Developing a BIM-enabled Bilingual Safety Training Module for the Construction Industry

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ABSTRACT
This research documents and assesses the development of a construction safety training module featuring BIM-enabled 3D visualization narrated in both English and Spanish to test if such information can enhance safety training for construction management students and construction workers. A pilot (English version) of the module was administered to construction management students and their responses were generally positive. Spanish and English versions of the modules were then administered to professional mason laborers on-site in Denver, Colorado. This paper highlights the technical challenges and the lessons learned through the development of training module, particularly for use and research on real construction sites. Findings support and highlight future opportunities to develop more advanced, and custom (project specific) bi-lingual safety training modules.

INTRODUCTION
Opportunities exist to improve construction safety training. The construction industry consistently maintains a higher rate of injuries and fatalities than other industries. In 2012 there were 775 fatalities in the private construction sector (BLS, 2013). The fatality rate regularly rates the industry among the three most dangerous in the United States (Abudayyeh, Fredericks, Butt, & Shaar, 2006). In 2012 construction had the highest number of fatalities when compared to any other industry sector (BLS, 2013). Furthermore, over the past 10 years fatal and non-fatal injuries and illness rates in construction have maintained high levels despite focused attention by the industry on safety procedures and programs (Abudayyeh, et al., 2006). Such data suggests that there is a lack of successful communication regarding safety procedures, hazard identification and site-specific conditions on construction sites. In particular, workers who have limited worksite experience, such as interns and recent construction management graduates are more likely to get injured on the worksite than workers with more experience. (OSHA Young Workers, n.d.). Hispanics are another a group that is at increased risk on the worksite. Hispanic construction workers are twice as likely to get injured on the jobsite as non-Hispanic workers.
workers. Research suggests the higher injury rate may be due, in part, to language and cultural barriers present in the Hispanic workforce (Lopez del Puerto et al., in-press).

According to the Occupational Safety and Health Administration (OSHA), employers are responsible for providing safety training in a language and vocabulary workers can understand (OSHA, n.d.).

Construction companies often require daily “tool box” safety talks in which management discusses with employees the work that will be completed and shares safety information related to the tasks to be completed (Wilson, Enno and Koehn, 2005). Tool box safety talks often have a written component in addition to the oral presentation. The oral presentation is typically in English with handouts sometimes available in both English and Spanish. The OSHA Fact Sheet on Preventing Falls is a good example of the material available during safety trainings on the worksite (OSHA Fact Sheet, n.d.).

Providing such written material even in the worker’s native language, however, is not sufficient to effectively train workers. Oconor, Loomis, Runyan, del Santo, Abboud and Schulman (2005) interviewed 50 young Latino construction workers and found that the median training time was one hour. They also found that workers with higher English language skills receive more training than workers with lower English skills. Alsamadani, Hallowell, Javemick-Will and Cabello (2013) studied the relationships among language proficiency, communication patterns, and safety performance of construction workers and concluded that in order to have a safe jobsite, safety training and other communications should be provided in the employee’s language.

Researchers have begun to investigate opportunities to use Building Information Modeling (BIM) to improve construction safety planning and management (Zhou et al., 2013; Azhar et al., 2012; Rajendran and Clarke, 2011), and to enhance communication within the context of construction safety training (Park and Kim, 2013; Azhar and Behringer, 2012; Chi et al., 2012). However, less research exists that focuses primarily on the role of visualization in safety training (Han, 2009), or in bi-lingual safety training in particular (Clevenger and Lopez del Puerto, 2011).

In sum, critical need exists to improve safety training to both English and Spanish speaking construction workers and BIM-enabled 3D visualization may provide an innovative platform to address such a need. This research documents the challenges and lessons learned in the development of a construction safety training module featuring BIM-enabled, 3D visualization narrated in both English and Spanish as a potential training tool. The authors elected to create a module on scaffold safety because falls are the number one cause of fatalities in construction (OSHA, n.d.). Future research documents the learning outcomes of the training module implemented on-site with actual construction laborer participants. The goal is to test if BIM-enabled training modules effectively enhance communication regarding safety procedures, hazard identification and site-specific conditions with the ultimate goal to reduce the number of injuries and fatalities on construction worksites.
DESCRIPTION OF MODULE DEVELOPED

BIM technologies can be used in a variety of areas to assist in issues related to construction health and safety including: (1) Design for safety; (2) Safety planning (3) Safety training; (4) Accident investigation; and (5) Facility and maintenance phase safety (Rajendran and Clarke, 2011). In particular, narrated, BIM-enabled, 3D visualizations are well situated to play a critical role in enhancing safety training for both English and Spanish speaking laborers (Clevenger and Lopez del Puerto, 2011; Azhar and Behringer, 2012).

For this research, the authors developed a two part training module consisting of interactive training and an on-line assessment. This module was produced in two versions: one in English (subtitles and narration) and one in Spanish (subtitles and narration). Creating the visual and accompanying audio content of the safety training module, the authors followed the guidelines developed for educational materials targeted to Hispanic workers including use of language familiar to workers, clear and realistic graphics, and delivery of training material in a learning-centered environment (Brunette, 2005; Clevenger and Lopez del Puerto, 2011).

The authors elected to create the BIM-enabled safety training module using Adobe® Captivate® 6 software (Adobe, 2013). Captivate is a eLearning content development software capable of integrating visualizations and animations, text and audio clips into interactive simulations, branching scenarios, and quizzes outside of the original, native software(s) platform. To create the BIM-enabled safety training module, the authors first created visualizations and animations in native 3D modeling Revit software to illustrate the safety training concepts. The module developed met OSHA requirements for scaffolds as stated in 1926 subpart L – Scaffolds. Subpart L includes specifics regarding platform width, plank spacing, guardrails, access points, etc. that must be followed to comply with the regulation (OSHA, n.d.). The current illustrations created in Revit are relatively simple, but demonstrate a strong proof of concept that more complex equipment or site-specific 3D safety illustrations can be generated using native software currently already widely used by the construction industry to model building projects and sites.

Part one, the interactive training developed, uses the following activity types to engage the trainee and demonstrate these safety concepts: drag and drop selection, video animations (fly-arounds), and user guided placement (e.g.; placing a mid-rail or arranging plank overlap etc.). Figure 1 illustrates the use of an interactive drag and drop selection activity to demonstrate minimum plank width to the trainee. Figure 2 illustrates the use of interactive user guided placement activity to demonstrate proper mid-rail height to the trainee.
Part one concludes with an illustration of how to place the scaffolding on the specific construction site where the laborers are working. Again, while the models shown are simplistic, laborers who participated in the pilot study were able to distinguish important landmarks representative of their construction site and to recognize that the concepts being presented are directly applicable to their job. Figure 3 is a screen capture of the animated fly-through of the specific construction site where research participant trainees are laboring.

Part two of the training module developed consists of seven multiple choice questions that assess if the trainees can correctly identify and apply safety concepts related to the scaffolding as conveyed during part one of the training module. Figure 4 illustrates an assessment question where the trainee must identify the proper placement height of the scaffolding mid-rail. Figure 5 illustrates an assessment question where the trainee must identify correct plank overlap. All seven assessment questions are presented interactively, on-line and individual results are recorded.
Once the content of part one and part two was developed using Adobe Captivate to integrate the Revit-generated illustrations, videos, text and audio narration, the safety training module was published to an html file. The resulting product is a stand-alone, software independent, executable file that can be viewed using an Adobe flash player or an internet browser. Using such a platform, individual assessment scores can be recorded directly through a web-based learning environment such as Blackboard.

CHALLENGES IN DEVELOPMENT AND IMPLEMENTATION

Several technical challenges were quickly revealed during the development and pilot testing of the safety training module, several that are indicative to the creation of e-learning environments in general. First was the challenge of creating a fully “tested,” on-line training module. During both student and construction worker pilot implementations errors or bugs appeared that the authors had not witnessed during development or testing of the training module despite having viewed the module using a variety of computer systems. These included 1) problems restarting, advancing or rewinding the module, 2) problems viewing the videos or asynchronous narration with slow video and 3) problems recording assessment results. Such issues were mainly the result of either different software or hardware specifications, slow internet speed, and/or impatient, inconsistent users. Specifically, when training modules were implemented by students on-line, they viewed and interacted with the e-learning environment using both windows and mac operating systems as well as using numerous (and numerous versions of) browsers. Such difference led to minor yet, at times, problematic changes in screen layout sizing etc. In addition, construction sites are notorious for varying reliability of internet connections, which, at times, further compounded issues with viewing of the module, and its video components, in particular. Furthermore, students and construction workers are demanding on software and frequently double-click, reverse, restart, or repeat optional entries, in an unforeseen manner, which can be problematic if untested.

A second issue, particular to construction laborers, was a general lack of computer literacy. Several of the laborers tested were uncomfortable with computers, and specifically, unfamiliar with the use of a mouse. Such a learning curve greatly inhibited the potential effective of the safety training module. To address this issue,
the authors used Captive 6 to publish both desktop and Ipad (touch-screen activated) versions of the teaching module. Such a solution generated additional issues, however, regarding the ability of Adobe Flash to play on Ipads.

A third issue that proved difficult was the handling of computers on the construction site by construction laborers. Finding a stable, dry surface was frequently possible only within the construction trailer. Laborers hands were frequently somewhat dirty and their fingers were, at times, significantly calloused making the touchscreens less responsive to their touch than a typical office worker. Based on observation, a stylus may be the best data enter tool for a computer in the construction environment. Finally, although reportedly only a temporary upgrade issue, another issue was that the author’s university’s blackboard digital learning platform was not compatible with robust collection of either individual or group assessment results and such data had to be collected manually. Despite of these issues, the safety training modules were generally well received by both the students and construction workers during pilot implementation.

**USER FEEDBACK**

As shown in Table 1, feedback on the safety training module from both student and construction workers was strongly positive.

**Table 1. User feedback on safety training module**

<table>
<thead>
<tr>
<th>Interacting with the computer simulation model increased my understanding of proper use of scaffolds</th>
<th>Highly Agree</th>
<th>Agree</th>
<th>Neither Agree or Disagree</th>
<th>Disagree</th>
<th>Highly Disagree</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction Management Students</strong></td>
<td>27</td>
<td>13</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4.18</td>
</tr>
<tr>
<td>Number of Students</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>27</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>0%</td>
<td>0%</td>
<td>11%</td>
<td>60%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td><strong>Construction Workers</strong></td>
<td>11</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4.27</td>
</tr>
<tr>
<td>Number of Workers</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>0%</td>
<td>4.5%</td>
<td>4.5%</td>
<td>50%</td>
<td>41%</td>
<td></td>
</tr>
</tbody>
</table>

Eighty nine percent of construction management students and 91% of construction workers either agreed or highly agreed that interacting with the computer simulation model increased their understanding of proper use of scaffolds.

The following are abridged lists of representative open-ended feedback comments provided by construction students and construction workers after completion of the pilot safety training module.

**Construction student feedback:**

- I found this exercise beneficial. It should be implemented in future classes to teach students. The interactive 3D model is a great way to learn and preferred over traditional methods.
• Picture and demonstrations helped me understand the material. I liked the quiz and questions afterwards to make sure I learned the material.
• The information was very useful and informative.
• Interactive assignments like this would be good reinforcement of homeworks.
• Very interactive program, really kept my attention as well as helped me.
• There were a few confusing parts, but overall I thought the simulation model was an excellent learning exercise.
• The models/videos were very helpful. I think this is a good idea for industry.
• It was a lot of the same information we learned in class, so it was a little repetitive.
• If we didn’t go over scaffold in class, it would have helped more. The drag-and-drop were very cool. The talking guy is annoying. Some of the 3D images were repetitive.
• The [narrator’s] voice is kind of repetitive and annoying.
• Having good internet is important.
• Kind of hard to work program.

Construction Worker Feedback:
• I think specific site training is a very good idea. Makes more sense to show people how [to perform safety requirements] on a job.
• Having a site specific picture helps in training. I think there should be different types of scaffolds in the training.
• It is better to train in Spanish for those of us who cannot read English. Thank you for understanding.
• The site specific view of the scaffolding was helpful.
• Generally hands-on experience works for me.
• Was very interesting, would rather have computer training than boring slide shows.

LESSONS LEARNED
A significant opportunity exists for construction safety training to utilize BIM-enabled visualization to provide a robust, interactive, site-specific educational experience for construction laborers regardless of native language. However, implementation of the pilot bi-lingual safety training module highlighted the following issues worthy of future research.
• Construction companies differ in their safety practices, and specifically many companies exceed OSHA requirements. As a result, detailed yet generic safety training may not be useful or relevant on construction sites, and training libraries will have to be extensive to cover the full range of potential issues. Therefore, it may be difficult and/or not cost effective to develop training modules that are as custom, appropriate or successful as the safety training provided an experienced construction safety professional looking at real-time site conditions.
• Exploration of additional BIM capabilities may lead to more training opportunities. In particular, phone apps may present a construction-site
friendly platform for interactive safety training and/or online training “libraries.” For example, equipment manufacturers can provide safety data or animations that can be placed in BIM 3D models and/or accessed through QR codes directly on-site using mobile telephones.

- A significant benefit to e-learning platforms for critically important topics such as construction safety is the opportunity to facilitate quick and individual assessment. Using custom online safety training modules with built-in assessment capabilities may prove invaluable to be able to confirm and test the effectiveness of communication, a particularly important issue for safety training for Hispanic construction workers. It may be important, however, to safeguard against “answer sharing” which appears more culturally accepted in such a community.

CONCLUSION

The authors developed and piloted a construction safety training module featuring 3D visualization narrated in both English and Spanish. The English version was administered to construction management students, and both Spanish and English versions were administered to construction workers. While initial feedback from both groups of participants was largely favorable, valuable lessons learned were generated. Some of these lessons will be helpful to individuals developing e-learning training environments for construction applications in general; and some will be helpful to individuals specifically interested in increasing the effectiveness of safety training to construction workers, having a range of native language skills. Additional and separate research will report findings regarding the impact of the training module on understanding construction safety. This research, however, supports and highlights future opportunities to develop more, advanced, and e-learning training modules for construction safety training and beyond.

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REFERENCES


OSHA Young Workers https://www.osha.gov/ Publications/young_workers.html


