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A user-centered information and communication technology (ICT) tool to improve safety inspections

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ABSTRACT

Occupational safety is imperative in construction, and safety inspection is among the most common practices that help enforce job safety on site. The safety inspection process, however, suffers from several drawbacks that hinder the efficiency, effectiveness, and analytical learning capacity of the process. Dedicated tools for user-centered information and communications technology could significantly reduce such drawbacks. This paper discusses the use of an original two-step user-centered design approach to develop and evaluate an iPad application that aims to address such drawbacks and improve the day-to-day practices and management of safety inspections. Evaluation results indicate the usefulness and practicality of the application and identify innovative uses not previously envisioned. Furthermore, the developed tool allows consistent data collection that can eventually be used to aid the development of advanced safety and health data analysis techniques.

1. Introduction

Workforce safety is an important topic across global construction industries [1]. According to the United States (US) Bureau of Labor Statistics, more than 1000 work-related fatalities took place each year between 1994 and 2011 in the US construction industry on average. Furthermore, construction consistently ranks as one of the top three most dangerous industries in the US, with the greatest total number of work-related fatalities among all industries.

In the US, safety regulations, in particular the "General Duty Clause" from the Occupational Safety and Health Administration (OSHA), require that employers provide their employees with safe and healthy working environments free from recognized hazards. To meet this requirement, contractors typically adopt a mix of safety approaches, such as regular safety meetings, substance abuse programs, task specific safety training, and pre-project safety planning. Among these common approaches, conducting regular and frequent construction site safety inspections is particularly important [2,3]. Abudayyeh et al. [4] conducted a survey concluding that the injury and illness incidence rates of companies that performed safety inspections were significantly lower than those that did not. By analyzing the total OSHA recordable injury rate of 59 projects, the Construction Industry Institute [5] concluded that the practice of checking safety inspection records on a regular basis is generally associated with projects that have better safety performance. Kaskutas et al. [7] determined that safety inspections could measure the risks of observed projects. Aksorn and Hadikusumo [6] suggested that safety inspections are very effective in preventing accidents.

Although safety inspections are a successful and widely used strategy for improving safety in construction, the inspection process lacks a comprehensive and structured procedure and is accompanied by ineffectiveness and inefficiency throughout. For instance, during a typical safety inspection, a safety specialist looks for violations on site and takes notes to record observed issues. However, inspection notes taken by different safety specialists may vary greatly for the same type of issues, making it difficult to have a systematic understanding of the observed issues. Current practices do not take advantage of the time and resources that safety professionals have already committed during site inspections. Therefore, repetitive steps are taken to transform field notes into office files and then administrative reports. In addition,

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inspection results are rarely analyzed further to serve as performance indicators for administrative and management use or to reveal the unsafe patterns on site.

These limitations may severely reduce safety specialists' effectiveness and efficiency in collecting and compiling field observations, and as a result may hamper their ability to monitor site safety performance. However, dedicated information and communication technology (ICT) tools, such as portable tablets capable of retrieving applicable safety procedures, rules and regulations, and software capable of automating recurring activities (e.g., creation of violation statistics and reports), could significantly improve the day-to-day practices and management of safety inspections.

Numerous ICT tools have been beneficial for the construction industry. Goodrum and Haas said, “Many industries have spent considerable time and money studying how technology influences productivity. These studies have led to sizeable gains in productivity and profit margins” [8]. Furthermore, the Construction Industry Institute [9] stated, “Advances in technology have many benefits. Among the most often cited are improved quality and productivity.” ICT tools also provide benefits to workforce safety and well-being. For instance, ICT innovations allowing the industrialization and automation of work tasks were considered to be one of the main factors preventing a significant increase of injury rate in the US construction industry during the 1990s [10]. The importance of ICT-enabled automation in improving safety was also supported by Kim and Cho [11] and Cinkelj et al. [12]. Han et al. [13] and Sulankivi et al. [14] implemented building information modeling (BIM) and a 4D model for safety planning. Chi et al. [15], Teizer [10], and Walia and Teizer [16] employed 3D imaging sensors to reduce the occurrence of collisions within a construction site. Wu et al. [17] used a radio-frequency identification (RFID) sensor network to create an autonomous real-time tracking system of near-miss accidents and Yang et al. [18] applied the same technology to identify accident precursors.

However, many innovative technologies that have been proven to be beneficial are not commonly adopted by construction practitioners. There are different reasons for this. First, it is well known that the construction industry is considered reluctant regarding the adoption and implementation of innovations [19,20]. Koningsveld and van der Molen commented that “As we look at the pace of innovation in other branches of industry, the building and construction industry should be characterized as most conservative” [21]. Furthermore, ICT tools have traditionally been developed by adopting a technology-centered design [22]. A technology-centered design occurs when researchers develop a new technology or apply an existing technology to a different field, without considering users' needs and capabilities. Thus, a technology-centered design forces users to adapt to the new technology and eventually fosters the occurrence of errors. According to Rogers [23], a technology-centered design also implies that innovative technologies are developed without considering factors that can significantly affect innovation diffusion and acceptance. Such factors include relative advantage (“the degree to which an innovation is perceived as being better than the idea it supersedes” [23]), compatibility (“the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters” (p. 15)), complexity (“the degree to which an innovation is perceived as relatively difficult to understand and use” (p. 15)), trialability (“the degree to which an innovation may be experimented with on a limited basis” (p. 16)), and observability (“the degree to which the results of an innovation are visible to others” (p. 16)). Several studies have demonstrated that when an innovation has relatively higher advantage, compatibility, simplicity, trialability, and observability, the innovation also has a higher chance to be extensively and rapidly accepted [24]. In fact, Mitropoulos and Tatum [25] suggested that uncertainty in obtaining benefits or competitive advantages from using innovative technologies is among the barriers that impede the introduction and development of innovative technologies in construction.

To mitigate technology-centered design issues and limitations, innovative ICT tools should be designed and developed through a user-centered (also known as human-centered) approach [26]. When a user-centered design is used, researchers develop a new technology, or apply an existing technology to a different field, by adapting it to users' needs and capabilities and understanding how users interact with it [27,28]. The employment of user-centered design principles has been shown to be successful [29] and the importance of user-centered design is also emphasized by the fact that the International Organization for Standardization [30] issued a specific standard for user-centered design. The limitations of current safety inspection procedures can be addressed by dedicated ICT tools, but introducing innovative ICT tools in construction cannot be successful without a user-centered approach.

To this end, the objectives of this study are twofold. First, through a user-centered approach, this study aims to verify the technological requirements that correspond to the safety inspection procedures and their management implications. Second, based on the verified technological requirements, this study intends to develop an iPad (Apple) application for potential users to experience how the tool can effectively support the day-to-day practices and management of safety inspections. Echoing Mitropoulos and Tatum's suggestion [25], adopting a user-centered approach as the main research strategy is expected to reduce user uncertainty about the technology and illustrate the competitive advantages of using the technology.

2. Background: The safety inspection process

Based on field observations, the safety inspection process can be divided into three phases. These are the project information collection phase, the recording of observed violations phase, and the administration of inspection results phase. The conceptualized safety inspection process is illustrated in Fig. 1.

After the details of a project are mostly settled and as the project commences, safety specialists responsible for the project begin to conduct inspections at the project site. Generally, the site inspection frequency depends on the scale and importance of the project. During a site inspection, a safety specialist typically takes notes of any violations and safety issues identified and communicates with workers on site to express observed concerns. Upon returning to the office, the specialist then recaps and compiles the inspection results into a report. Inspection results are often further discussed during regular project management meetings to prevent similar issues from recurring, to target specific areas for training, and to raise safety awareness among all employees [31]. Eventually, the inspection results can be used to identify strong indicators for safe (or unsafe) projects and improve site safety performance by identifying and understanding the trend of unsafe working conditions/behaviors. The inspection results can also potentially be used to establish relationships between project safety and other aspects, such as schedule, productivity, and cost of the project. An integrated approach that examines the results of safety inspections and productivity has been explored [32] and such efforts could inform organizations on how project management factors influence each other. In addition, integrating safety inspection results with other aspects of the project has proved to be beneficial in reducing accident rates and improving productivity [33].

The safety inspection process, however, is ineffective and inefficient because of several drawbacks in current practices. The five main drawbacks are described in the following paragraphs.

Drawback 1: Lack of Process Standardization

A safety inspection is expected to identify safety issues related to the various trades, means, methods, and materials of construction, after considering all applicable safety standards [34]. However, the volume of applicable safety standards is sizable and it is impossible for safety specialists to verify whether all applicable standards are