber, et al. 2005). This technology includes video, graphics, and geographical positional systems to mediate and enhance the human's perception of reality (Barfield and Caudell 2001). This research demonstrates that the ART supports CM students for having unlimited access to otherwise limited opportunities to participate in jobsite experiences.

While ART as an instructional mechanism is used to virtually incorporate jobsite visits, the technology instructional design focuses on the creation of case study. The case study takes place during any construction phase of a project and it is designed according to a required CM outcome from a particular CM course of interest. The purpose is to fully demonstrate the spatial temporal constraints in classroom environments to effectively bring the exposure of on-site experiences during any phase of the construction projects into construction courses. This set of case study is a pedagogical resource to enable instructors replicates such cases into other courses in the program, including their use by the academic community. The case study focuses on essential elements of the real job-site problem. Thus, experts (instructors, professionals) provide input to assemble the virtual objects and the simulations with ART for each one of the built case studies.

Augmented Reality (AR) component assist students, for instance, to better understand concepts such as the management of space- a case study- (arrangements and potential conflicts in construction processes). Such concepts are easily incorporated and integrated into the case study. Augmentations effortlessly illustrate, for instance, the use of materials and construction safety- a case study topic.

For pedagogical purposes, therefore, ART enhances the learners' perception. ART serves as a supplementary tool to perceive and to identify spatial-temporal constraints through the interaction of virtual elements and the representations of real environments. The implementation of ART enhances the learners' awareness and understanding of construction products, processes, sequences and problems found within the context of the project.

This researcher anticipates that the use of ART in the classroom will enable the enhancement of problem solving and learning visual, auditory, and kinesthetic skills for CM students' body. In sum, as the focus of this investigation is the understanding of methods and strategies to enhance students' learning within CM courses, this research effectively find uses of technology through ART by emulating real job-site experiences for enhancing students' learning.

METHODOLOGY AND APPROACH

Simulations of continuing construction activities from job sites are performed through ART as a research strategy. The research subjects are students and instructors using this instructional methodology. The methodology is designed to enable real-world learning experiences with the use of ART. The objective of the implementation phase, for instance, is to build the prototype using an augmented reality teaching and learning environment.

The approach has three basic steps: (1) Rendering virtual object and their composition- by focusing on the design and implementation of the prototype; (2) Simulations- aimed at developing situated using ART; and (3) evaluation and assessments- testing the case study.

In creating a learning context and to capture and organize information from the construction site environment, and as part of the implementation process, the following is an illustration of the method used to create the computer-enhanced objects.

Virtual Models Generation. The models consist of a set of computer-generated virtual objects designed to meet instructional objectives. The objects themselves have a set of variables that were manipulated by the user. The object designs are aimed to occupy a continuum within construction activity to meet the intended learning aims including the activity context (i.e., the object designs address the specific learning goals, such as the number of virtual objects that represent components and equipment for a particular activity). The set of virtual of objects are built using 3D CAD platforms and the available library of geometric objects.

Virtual Object Composition. The set of stored video clips and images are composed (connected) to the virtual model objects. These virtual model objects are superimposed on the selected images from the video clips and set of images. The composed virtual objects allow users to contrast real-world images with the virtual objects, generating the AR experience. The researchers use an AR platform to coordinate the images and the virtual objects for each case study. Experts and graduate students manually localize and map the virtual objects into the image coordinates.

The sensory input data of the proposed model is mostly visual. Several studies have shown that the synergy of multiple visual resources provides a powerful tool for students to understand many complex and abstract engineering concepts/solutions related to dynamic constructing processes (Teasley, et al. 2000). In addition, understanding the means and methods of the way a product is put together under particular project conditions gives construction management students a broader perspective when they actually participate in product design (Marc, et al. 2007).

Simulations. In the classroom, students manipulate superimposed real-world images as they access and retrieve the images through a computer application in the classroom. At the same time, the instructor uses a multi-display panel to show the view of same field images/stream video with or without the virtual models (i.e., the instructor will illustrate and assist the learning process, by showing the composed or not composed set of images, including their superimposition of the computer generated objects and other auxiliary information).

In sum, this research uses a video device to capture particular scenes on the jobsite. The video device is positioned in a strategic, safe place to allow capturing the main components of the construction project environment. The selection of the construction activities and the broadcast time is arranged with personnel on-site. The video is further filtered, edited, tagged and stored in a database. The data output consists of a set of video clips and images, classified according to the construction process and materials used to execute on particular construction activity.

CASE EXAMPLE

A typical high-level class in CM curricula is the Construction Methods course. Its focus is on construction processes found in construction of building and infrastructure projects. It covers, for instance, the utilization of construction equipment within construction processes, during all phases of the project (i.e., from planning, scheduling and control from the initial phase of construction to the end phase until the close-out). The course requires students to become proficient in decision-making, problem solving, and prediction and evaluation of construction products and equipment within the involved processes.

Students rely on concepts learned in previous low-level courses. Therefore, strong connections to low-level courses' subjects and concepts are required to learn new knowledge and assure knowledge transfer. For example, knowledge of the behaviour and properties of materials, assembly composition, and functionality of the building systems are essential to successfully understand construction processes. Basic knowledge from low-level courses is also required to comprehend the spatial arrangement of materials and location of the equipment during a specific time interval.

Figures 1 and 2 illustrate the formwork assembly process of the cast-in-place reinforced concrete beams of an infrastructure project (interstate on-ramp). This construction process (the assembly process) has an intensive use of construction equipment: scaffolding equipment and formwork. Scaffolding is a temporary, assembled and erected, modular structure to support materials and workers on the construction site. It also provides safe access to the workers so that they can transport material and have mobility within a confined space. Formwork is the structure used to support wet concrete. Key elements of formwork equipment are the standards (vertical scaffolding that support the mass of the structure to ground), ledgers (horizontal tubes that connect the standards), and transoms (tubes positioned at certain angle that give reinforce the ledgers).

Positioning the formwork require instructions to secure a safe structure and a rapid erection on site. The formworks' structural stability, for instance, is at risk when there are failures in the assembly processes, soil conditions, and in the structural strength of the materials.

Figure 1: Virtual objects to visualize formwork assembly method

Learning the assembling of each component of this temporary structure and relating the process to the typical conditions of a project is critical. For instance, conditions of space are unique to a particular project. Also conditions of the ground (soils) are very complex to generalize. The instruction of tolerance, such as the horizontal movements in the joints under loading conditions, is fundamental since soil movements may cause changes in the loading conditions that substantially affect the stability of the scaffolding system.

As shown in Figure 2, ART enables students to learn within the context of the project position and assembly by directly manipulating the assembly parts represented as computer generated virtual objects. At full scale, students are able to visualize the critical elements, for instance, for load transfer. It is important to note that the detailed assembly process of this equipment is not included in a typical construction methods course.

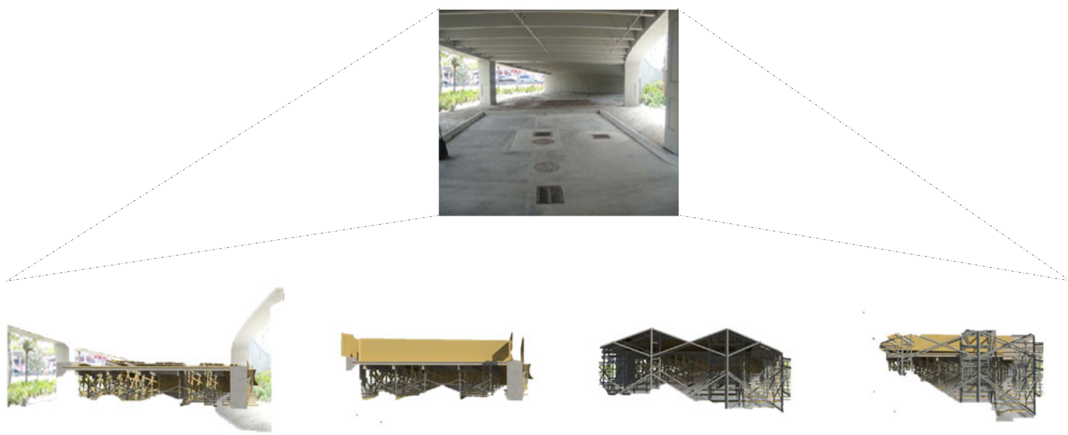

Figure 2: Sequence of images to visualize working and access spaces during the formwork assembly

CONCLUSIONS

This research provides a potentially viable solution to bringing field experiences to classrooms, including an open source, cost-effective mechanism for sharing educational resources among participating faculty members. Such a capability would be beneficial to a wide range of CM and engineering education, since the shared challenges and the proposed approaches are common to many other engineering disciplines. It is anticipated that the ART users will significantly grow as well as the users' feedback based on trustful relationships among users (Issa and Haddad 2008).

Results of the project directly impact the teaching and learning of a wide variety of construction engineering courses, which rely heavily on students' spatial-temporal cognition skills of building systems and construction processes

In particular, the resulting proof of concept and the data of this research might be used to inform the design of a scalable teaching/learning environment (i.e., the follow-on ART design environments within the classroom will facilitate the ART use and its implementation within CM programs from other US institutions).

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