Mobile Computing for Accident Prevention through Design

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Abstract

Prevention through Design (PtD) is recognised as an effective way to curtail workplace accidents in construction. Many governments around the world therefore have mandated PtD; a major modification to designers' responsibilities. However, industry surveys show that designers face enormous challenges in implementing PtD due to lack of knowledge regarding risks caused by their design choices and how they may be reduced or eliminated. This research aimed to develop a mobile app as a decision support system that can assist designers with PtD. Knowledge acquisition for the development was conducted via a combination of content analysis of PtD literature and an interview survey with construction practitioners. Then, the mobile app was prototyped and subsequently tested with a case study approach. The mobile App will be instrumental in enhancing designers' competency in PtD and thereby reducing workplace accidents on construction sites.

Keywords: Workplace health and safety, Prevention through Design (PtD), Knowledge management, Mobile computing

Introduction

Research has repeatedly confirmed that design is a significant cause of fatalities and severe injuries in construction. Gibb et al. (2004) in the UK, for example, meticulously studied 100 construction accident cases and concluded that slight changes to the designs would have significantly minimised the risk in nearly half (47%) of the cases analysed. Similarly, an analysis of 450 construction accident reports in the US found that in almost a third (30%) of cases, the hazards that caused the accidents could have been prevented by design changes (Behm 2005). In Australia, too, Creaser (2008) established that 37% of fatalities on construction sites involved design-related causes.

Traditionally, designers' role has been to produce building designs compliant with the local building codes and the responsibility for site safety has been left to the builder. Nonetheless, research indicates that designers can significantly influence on construction site safety at concept, preliminary and detailed design phases. Accident Prevention through Design (PtD) derives from this notion. The approach of PtD is applied through the different phases of the design process to identify and mitigate or even eliminate hazards potentially encountered by workers during construction as well as maintenance of a building or structure. PtD entails systematically identifying construction hazards and risks posed by a design and introducing an alternative design option that satisfies both the client's requirements and local building codes while ensuring a safe workplace for workers (Kamardeen 2010a). Hence, PtD is a very pertinent and needed solution/strategy to curb the distressing accident statistics in the construction industry.

Realising the critical role that design decisions have in creating safety risks and the urgent need to reduce the accident toll in the construction industry, many governments around the world have mandated accident prevention through design in their legislations. In the UK, for example, PtD has been mandatory since 1995 through the Construction Design and Management (CDM) Regulations. Similarly, the Australian government has mandated PtD in its latest Work Health and Safety legislation which took effect from January 2012. Designers are now required by law to include PtD in their design practices; a major modification to their previously accepted role.

In order to adopt PtD, designers must know the construction contexts of their design. Every design creates a construction context, which dictates the level of hazard resulted by the design choice. The construction context can be usefully conceived of as including five elements: site settings – site terrain condition, space and accessibility, road and traffic condition and vicinity; task settings – location of the task and temporary structures/facilities needed to build it; materials – type and nature of materials used; equipment – type and nature of equipment used; and labour - type and skill level. A construction accident can emanate from one or a combination of the contextual elements. Prevention through design must therefore perform a what-if analysis for all possible design options for a building project to take account of their construction contexts and make safe design choices, using an iterative process from inception through to the detailed design phases.

The critical challenge here is the skill gap of designers. Recent industry surveys show that many designers do not have either this kind of knowledge or the skills to undertake PtD effectively (Zou, Yu and Sun 2009; Cooke, Lingard and Blisman 2008), thus continuing to expose construction workers to unnecessary risks and themselves to new legal liabilities. Since designers are predominantly trained in design principles and they do not often work on construction sites, they usually have only limited practical knowledge of construction operations and contexts triggered by their designs. Detailed knowledge of construction technology, workplace health and safety, and risk management is essential to undertake meaningful PtD analyses. Hence, the availability of a mechanism to provide designers with integrated knowledge and decision support is of critical importance to overcome this challenge and thereby fostering PtD adoption in industry. Moreover, any new system proposed should be affordable and available for most designers regardless of their organisational size.

Recent advances in mobile computing technologies provide unique opportunities for developing cost-effective, novel decision support systems for the construction industry. The management of knowledge and information made possible by mobile computing devices (e.g. personal digital assistants, smartphones and iPads), together with mobile Apps, has critical aspects that best suit and appeal to designers as they can provide anytime, anywhere access to contents, just-in-time support and a media-rich interactive environment (Acar et al. 2008). Many construction-specific mobile Apps are already in use, ranging broadly from specific purpose calculators to design, collaboration and site monitoring tools (Mike 2011; ConstrucTech 2011). In contrast, and despite this proliferation, the potential of mobile computing technologies for accident prevention through design has not yet been explored.

In light of the critical issues and knowledge gaps discussed above, this research aimed to establish a new knowledgebase and system models necessary for the development of a mobile computing solution, which can assist designers in reducing the high toll of construction accidents by prevention through design strategies.

The realization of the research aim was achieved in the context of fall prevention in construction. Research shows that falls are a dominant cause of fatalities and serious injuries in construction globally. In the US and Hong Kong, for instance, almost 50% of construction fatalities are due to falls from heights (Bureau of Labor Statistics 2010; Chan et al. 2008). Likewise, Australian Safety and Compensation Council (ASCC) (2009) reported that falls from heights represent the largest cause (one-third) of all construction fatalities in Australia. Prevention and control of falls is therefore a key priority in construction.

Research Methodology

The research consisted of five facets, and each facet involved different research methods, as illustrated in Figure 1. The facets were: (1) Establishing a new knowledgebase to support fall PtD; (2) Developing a rapid prototype mobile App for the purpose of reviewing the new knowledgebase and for acquiring user expectations of App functionalities; (3) Industry review of rapid prototype mobile App; (4) Developing a working mobile App for fall PtD; and (5) Verifying and validating the mobile App.

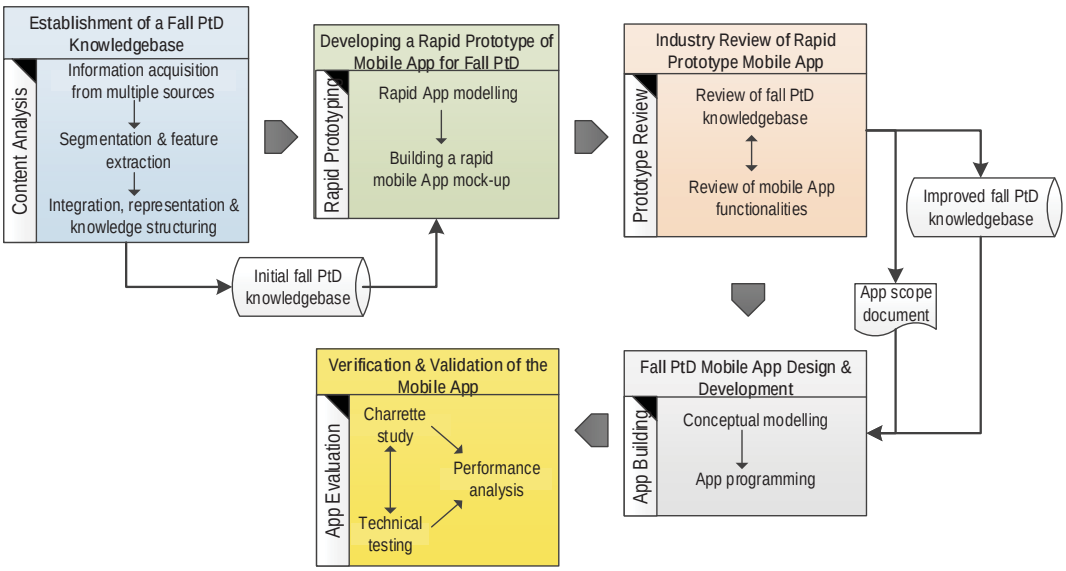

Figure 1: Research process

The establishment of a new fall PtD knowledgebase was fundamental to the development of the mobile App. The knowledgebase was built through a detailed content analysis of documents and literatures such as research publications, workplace health and safety authority manuals and industry reports. In the content analysis, information from multiple sources was extracted and grouped under themes and sub themes, and then was integrated to form PtD suggestions under the themes and sub themes. In parallel, 3D illustrations were also developed to strengthen the PtD suggestions with visual explanations.

It was essential to: (1) review the PtD knowledgebase before using it in the App, and (2) acquire user expectations of the App functionalities to support fall PtD. A rapid prototype App/mock-up was developed based on the author's ideas of the functionalities required to support PtD. Following that an industry review of the rapid prototype was administered in that the prototype was demonstrated to industry professionals who are involved in design reviews for safety. Their approvals of the PtD knowledgebase and the App functionalities as well as suggestions for further improvement were acquired. These facilitated the establishment of solid a scope document and a knowledgebase for an effective App.

With the verified scope and the knowledgebase, the research proceeded to develop a working mobile App. Conceptual models such as a knowledge representation map, decision logics, App layout model and App operation model were first created, which were then followed in programming the App in Apple's software development kit, Xcode. Finally, the App was evaluated in a case-study driven charrette workshop whereby the App was crosschecked whether it can effectively achieve its intended purpose of harnessing fall PtD.

App Conceptual Modelling

The goal of the proposed App was to provide building designers (architects and engineers) with decision support during early and detailed design stages to enable them to implement fall PtD effectively. Hence, it was crucial to understand and acquire the expectations of potential users of the App in terms of its functionalities. Nonetheless, it would be difficult and ineffective to document user needs only by interviewing potential users when they have never had any experience with an

App of this nature. Therefore, the author adopted an experiential approach to acquire user requirements with a help of a rapid prototype App.

After establishing the fall PtD knowledgebase, the author developed a rapid prototype App based on his ideas of the functionalities required for the App to support fall PtD decisions. Then, the mock up was demonstrated to construction industry professionals followed by interviews, seeking their approval for existing functionalities and suggestions for further functionalities. This enabled the acquisition of user requirements productively as the potential users felt the proposed App through the prototype and responded pertinently. The demonstrations and interviews were held with architects and engineers in two well-known firms in Sydney; one of them was an architectural practice while the other was a design-build contractor. Subsequently, the following functional requirements were finalised for the App:

- The PtD knowledgebase should be organised and presented in a modular fashion so users can easily and quickly view/retrieve necessary information from the App.
- A content filtering method should be made available in the App so users could obtain specific PtD suggestions for a particular design project undertaken at a given time.
- Users should be able to save project-specific PtD suggestions for later use or record keeping purposes.
- Facilities for the creation of PDFs of project-specific PtD suggestions and emailing the PDFs should be made available in the App.
- The App should standalone and work without internet connectivity for improved applicability and flexibility in use at work, regardless of the user's location.
- From the author's perspective, it was necessary to include a disclaimer and acknowledgements for purposes of potential liability management.

In addressing the user need of modularised PtD knowledge contents, a knowledge map was created to logically represent fall PtD knowledge into appropriate clusters. Altogether there were 85 sets of design suggestion in the knowledgebase, accompanied by 3D illustrations. These suggestions were organised into clusters as outlined in Figure 2.

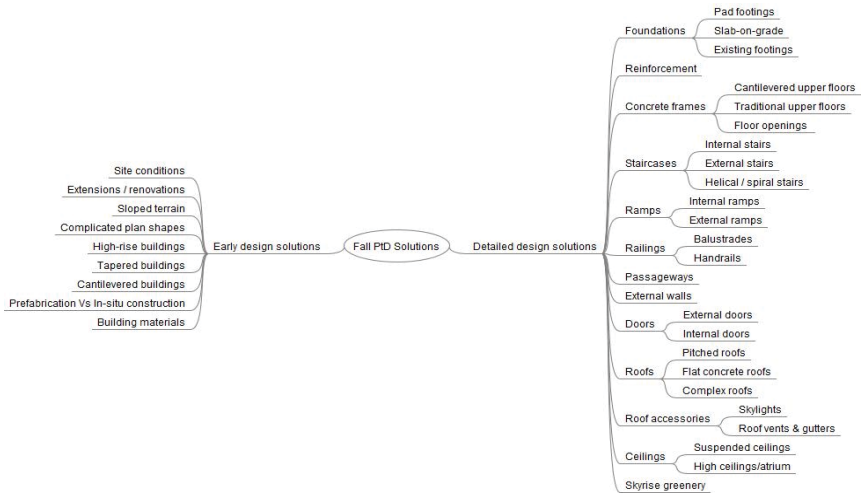

Figure 2: Fall PtD knowledge representation/map

The functionality for content filtering was achieved by the introduction of two questionnaires, corresponding to the two design phases shown in the knowledge map. The questions in the questionnaires correspond to the clusters in the knowledge map. Completing the appropriate questionnaire at a given phase will result in the user obtaining project-specific PtD suggestions for the clusters.

It was decided that the App would have an in-built database to store PtD knowledge and project details, rather than adopting a server or cloud-based model. User operations and functionalities of the App were modelled as shown in Figure 3, which lays out the App pages and explains how different functionalities are integrated into different pages. The key functions of the App are as follows:

- Splash screen - shown on App launch. After few seconds later, the App will start.
- Disclaimer - shown after the splash screen, displaying disclaimer contents. The user will have to accept the disclaimer to use the App.
- Acknowledgements - Once the user have accepted the disclaimer, the user will be navigated to the acknowledgement page, which displays pre-defined contents and the user will be able to use the App for decision making after navigating from this screen.
- Home Screen - will act as the main screen of the App and will provide two options for the user. Available options will be - Early Design Fall PtD and Detailed Design Fall PtD. The user can select a preferred option.
- Early / Detailed Design Fall PtD Screen - displays informative text and three options, namely; all PtD suggestions, project specific PtD suggestions and saved projects.
- All PtD Suggestions - clicking on this will enable the user to view all suggestions stored in the App under the category (either early design or detailed design). Knowledge contents for the categories are arranged according to the clusters shown in the knowledge map. In order to simplify knowledge retrieval, the PtD suggestion sets and the associated 3D illustrations for a given cluster are laid-out in a thumbnail fashion, in which, whenever the user selects a thumbnail it will expand in a separate page and display the full content of PtD suggestions. This also offers improved flexibility and easiness in moving across different sections and subsections.
- Project Specific PtD Suggestions - this option allows the user to create new projects wherein the user can view suggestions based on his/her project requirements. Selecting this option will ask the user to provide a project name to start. Thereafter the user will be presented with a questionnaire, which the user would need to complete to obtain suggestions tailored to project needs.
- The questionnaire presents pre-defined early/ detailed design fall PtD questions wherein the user has to answer each question by either selecting Yes or No. Answers will be immediately saved as the user provides. The user has to answer all the questions to view the suggestions, and at least one question must be answered to have the project saved in the App for future retrieval.
- The user would have an option to reset the answers. It will clear answers of all the questions for a given project. However, a project without any answers will not be saved. Hence, a reset project will not be saved. If a project's answers are reset and no questions are answered thereafter, then the previous answers will be retained.
- Upon completing the questionnaire, the user will be presented with the suggestion page whereon the user can select any one and view, generate a PDF of all project specific suggestions or share the PDF via email.
- Saved Projects – previously saved projects will be listed on this screen where the user can view suggestions, change answers to the questionnaire or delete the project from the database.

Following the planning and scoping process, wireframes for the App were created using OmniGraffle, based on the aforementioned functional requirements, business logics and view layouts. These wireframes then guided the programmer in building the App.

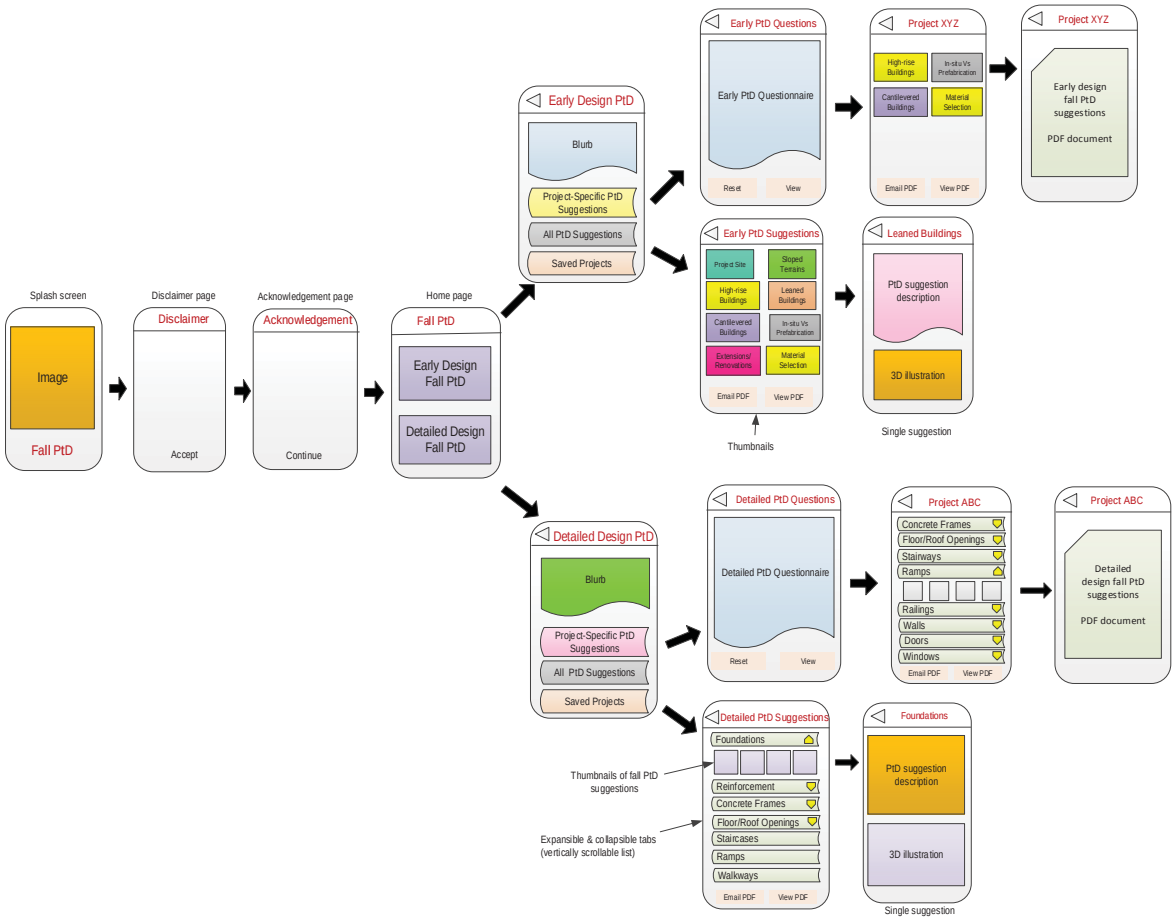

Figure 3: App layout model

Add Building

The fall PtD mobile App was built to be compatible with Apple mobile devices such as iPhones and iPads. Mobile Apps can be developed for a single or multiple platform compatibility, such as Apple, Android and Windows mobile. However, building mobile Apps for multiple platform deployments requires cross platform testing, additional resources and extra time. In order to optimise the efforts and resources in the research, it was decided to build only an Apple compatible App. Apple's SDK, Xcode, was fully utilised to build the fall PtD mobile App. Figure 4 shows iPhone versions of some screenshots of the App views. The first three images depict how project-specific PtD suggestions are obtainable at the early design phase whilst the second three images illustrate how individual suggestions from the "all PtD suggestions" can be viewed.

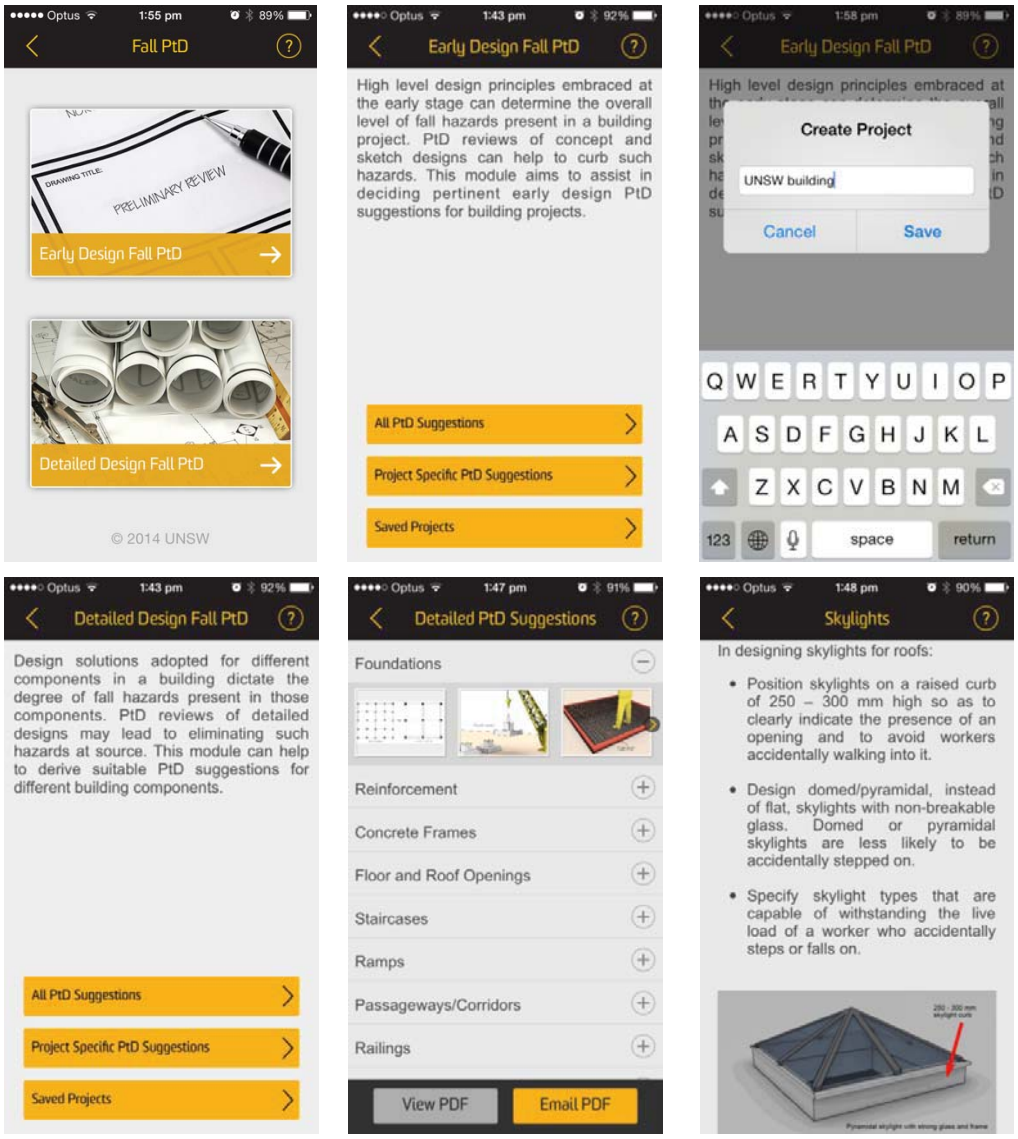

Figure 4: App screen examples

App Evaluation

The research adopted a case study-driven charrette workshop technique of evaluation. Charrette workshops allow conflicting issues around proposed design solutions to be tabled and evaluated by stakeholders, leading to the arrival of refined design solutions in an efficient and collaborative manner (Smith 2012). This is a well-established methodology for design reviews in the construction industry, whether it is for project feasibility studies, value management studies or safe design reviews. This approach was deemed more appropriate for the evaluation of the new mobile App because:

- The process exercised in the evaluation would be a simulation of how the mobile App would be used in the industry in different projects/scenarios
- It would provide a quicker evaluation opportunity
- Feedback from the evaluation participants are drawn from firsthand experience with the process and the App, thus would be more effective.

The workshop was administered with eight early career building professionals in a session that lasted for about four hours. The participant mix included five architects, two civil engineers and one builder. All of them possessed at least a bachelor's degree in their relevant discipline. On commencement of the workshop, a short questionnaire survey was conducted with the participants to assess the degree of their pre-knowledge, skills and experiences in accident prevention through design. Responses for the following question were sought for this purpose:

> *How would you rate your current level of skills/knowledge in making better design choices to prevent fall accidents during construction and maintenance of buildings (1 = low; 5 = high)?*
>
> *1 2 3 4 5*

The result demonstrated that the participants possessed only limited knowledge, skills and experiences in fall accident prevention through design before the workshop. Subsequently, the workshop proceeded in the following manner:

- A powerpoint presentation covering the concept of accident prevention through design was made to the participants, which lasted for about 30 minutes;
- Then, the fall PtD mobile App was introduced and the participants got it installed on their iPhones or iPads;
- Next, two groups were formed and were assigned the task of reviewing two real building designs with the support of the mobile App. One of them was a conceptual design while the other was a detailed design of multi-storey commercial buildings;
- The design review exercise lasted for about three hours and the participants recorded the review results in a template provided.

The participant group that analysed the concept design discovered eight critical design issues that are conducive to fall hazards and the other group discovered ten hazardous design features and provided alternative design suggestions within the limited time available.

The initial survey that assessed the participants' proficiencies in PtD proved that they were less-skilled. However, with the support of the mobile App, they produced design review reports of high standard as expounded in the preceding section. Moreover, at the conclusion of the review exercise, the question was repeated to the participants. The two different responses given by the same participants for the same question are compared in Figure 5.

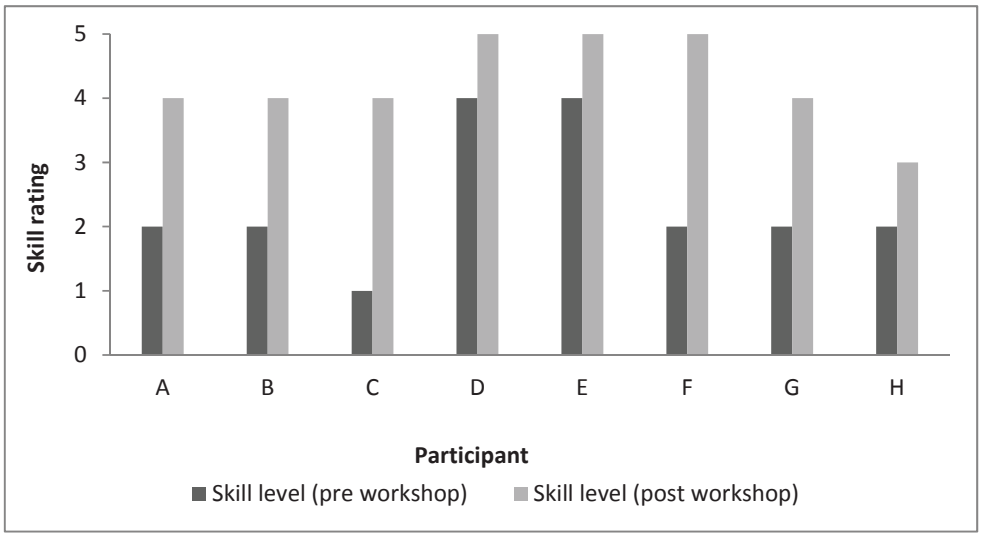

Figure 5: Comparison of skill levels

Conclusions

Building design concepts and choices made by architects and engineers are criticized to be a key causal factor for these falls in about 40 – 50% of circumstances. Conversely, better designs can significantly reduce falls in construction. Prevention through Design (PtD) is therefore recognised by the construction industry and researchers as an effective means to improve site safety as it helps to eliminate hazards at source. Realising its potentials to curtail construction accidents, many governments around the globe have mandated PtD since recently. This legislative change has redefined the roles and responsibilities of designers that they are now required by law to exercise PtD in their design practices. In other words, designers such as architects and engineers may be held liable for accidents that befall in projects designed by them. Whilst this change is healthy for the construction industry and operatives, it concerns designers because of the gaps in knowledge and skills they are encountering. Having primarily trained in design principles and not been exposed to construction processes, designers have limited understandings of the hazards and risks triggered by their design concepts and choices. This impedes the successful adoption of PtD. It is therefore essential that designers have access to such integrated knowledge and decision support tools if curtailing lethal fall accidents in construction to be achieved.

To this end, this study, harnessing the power the mobile computing technologies, provided designers with a mobile App for receiving modular and just-in-time PtD decision support. Mobile Apps in general are: simple and easy to use by designers with any level of ICT competency, and cost effective and offer wider accessibility compared to web systems or standalone decision support systems. Hence, this technology is less likely to face resistance within an organisational context due to these desirable qualities.

The mobile App could act as a catalyst for a faster adoption of PtD in design practices of all sizes, and help designers to exercise their duty of care and due diligence under the workplace health and safety legislation. Consequently, this can assist in producing safe-to-build designs in the industry and thereby reducing construction accidents, particularly falls. This would discharge not only designers from their legal responsibility, but also clients and builders because in the event of an accident, the current situation is that everyone along the supply chain is likely to be held accountable and/or investigated. This causes productivity losses and other economic and business negative impacts for all the said parties.

References

Acar E, Wall J, McNamee F, Carney M and Öney-Yazici E. (2008). Innovative safety management training through e-learning. Architectural Engineering and Design Management, 4(3):239-250.

Australian Safety and Compensation Council (ASCC) (2009) Compendium of workers' compensation statistics Australia 2006-07. URL (accessed 09 Nov 2009): http://www. Safe work australia.gov.au / NR/ rdonlyres/ 6661279D-D04E-4142-97E7-69997CEC0157/0/ PARTEJourneyclaims200607.pdf.

Behm M. (2005) Linking construction fatalities to the design for construction safety concept. Safety Science, 43(8):589-611

Bureau of Labor Statistics (2010) Census of fatal occupational injuries summary 2009. Economic News Release, URL (accessed 10 Feb 2012): www.bls.gov/iif/oshcfoi1.htm.

Chan A, Wong F, Chan D, Yam M, Kwok A, Lam E and Cheung E. (2008) Work at height fatalities in the repair, maintenance, alteration and addition works. Journal of Construction Engineering and Management, 134(7):527–35

ConstrucTech (2011) Construction Apps extend functionality, URL (accessed 09 Jan 2012): http://www.constructech.com/news/articles/article.aspx?article_id=8864.

Cooke T, Lingard H & Blisman N. (2008) ToolSHeDTM: the development and evaluation of a decision support tool for health and safety in construction design. Engineering, Construction and Architectural Management, 15(4):336-351.

Creaser W. (2008) Prevention through design (PtD) safe design from an Australian perspective. Journal of Safety Research, 39(2):131-134.

Gibb A, Haslam R, Hide S and Gyi D. (2004) The role of design in accident causality. In Hecker S, Gambatese J and Weinstein M (eds), Designing for Safety and Health in Construction: Proceedings, Research and Practice Symposium. Eugene, OR: UO Press.

Kamardeen I (2010) 8D BIM modelling tool for accident prevention through design. In Egbu, C (ed), Proceedings of the 26th ARCOM Conference. University of Leeds, UK, 6-8 Sept. 2010. Leeds: ARCOM. Vol.1, pp.281-289.

Mike, N. (2011). How mobile apps changed the construction industry. URL (accessed 9 Jan 2012): http://www.onthegoware.com/mobile/mobile-apps-changed-construction-industry.

Zou P, Yu W and Sun A. C. S. (2009). 'An investigation of the viability of assessment of safety risks at design of building facilities in Australia. In H. Lingard, T. Cooke and M. Turner (eds), Proceedings of the CIB W099 Conference, Melbourne, Australia, 21-23 October 2009, Melbourne: RMIT University. CD-ROM, paper No 12.

Smith N. D. (2012) Design charrette: a vehicle for consultation or collaboration. URL (accessed 12 Feb 2014): http://www.kwokka.com.au/assets/nicola-d-smith-design-charrette.pdf.