

DESIGN RISK MANAGEMENT PRACTICES AND ASSESSMENT TOOLS FOR SAFETY IN CONSTRUCTION: OPPORTUNITIES FOR BIM

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The imperative to improve workers safety and health is gaining momentum in the construction industry in a number of countries (e.g., UK, Australia, US). Prevention through Design (PtD) or comparable concepts (i.e., Design for Safety) are a core strategy considered critical in improving overall safety performance. PtD proponents argue that architects and engineers can have an impact on safety considerations during design. However, there is lack of knowledge on what tools designers utilize for safety design. Design risk management strategies and assessment tools for safety are studied and opportunities for BIM safety design tools are identified. To gather broad industry perspectives, this investigation adopted the survey research method that involved professionals from the US, UK, Australia and other countries. The survey was developed based on literature on hazard identification/risk assessment tools, and expert interview discussions. The survey collected data on general design protocol and BIM infrastructure, familiarity with PtD, references of safety regulations and standards, and PtD tools and processes. The findings illustrate most commonly used tools and effective strategies, type of design tools used for construction, maintenance/operations, comparisons of disciplinary perspectives and comparisons of countries. The survey illustrates common usage of BIM for safety considerations and reveals which types of PtD tools provide potential for integration with BIM, and shortcomings of BIM for PtD. This research has practical and social implications for professionals particularly designers, by providing a broad perspective on PtD adoption and PtD tool usage. It provides insights for BIM software developers highlighting potential areas for tool development. The project contributes to the body of knowledge of PtD tools which will benefit from this baseline study on current tools and exploration of potential areas for BIM tools.

Keywords: risk assessment, BIM, design, PtD, safety

INTRODUCTION

Construction continues to result in frequent loss of life, injuries, near-misses, and collateral damages which can be prevented through design considerations for safety. However, designers' interests in worker safety remain low. Gambatese et al. (2005) found that designers ranked "quality of work" their highest priority and "construction worker safety" as their lowest. "Final occupant safety" is ranked as second in this list followed by "project cost", "project schedule" and "aesthetics".

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Factors contributing to the low attention to workers' safety are the lack of tools and resources that assist designers and engineers. Current approaches in the field are primarily text-based check-list-type tools either accessed via paper or software interfaces (e.g., CII IR101-2, Design for Construction Safety Toolbox, 2011), and are applied manually to design drawings or in construction documentation in the field (e.g., by in-the-field tablet computers). Past safety research shows that the construction industry lacks design support tools for hazard identification and control in the early phases of design and planning (Ku and Mills 2010).

On the other hand, performance-based design approaches supported by BIM are becoming state-of-the-art practices (Hänninen 2006). BIM tools with parametric capabilities linked to various simulation tools offer the ability to rapidly generate and evaluate many design alternatives in the search of successful schemes (Akin 2002). Adopting this trend, the US AIA offers energy modelling guidelines incorporating BIM processes as an important area of performance modelling (AIA 2012).

In parallel, design risk management focusing on health and safety risks (Griffiths and Griffiths 2011) has evolved from design management processes (Gray and Hughes 2001). Adding to the scope of design reviews which consider reliability, serviceability and maintainability of the building, assembly tolerances, buildability, aesthetic criteria, failure modes and fault analysis, etc., design risk management involves risk assessment with a process of hazard identification, consideration of the risk and best design action to avoid, reduce or transfer the risk to another party for action.

The performance-based design paradigm is offering rational ways of addressing several types of risk in built facilities and environments such as structural collapse, damage, comfort, quality of life and preservation of cultural and historical values (Augusti and Ciampoli 2008). Performance based design shifts the focus of design objectives from ensuring engineering solutions at a minimum cost in a deterministic context to aiming at minimizing the total probabilistically calculated losses or life cycle costs. However, defining the problem of health and safety into probabilistic approaches is a significant challenge. Furthermore, optimizing health and safety design considerations with multidisciplinary performance criteria of aesthetic, social, ethical, and financial aspects requires simultaneous research in the areas of design risk assessment, performance-based design and BIM. To provide a baseline of performance driven design approaches in design risk assessment for health and safety, this research examined existing design tools for safety and health, and the effectiveness of these tools in practice. The use of current BIM tools and methodologies were investigated to identify opportunities for new tools.

RESEARCH METHOD

This investigation was part of a three stage research (Ku 2013) defining the baseline of most commonly used tools and effective strategies in designing for safety construction, maintenance, and operations, and the potential opportunities for BIM tools to improve such processes. Findings from the second phase are presented in this paper. The second stage was based on an online survey on the most commonly used tools and effective strategies, type of design tools used for construction, maintenance/operations, compared

by disciplines and comparisons of countries. The survey collected data on common usage of BIM for safety considerations and revealed which types of PtD (Prevention through Design) tools provide potential for integration with BIM and the shortcomings of BIM for PtD.

The survey questions incorporated input from expert panel interviews conducted during the first phase which helped to focus the scope of survey.

The online survey was distributed via SurveyMonkey (<https://www.surveymonkey.com>) between May 23 and June 21, 2013, to reach a broad sample of participants. Architecture, engineering, health & safety professionals and construction firms were identified. Contacts were collected based on various online sources, industry connections, and regional and international professional trade organization chapters. 459 individual contacts of architecture, engineering, and integrated design/engineering/construction firms were identified based on Engineering News Record (<http://enr.construction.com/toplists/>) and individual companies websites, 75 architects in the Philadelphia Region, 17 US professional organizations (e.g., AIA and ASCE, structural engineers regional chapters in New York City, Philadelphia, Chicago, Los Angeles, etc.) and corresponding chapters in the UK (8 RIBA chapters and 12 ABE chapters) and Australia (12 RIAA chapters-subcommittees and 5 engineering association chapters). The survey link was also posted on social network LinkedIn (<http://www.linkedin.com/>) interest groups - the Safety in Design and Safety in Design UK group. A total of 141 people responded of whom 138 were included in the analysis as they responded by the deadline.

The survey was broken up into six subsections including: (1) Demographics, (2) General Design Protocol/Procedures & BIM, (3) Prevention through Design (PtD), (4) Standards/Regulations, (5) Tools and Procedures, and (6) Final Remarks. Key results from the survey are selectively presented below.

SURVEY RESULTS

Demographics

Regarding the country of practice, 69% of the respondents practiced in the US, while the numbers of UK and Australian participants were equally at 14%. People from countries outside of these three comprised just 3% of responses.

Respondents were allowed to check multiple roles for their profession as it was anticipated that certain professionals would have multidisciplinary responsibilities and backgrounds. The roles were then condensed into 5 categories including architect, engineer, construction manager, H&S professional, and other, accounting for primary roles. The majority indicated a single primary role; others indicated multiple roles such as architect and engineer, or construction manager and H&S professional. The "Other" category comprises people who did not identify as Architect, Engineer, Construction Manager, or H&S Professional and included Trademan, Software Developer, Facility Manager, Developer, Academic/Educator and a few others.

Figure 1 shows the distribution by profession, architects being the largest group.

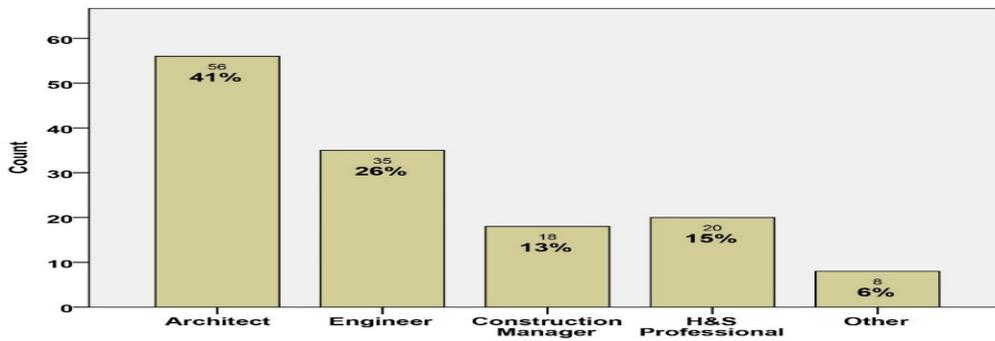


Figure 1: Demographics by profession

In terms of positions within companies, the largest number of respondents indicated they were at the Executive/Principal level (45%), while Senior Project Managers and Project Managers made up 28% and 20%, respectively. Junior and Entry level employees made up just 7% of the respondent pool.

72 of the 138 respondents completed the survey at a completion rate of 52%. The drops in the survey population progressively coincided with the sections which moved from general practice questions towards more specific safety design practice and tools questions.

General design procedures and BIM

The survey asked about general design review procedures where the majority of engineers (89%) and architects (80%) indicated participation in design reviews frequently while only half of H&S Professionals participated in design reviews. This question was used as a filter for the following question asking about the purpose of the review. Those participating in design reviews were asked about the purpose. The top response was Code Compliance (17%) and General Design Revision (17%) and Constructability (16%) followed third. Overall, construction (9%) and Maintenance worker's safety (8%) were lower priorities. For US respondents construction and maintenance worker's safety were lower priority compared to their UK and Australian counterparts.

To understand company infrastructure, the survey questioned usage of BIM. The US exhibits a far higher usage of BIM tools at 69% (of 78) compared to 56% (of 16) in the UK and 44% (of 18) in Australia.

Revit was the most reported BIM platform to be used by the respondents at 48% while four major BIM applications were identified. The first and second applications were clash detection and coordination (14%) and design configuration/scenario planning (14%). The third and fourth applications were design communication, presentation, review (13%) and space planning & program compliance (12%).

Prevention through Design

Section 3 of the survey, entitled "Prevention through Design", focused on the respondents knowledge of PtD, as well as practices and attitudes associated with its implementation. One question was designed to establish if knowledge of PtD exists in the survey sample.

In this check-all question, the respondents were given the choice of PtD, CHPtD, Design for Safety, Safety in Design, Other similar Concepts, and finally "Do Not Know". The results show that general knowledge of PtD by Architects in the US is low, while the small sample of UK and Australian architects were aware of the concept. Other professions in the US including Engineer, Construction Manager, and H&S Professional showed more knowledge of PtD, however represented a smaller sample size.

To a question about whether the respondent thought considering safety during design can improve worker's safety and health, 92% (of 105 respondents) reported it could be improved.

Survey participants were asked about their experience with both hazard identification and risk assessment in Construction Safety, Maintenance and Repair, and Demolition. Figure 2 relates this data by profession. Across all professions, respondents had the most experience in Construction Safety compared to maintenance and demolition. Interestingly, for both hazard identification, and risk assessment, architects chose "N/A" more frequently than the other choices. These results are biased towards US architects who were the largest group in the demographics and illustrates that the architects do not apply hazard identification or risk assessment for worker safety.

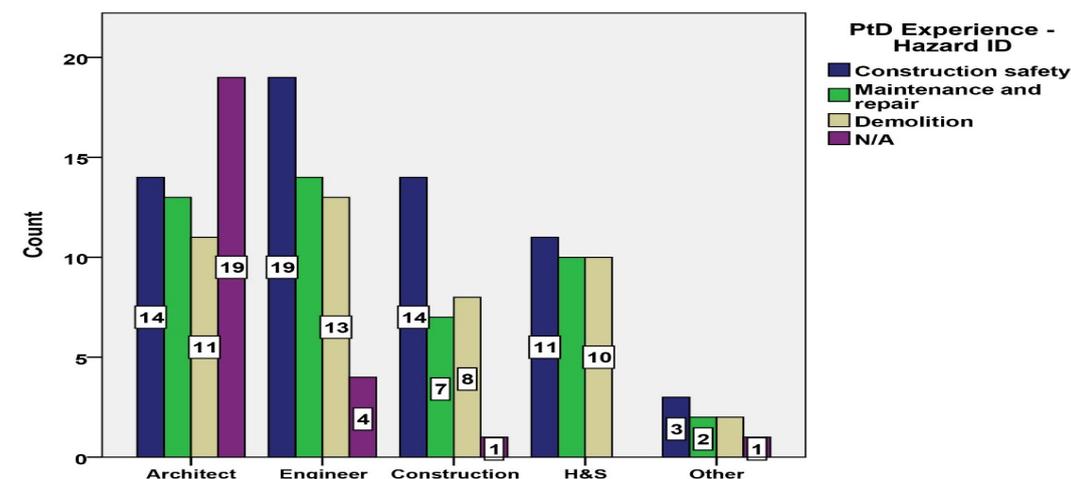


Figure 2: Hazard identification experience by profession

The survey continued with a follow-up question about the hazard prevention concept known in the UK as ERIC - the acronym for "Eliminate the hazard, Reduce the hazard, Inform of the Risk, Control the risk" - or described as a "hierarchy of engineering controls." The idea for any given hazard is that if you cannot eliminate it, then reduce it, and if you can't reduce it, then inform people of it, and so on. The responses show that all professions except for architects have knowledge of this concept. 22 of 38 architects reported that they were not familiar with this method of thinking. This matches the lack of responses for PtD knowledge and shows a trend that the architects in this survey have yet to make safety and hazard prevention a part of their design process.

The next set of questions asked about the design phases during which participants addressed safety and health issues with respect to construction workers, maintenance

workers, and demolition workers. For construction worker safety and health issues, design considerations tend to be addressed most frequently during the Construction Documentation phase. Similarly for maintenance workers, however a slightly larger number of respondents indicated the design development phase, meaning that this might occur a bit earlier in the process. For demolition workers, next to construction documentation phase a larger population selected N/A for the response, indicating that this category is often not considered during design.

Standards and regulations

Section 4 of the survey had a single question about the standards and regulations used by the respondent's practice. In the US, the IBC 2012 standard was listed as the primary standard referenced, with OSHA standards 1910 and 1926 mentioned the second and third most amount of times. In the UK, only two choices stood out as frequently used standards, with the CDM 2007 regulation coming in as the first most reference, and then the Assurance in Construction regulation. Australians also cited the Assurance in Construction regulation, but the majority of respondents listed "Other" as the standard. While not very specific, in the open response section for this question respondents mentioned that Australia has its own set of building regulations and codes that were not on this list.

Design tools and procedures

Section 5 asked about design tools and procedures used in consideration of construction and maintenance safety issues. Figure 3 shows the frequency of responses for each tool broken down by profession within each country. In the US, the tools with most responses across all professions were material safety data sheets and code compliance checklists. Respondents from the UK picked design guides most frequently for the Engineering and H&S Professionals. However, the other professions did not have enough respondents to offer conclusive interpretation. Australia was a small sample size but for the architects code compliance checklists seemed to be the most popular choice.

Similarly the next set of questions required survey participants to rate five types of design tools from "least effective" to "most effective", with an additional option of "N/A". Architects tended to rate code compliance checklists higher, while engineers and health and safety professionals tended to prefer design guides when designing for safer construction or maintenance. When viewed by country, respondents from the US tended to rely more on code compliance checklists, while design guides were favored in the UK and Australia.

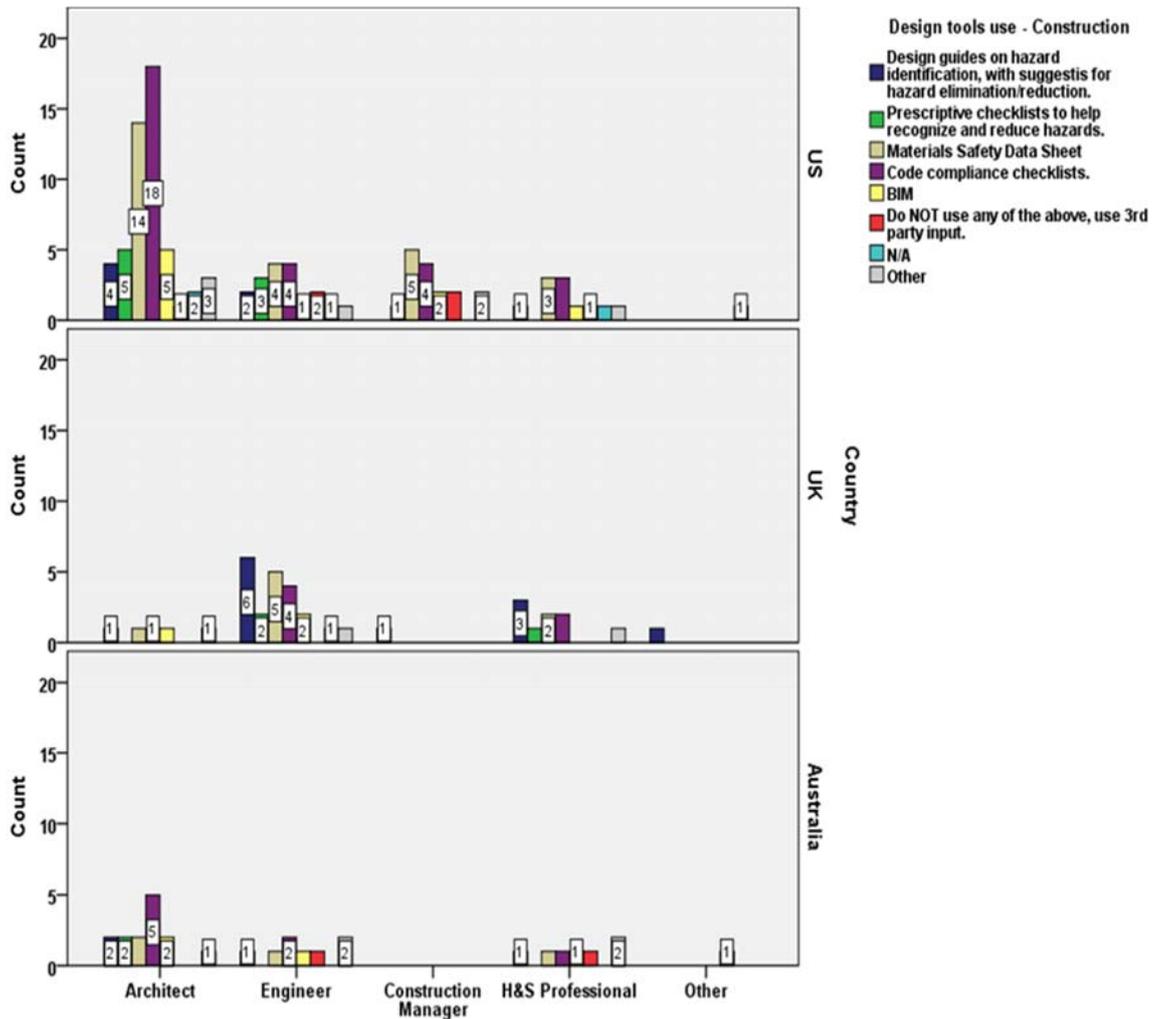


Figure 3: Usage of safety design tools by profession and country

The survey asked respondents to select all of the tools that they have used for risk assessment in their practice. A large number of US architects responded that they do not use any of the risk assessment tools themselves but a number of architects responded they use risk assessment matrices, cost-benefit matrices and colour coding techniques. The UK and Australian sample was small but engineers and H&S professionals named Risk Assessment Matrices most frequently.

Similarly to the previous question, the participants rated the effectiveness from least effective to most effective. Risk assessment matrices were rated higher among architects. Colour coding techniques and residual risk registers, were rated higher amongst engineers and H&S Professionals. Construction managers rated BIM tools highest. When viewed by country, colour coding and BIM tools were rated highest in the US, where residual risk register was rated the lowest. In contrast the UK and Australian participants rated BIM tools as the lowest in effectiveness, while Risk Assessment matrices and colour coding were rated the highest. One question asked respondents to select which methods they used

to conduct design reviews. Overall results show that two most popular methods were “Integration throughout the Design Process” and “design reviews at 30%-60%-90% completion points (30-60-90).” When viewed by country, as shown in Figure 4, the “Integrated” and “30-60-90” approaches were the top choices in the US. In the UK, the “Integrated” method received the majority of responses, but “Specialized review teams” came in with the second highest level of responses. In Australia, the highest number of responses followed the overall trend, showing “Integrated” and “30-60-90” as the primary methods, and the “CHAIR” method was also among top choices.

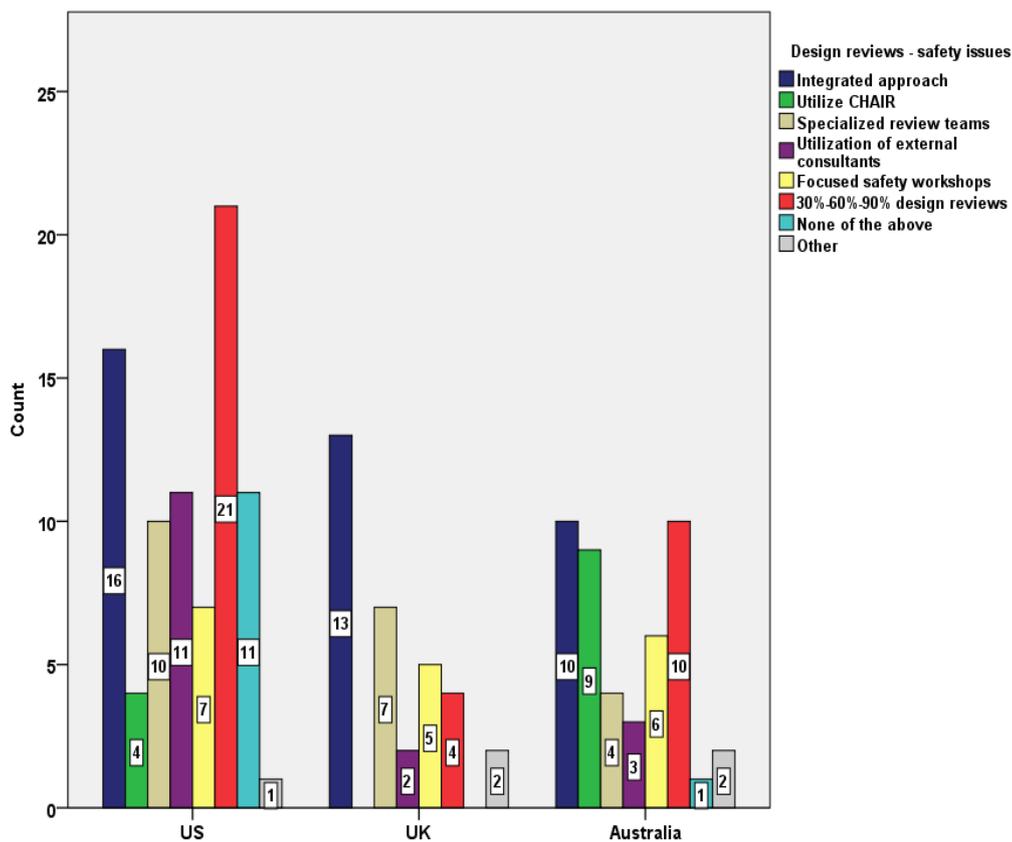


Figure 4: Design review techniques by country

The mean effectiveness ratings for the design review approaches show that the two highest mean ratings are received by the “Integrated Process” and “Review teams within Company”.

By profession, as shown in Figure 5, the “Integrated approach” was given the highest mean ratings by architects, engineers, construction managers, and members of other professions. H&S safety professionals gave the highest mean rating to “30-60-90” reviews; however, “Integrated Approach” and “Focused safety workshops” were given equal and slightly lower mean ratings.

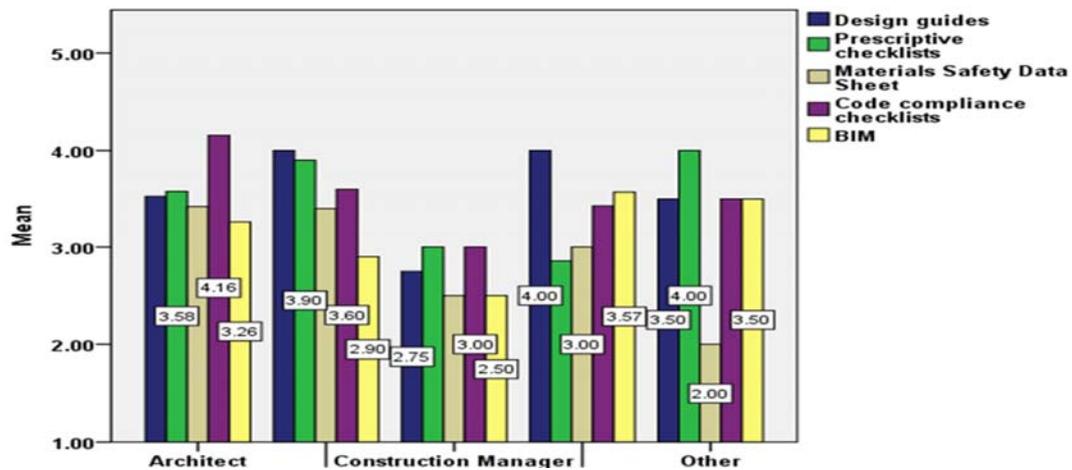


Figure 5: Design review techniques effectiveness rating by profession

Fel! Hittar inte referensskälla. Analysing the mean effectiveness ratings by country, the “integrated approach” had the highest mean effectiveness rating across all countries. “Utilization of external consultants” in this view, seems to have the lowest effectiveness of all of the options.

Regarding use of digital models, 3D models were the most popular type of digital models utilized in safety design (25%). However, an equal number of people indicated that they do not use models to consider health and safety issues. And 4D sequence visualization was used by only 14%. Further filtering the result by profession reveals that architects think 2D modeling has a slight advantage over 3D and BIM tools, while 4D/Sequence modeling had few respondents across the disciplines. There was also a sizeable portion of architects who do not use models for safety. For engineers some indicated that they use 3D models but the majority responded N/A. While response numbers were lower for construction managers and H&S professionals, 3D modeling had received the most responses out of this group.

The next question asked respondents to select the design phases during which they typically use a selection of safety design tools. For concept/schematic design, in the US, a large number of the sample does not use any design tools. For those that use tools however, the most popular tool was the design guide. In the UK and Australia, the most popular response was risk assessment tools. During design development phase, a large number of US respondents indicated they do not use safety design tools but those who use design tools responded BIM/Visualization tools and design guides as their main tools. UK and Australian respondents again chose risk assessment tools most frequently during this phase of the project. Hazard identification checklists and design guides were chosen as the second and third highest responses for these countries.

For construction documentation phase, most US respondents indicated the use of BIM/Visualization tools. Respondents from the UK and Australia answered similarly as in the previous project phases, choosing risk assessment tools as the primary tool used, followed in both cases by hazard identification checklists.

The next set of questions asked about the main collaborators using hazard identification checklist, design guide, risk assessment tool, and BIM/visualization tool. Across the three countries and the four different tools, in-house design teams were indicated mostly while each tool varied in terms of other collaborators including the owner, external design and construction team. BIM/Visualization had the greatest popularity in the US within the in-house design team, while external constructors, owners, and external design teams had also high response frequencies. Asked about the overall usefulness of tools and processes in identifying and improving worker safety, architects rated design guides as the most useful tool while engineers selected hazard identification checklists most often. In contrast, construction managers found BIM/Visualization tools to be most useful identifying issues and improving worker safety, while H&S Professionals found design reviews to work the best.

The next set of questions asked to indicate the main benefits of hazard identification checklists. The most selected benefits were “Enhances Communication Internally”, “Facilitates structured safety reviews”, and “Improves Evaluation of Hazards”. Asked about the main benefits of design guides, respondents selected “Enhances Communication Internally”, “Promotes Creative Solutions”, and “Improves Evaluation of Hazards” as the top three responses. Then asked to select the main benefits that Risk Assessment Tools provide, the greatest benefits identified were “Enhance Communication within Internal Team.” Secondary benefits were “Facilitates structured review of safety issues” and “Facilitates evaluation of multi-disciplinary design issues”. Lastly, about the benefits of BIM/Visualization tools, the highest frequency response was “Enhances communication within internal team”, while “Facilitates evaluation of multidisciplinary issues” and “enhances external communication”.

CONCLUSIONS

The survey attempted to provide a benchmark of current PtD processes and evaluate their perceived effectiveness. Because of the varying sample sizes between different disciplines and countries, it is difficult to draw conclusive comparison between these different groups. The data requires further analysis to clarify biases of responses. However, the sample offers insights into the different industry contexts which align with respective regulatory contexts and practices. The results align with expectations based on literature. For example, the UK and Australian respondents show higher awareness of PtD related concepts and adoption specific practices of risk assessment and design guides whereas US practitioners rely more on prescriptive means (e.g., code compliance checklists, material safety data sheet). This obviously may be the result of the sample bias but it establishes the foundation for a baseline study and helps to verify a number of opportunities:

25. US practices have a larger BIM base which provide opportunities to incorporate emerging design risk assessment best practices
26. US practitioners showed a higher awareness and usage of PtD practices and process than expected
27. US design practices highlight a gap in the general knowledge base of PtD and demand educational and legislative efforts to address this gap

28. There are lessons to be learned from UK and Australian counterparts' safety design best practices
29. Safety design tools need to address both internal design team processes and external team processes.
30. BIM for safety purposes in the US is mainly driven by contractors.
31. BIM and visualization tools lack integration with current best practice tools for hazard identification, risk assessment and other design processes. The majority of the survey participants do not use software that assists evaluating hazards in designs and/or proposing alternative solutions to aid design decision making. Only a limited number of US participants mentioned the use of rule checking software like Solibri (<http://www.solibri.com/>), as well as BIM tools in Revit, Tekla (<http://www.tekla.com/us/>), etc. Some other software mentioned were Dyadem and Primetech. Many of the respondents believe that BIM can help designers to consider occupational safety and health during design more effectively. This requires improving and customizing content of the BIM tools. The study results offer a positive outlook for designing for construction worker safety with potential advancements in BIM to better visualize hazards during design.

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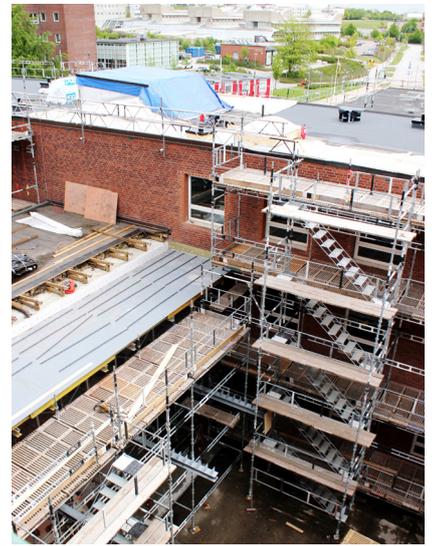
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