

Improving designers' knowledge of hazards

Development of a mixed-media digital tool to improve how designers learn about preventing hazards in their designs

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Abstract

Research has shown that up to half of construction accidents in the UK had a connection to the design. The UK's Construction (Design and Management) Regulations (2015) place duties on designers of construction projects to Design for Occupational Safety and Health (DfOSH). However, the majority of designers fail to recognise the impact on health and safety that they can make. Previous work shows that visual methods have been used to develop shared mental models of construction OSH hazards. There could also be links to alternative construction processes that may be utilised by the designer to reduce the inherent hazards in the design, thereby enhancing their knowledge of construction and maintenance processes.

The study aimed to improve how designers involved in construction projects learn about how their design influences the management of occupational safety and health once the design is implemented. The method involved the development of a multimedia digital tool for educating designers on typical design-related hazards. This tool was used in an intervention study with novice (n:20) and experienced (n:20) designers, split evenly between experimental and control groups. These groups were assessed via a novel hazard test using fictitious CAD drawings.

The results showed all experimental groups outperformed control groups, with the novice groups demonstrating the greatest increase in both hazards spotted and quality of alternative options recommended. Current research in this area promotes automated design choices for designers via building information modelling (BIM). However, the research presented here advocates keeping the 'human' in control, supplementing designers' knowledge with tacit knowledge gained from interaction from the developed digital tool, so that they can make informed decisions.

This study has not only contributed to research-led knowledge in the OSH discipline, but it has also delivered practical tools to help improve industry practice. DfOSH is a moral and legal obligation for designers and the research reported here can help novice designers in particular to improve their effectiveness in this regard.

Executive summary

Introduction

Designing for Occupational Safety and Health (DfOSH) is known by various names and the importance of designers in the management of OSH risks related to construction is well documented. The UK's Construction (Design and Management) Regulations (2015) place duties on designers of construction projects to consider the health and safety implications of their designs in relation to the construction, use and maintenance (including cleaning) of structures. However, the majority of designers fail to recognise the impact on health and safety that they can make. While many attempts have been made to develop digital tools to aid designers in this respect, including those embedded with BIM technology, the need for the designer to be competent is a common thread. The nature and scope of education for designers, combined with relevant site experience, has shown to be critical to successful DfOSH outcomes. Therefore, technology that seeks to remove the designer from the decision-making process around DfOSH – such as automated processes – could do more harm than good. A knowledge-based system seems to be the favoured method of giving designers the ability to make informed decisions on DfOSH. However, text-based systems have proven to be cumbersome, whereas visual (pictorial, multimedia) databases may be able to overcome the problems posed by overly word-based systems and provide a more effective solution.

Aim and objectives

The aim of this research was to improve how designers involved in construction projects learn about how their design influences the management of occupational safety and health (OSH) once the design is implemented. This focused on the impact of design decisions on OSH risks during the construction, use and maintenance of structures.

To achieve this aim, the following objectives were set:

1. Identify sector-specific hazards that can be influenced (either mitigated or aggravated) by designers of construction.
2. Evaluate strategies on how the hazards (identified in objective 1) can be prevented or mitigated by designers of construction.
3. Develop a 'hazards test' for designers, tailored to sector-specific hazards (based on the findings of objectives 1+2).
4. Develop mixed-media strategies to fill the 'experiential knowledge gap' of designers who work on construction projects, to improve their ability to complete the 'hazards test', thereby improving their ability to identify, prevent and mitigate hazards.
5. Validate the mixed-media strategies (of objective 4).
6. Develop a pilot database of mixed-media materials to aid designers of construction in their statutory duty to identify, prevent and mitigate hazards flowing from their design.

Methods

The method employed was one of exploratory action research, combined with the use of an experimental design to evaluate the ability of a multimedia digital tool intervention on designers' OSH knowledge and practices. Sector-specific hazards, which can be influenced by designers of buildings and structures, were identified through a systematic review of academic and industry literature. Other experienced professionals were recruited from the research team's industry network. The 'design-influenced hazards' informed the development of the multimedia digital tool and linked hazard-test instruments in the form of computer-aided design (CAD) drawings.

A sample of 40 designers from two typical industry groups of architects and civil engineers were recruited for the next stage of the research. The sample was purposefully chosen with half (20) experienced and half (20) novice. Designers were invited to engage with the developed materials in a carefully controlled experiment, which evaluated the effects of the multimedia materials on decision-making and users' capability in designing for OSH in the construction industry. The experiment determined whether use of the multimedia materials improved users'

ability to foresee OSH hazards in designs by measuring both the quantity of specific hazards identified and the quality of design outcomes (design controls) put forward. The sample was randomly assigned into multimedia user (experimental) and non-user (control) groups. Participants were asked to review the set of CAD drawings in these sessions, to identify hazards and make decisions about designing for OSH. A weighting was allocated to designers' decisions based on their recommendations against the following hierarchical list:

- (5) Eliminate (through design): prefabrication; locate item at ground level;
- (4) Reduce (through design): design in edge protection; substitution of lesser hazard;
- (3) Reduce (engineering controls): local exhaust ventilation; temporary edge protection;
- (2) Inform of administrative procedure: 'contractor to provide method statement';
- (1) Control through PPE: 'contractor to provide PPE'.

Data was compared for multimedia user and non-user groups and also between novice and experienced designers. This consisted of collecting data before and after use of the multimedia tool and corresponding data for the control group. The resulting quantifiable data allowed visual graphical and statistical analysis to detect any rise in frequency of hazards identified or 'hierarchy' score among the designers.

Findings

After filtering for generic hazards, the 40 designers identified hazards a total of 599 times. These were sorted into 29 categories. The most common types of hazards identified by all designers related to work at height. But this was supplemented by mostly health-related hazards post-intervention. The experimental group (who used the digital tool) identified 339 hazards in total, whereas the control group only identified 260. This difference was due to the post-intervention differences: experimental group 105; control group 27. The largest increases in the experimental group related to issues highlighted in the tool, e.g. high-level lighting, flooring and paint COSHH, and welding steel frame. The smaller increase in the control group (using the internet) included hazards relating to dust and hazardous substances.

Civil engineers identified more hazards than architects: 318 and 281 respectively. Architects tended to identify more building-related hazards, such as open edges, structural openings and trip hazards, whereas civil engineers gravitated towards civil engineering issues such as piling, temporary works and excavations. Novice designers identified 293 hazards while experts identified 306. However, these figures constitute an increase of 105 post-intervention for novice and only 27 for expert designers. This increase in the novice figure was due to 70 additional hazards identified by the experimental group. The novice experimental group also improved the scope of hazards identified, with increases in 21 categories compared to only 16 in the control group. Filtering architects and civil engineers into experimental and control groups revealed a similar pattern: architects using the tool identified over three times the hazards as their control group post-intervention; for civil engineers the figure was five times; in both cases the scope of hazards identified was double the control group.

Mean averages were used to measure changes pre- and post-intervention. Hazard data was used, which was supplemented by a weighted score for the level of controls recommended by designers to address the hazards identified. The average number of hazards identified by designers pre-intervention was almost identical for experimental (11.7) and control (11.75) groups. However, post-intervention figures were 16.95 and 13.1 respectively, which were statistically significant. This pattern was repeated throughout the subgroups of novice, expert, architect and civil engineer. The number of cases reduced with this filtering of subgroups, but the statistical tests generally returned results to reject the null hypothesis even with the smaller numbers. As anticipated, novice designers improved to a greater extent than experts, with the experimental novice group gaining a higher average (16.4) than the expert control group (15) post-intervention. The split between architects and civil engineers followed the same pattern for the number of hazards identified, i.e. civil engineers' averages pre- and post-intervention were higher than the architects. At this level of analysis most statistical tests were significant but not all.

Recommendations

The following recommendations are based on the conclusions drawn from the study:

1. The sector-specific hazards database should be recommended for use as an educational and training resource, helping tutors to develop scenarios for teaching and training purposes for architects and civil engineers related to the construction industry.
2. The hazard-test drawings should be recommended for use as an educational and training resource, per recommendation number 1. These can be used as stand-alone materials or as part of a suite with the digital tool.
3. The digital tool should be recommended for use as an educational and training tool, per recommendation number 2.
4. The recommendations (1–3) should be carefully considered with respect to architects and consultation with the RIBA (RIAS in Scotland) should be sought to ensure recommendations made by previous RIBA-funded research (in relation to education) are implemented.
5. The digital tool should be developed and expanded for eventual use as a project tool, aligned with BIM PAS 1192-6 as a means to helping designers identify hazards and recommend suitable controls when developing and reviewing designs and specifications.
6. The digital tool should be owned by an organisation capable of monitoring, updating and sharing its contents in a transparent way. It is anticipated that its future success will depend on an 'open' format, with gatekeepers, so that experienced designers can continue to share their experiential knowledge with novices. This way, the content will grow and remain relevant.

Improved industry practice

The research has demonstrated that the digital tool (and related materials) is of most use to novice designers, such as students and new graduates. Adoption of the research outputs should foster long-term improvements in how new designers approach their designs with regard to DfOSH and their duties under the CDM regulations. The digital tool and hazard drawings need to be shared with tutors and trainers of architectural and civil engineering professions. However, architects will improve to a greater extent if the findings of this research are shared with and reciprocated by the RIBA.

In addition to the educational uses for the outputs of the research, the training benefits should not be underestimated. There are many CDM-related courses available to the construction designer community. It is expected that the hazard-test drawings in particular will be of significant use and other industry-specific versions could be developed based on the methods employed by this research.

The hazards database and digital tool also provide a format more accessible than other similar databases on the internet for sharing good practice. The recommended 'open' format (like a wiki) with designated gatekeepers, e.g. IOSH Construction Group, will allow experienced designers to share their knowledge and help the next generation of designers so that such knowledge is not lost.

Further academic study

The recommendations made regarding development of the digital tool for industry project application are dependent on further research to develop the size and scope of the tool before validating its use. By doing this, the scalability of the tool can be determined. Further data collection with a larger sample will also allow more confidence in its validity and reliability.

Future integration of the tool with BIM technology would provide an ideal opportunity to further develop and test the theories around visualisation and the application of knowledge databases through visual means. This may also help to determine additional strategies to help architects in particular gain more from use of the tool.

Finally, a logical development would be to monitor use of the materials developed and assess their impact on live projects. However, this would be only after the proposed research mentioned above is completed.

This study has not only contributed to research-led knowledge in the OSH discipline, but it has also delivered practical tools to help improve industry practice. DfOSH is a moral and legal obligation for designers and the research reported here can help novice designers in particular to improve their effectiveness in this regard.

1.0 Introduction

1.1 General introduction

Several research teams have investigated the relationship between design and construction accidents with Haslam et al. reporting that up to half of the accidents that they analysed had a connection to the design (1). The UK's Construction (Design and Management) Regulations (2015) place duties on designers of construction projects to (among other things) consider the health and safety implications of their designs in relation to the construction, use and maintenance (including cleaning) of the structures produced. However, the majority of designers fail to recognise the impact on health and safety that they can make (1). Several reasons have been identified as barriers: lack of resources and time, cost, client requirements and a lack of tacit knowledge gained through experience (1) (2). This last factor was explored by Hayne et al. who showed a link between site experience and the designer's ability to identify and mitigate construction hazards in designs (3).

Unfortunately, designers of construction in the UK are increasingly educated and trained with little or no site experience (3). Specifically, the main professional design institutions have been gradually withdrawing the requirement for architects and civil engineers to spend prolonged periods of time resident on construction sites. The situation is compounded by the increased academic requirement of a master's degree in order to become chartered by the conventional route and the tendency of universities to produce "engineering scientists" (3). Designers are increasingly working purely within the design office environment. They are immersed in the use of digital technologies, working in isolation, and not challenging the outputs of their computers. Essentially, they are becoming over-reliant on computer-generated information, which is eroding their skills, knowledge and experience of imperatives critical to health and safety (3).

It is therefore important that the details of potential hazards are communicated to designers in a way that will aid their development and training, augmenting the site experience they have (if any). This can be achieved by the use of links to visual files demonstrating the construction and maintenance process complete with experiences of construction operatives, foremen and facilities managers etc. to explain the actual details of the hazards. Previous work shows that visual methods have been used to develop shared mental models of construction safety and health hazards in construction and design teams (4) (5) (6). There could also be links to alternative construction processes that may be utilised by the designer to reduce the inherent hazards in the design, thereby enhancing their knowledge of construction and maintenance processes from the very people who are affected by the designs. Current research in this area promotes automated design choices for designers via building information modelling (BIM) (7) (8). However, the research study presented here advocates keeping the 'human' in control, supplementing designers' knowledge with experiential knowledge, so that they can make informed decisions.

1.2 Aim and objectives

The aim of this research was to improve how designers involved in construction projects learn about how their design influences the management of occupational safety and health (OSH) once the design is implemented. This focused on the impact of design decisions on OSH risks during the construction, use and maintenance of structures.

To achieve this aim, the following objectives were set:

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5. Validate the mixed-media strategies (of objective 4).
6. Develop a pilot database of mixed-media materials to aid designers of construction in their statutory duty to identify, prevent and mitigate hazards flowing from their design.

1.3 Outline method

The method employed was one of exploratory action research, combined with the use of an experimental design to evaluate the ability of a multimedia digital tool intervention on designers' OSH knowledge and practices. This was expected to improve how designers can influence specific hazards (relating to construction, use and maintenance of structures). To achieve this, the following methods were employed:

Sector-specific hazards, which can be influenced by designers of buildings and structures, were identified through a systematic review of academic and industry literature. The literature search was supplemented by interviewing experienced Health and Safety Executive (HSE) Construction Division inspectors, construction OSH professionals and facilities managers. Other experienced professionals were recruited from the research team's industry network. This included directors or senior managers. The 'design-influenced hazards' informed the development of a multimedia digital tool and linked hazard-test instruments in the form of computer-aided design (CAD) drawings.

A sample of 40 designers (based on the timeframe for the study), from two typical industry groups of architects and civil engineers, were recruited for the next stage of the research. These were recruited via the network of designers who have attended CDM courses and the network of designers known to the research team. The sample was purposefully chosen using the following criteria: half (20) experienced (deemed as more than 5 years' experience, which must include site experience) and half (20) novice (less than two years after graduation).

Designers were invited to engage with the developed materials in a carefully controlled experiment. The experiment evaluated the effects of the multimedia materials on decision-making and users' capability in designing for OSH in the construction industry. The experiment determined whether use of the multimedia materials improved users' ability to foresee OSH hazards in designs by measuring both the quantity of specific hazards identified and the quality of design outcomes (design controls) put forward.

The 20 novice and 20 experienced design professionals were randomly assigned into multimedia user (experimental) and non-user (control) groups. Design problem scenarios were presented to participants in sessions in a controlled environment. Participants were asked to review the set of CAD drawings in these sessions, to identify hazards and make decisions about designing for OSH.

Data was compared for multimedia user and non-user groups and also between novice and experienced designers. Collecting data before and after use of the multimedia tool enabled OSH knowledge, skills and abilities to be modelled and compared for both novice and experienced design professionals.

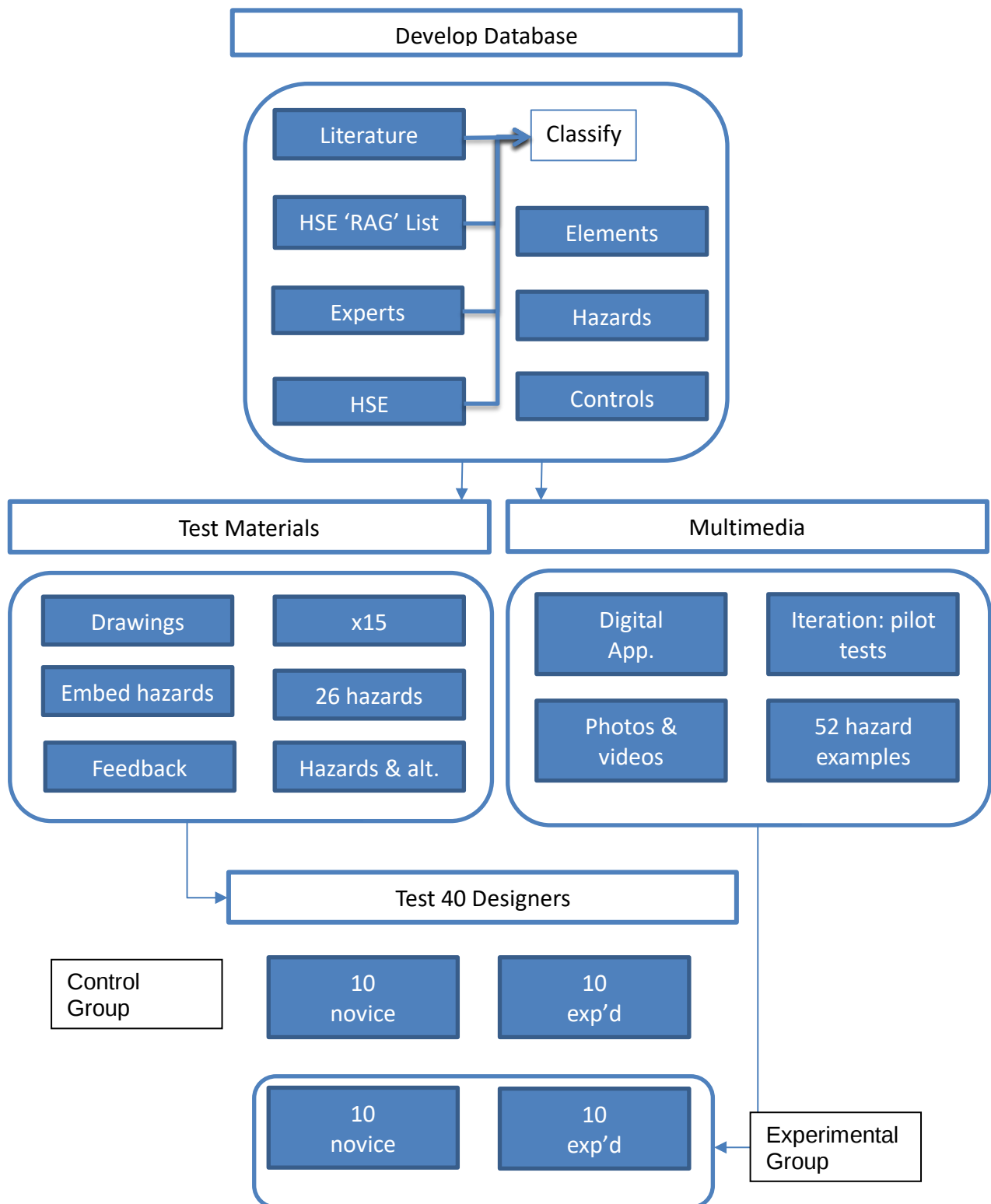


Figure 1 Roadmap of research process

2.0 Literature review

2.1 Introduction

Design and civil engineering training over the last few decades has been based on theory and learned through academic education, whereas the manual skills of building have been learned through hands-on site training (9). This division has resulted in the design industry tending to only consider the end user of the facility or structure rather than the 'constructor' (10) and views the burden of managing OSH during construction as solely the responsibility of the constructor (2). Additionally, the lack of construction skills and on-site training has meant many designers do not have the construction knowledge needed to understand how their designs could impact OSH (11) (12). The result of the designer's lack of responsibility for OSH means that contractors take on the full risk and burden of managing OSH, and in turn, suffer the consequences of building designs that could possibly have been modified to be safer to build while still retaining their design integrity (13).

2.2 Designing for OSH (DfOSH)

There have been a number of studies undertaken in recent years, using terms such as 'Design for Safety' (DfS), 'Prevention through Design' (PtD), 'Safety in Design' (SiD) and 'Design for Health' (D4H). These terms seem to be used interchangeably and can be collectively referred to as 'Design for OSH' (DfOSH). Therefore, this is the term adopted for the study reported here, even though these other terms may have been used by the authors cited.

Trethewy and Atkinson (14) define the principle of DfOSH as "Improved safety, health and environment outcomes through better design". In order for this process to be effective, hazards need to be identified during the design process and where possible eliminated or minimised (2) (15) (14). It is acknowledged that accident causation is often complex and multifaceted (16) (17) (18). However, research has been undertaken in the UK that shows up to half the accidents having a link to design while accepting it is often not the sole cause (1). This figure is close to that noted in the European Union directive 92/57/EEC (19) 13 years earlier and 11 years after the introduction of the CDM regulations which were aimed to improve this situation.

The results of the research by Haslam (1) align with the comments in the European Union directive 92/57/EEC and further suggest that little improvement had been made in the decade following the introduction of the Construction (Design and Management) Regulations (1994). It is important to recognise that this comment relates specifically to statistics and ignores the heightened awareness noted by Howarth et al. (20). Considering such comments, it is reasonable to assume that many UK designers fail to appreciate the benefits of DfOSH. Researchers have found that many designers do not recognise the impact on OSH that they, as designers, can make (1). Gambatese and Hinze (21) undertook a study in the USA where they identified that designers are not aware of their impact on site safety and lack the knowledge and ability to modify their designs to improve safety. This view is also supported by the work carried out by Qi et al. (22). It should be noted that unlike designers in the UK, American designers do not have a legal, contractual or regulatory requirement to consider OSH within their designs (2).

Few UK designers embrace the principle of DfOSH despite the CDM regulations being in force (1). Several reasons have been identified as barriers to designers: lack of resources and time, cost, client requirements and a lack of tacit knowledge gained through experience (1) (2). Other

research teams have also highlighted that designers are reliant upon tacit knowledge (23) (24) (25).

An issue that designers must overcome is that design information generally represents the completed artefact and does not include information pertaining to the construction techniques and processes needed to realise the project (26) (25). Scheer (27) takes this further by purporting that modern 3D digital models become simulations of the actual artefact and not the representation that drawings have been for millennia.

As a design is a representation or simulation of the complete artefact, it must be questioned how a designer undertakes the process of DfOSH. It has already been suggested that designers are reliant upon tacit knowledge, often developed from experience. The additional factor that is required is the ability to imagine, which Bronowski (28) clearly links with vision. Bronowski goes on to suggest that humans are unique in that they can imagine and consider options, which in the case of DfOSH would include construction processes previously witnessed, that would allow the adoption of processes with the least hazards. Foresight is also required when a design is reviewed; experience should give foresight of the consequences of the design and the associated construction process that has been imagined. Again Bronowski (28) suggests that foresight is unique to the human but has been evident for millennia. He provides the example of the discovery of stones in Olduvai that were stockpiled for use as stone tools. Ancient man had the experience that his stone tools would break and need replacing, hence he would collect suitable stones for later use. Subsequent research has identified that other animals such as primates possess the ability to imagine (29), but this does not detract from the need for imagination when undertaking DfOSH. Designers need foresight to anticipate what may occur when operators are constructing and maintaining their designs. For example, foresight will tell a designer that mechanical plant on the roof will need servicing and a safe access route to the plant will be required that will not put the maintenance staff at risk. This is a simple example that most designers would hopefully be aware of, but a more complex hazard could be that the plant will need replacing. Has the design allowed for a crane of suitable size to be located close to the plant or does the landscaping, with its planting and water features, prevent the use of a crane? If the designer has not been exposed to the latter situation their experiences will not give them the foresight to anticipate the situation arising.

Design is a complex process involving many actors who input to a design that undergoes numerous iterations. Design decisions are seldom made independently by a single designer. It is also common that OSH hazards which are identified early in the design process are replaced by unidentified hazards as development of the design occurs (30). Szymberski (31) asserts that the ability to influence OSH on site diminishes with time throughout the entire project schedule as illustrated in Figure 2. It is apparent that the conceptual stage of a project offers the maximum opportunity to influence OSH. It is also evident that hazard identification should be repeated with subsequent iterations of the design to ensure new unidentified hazards are not adopted into the revised design.

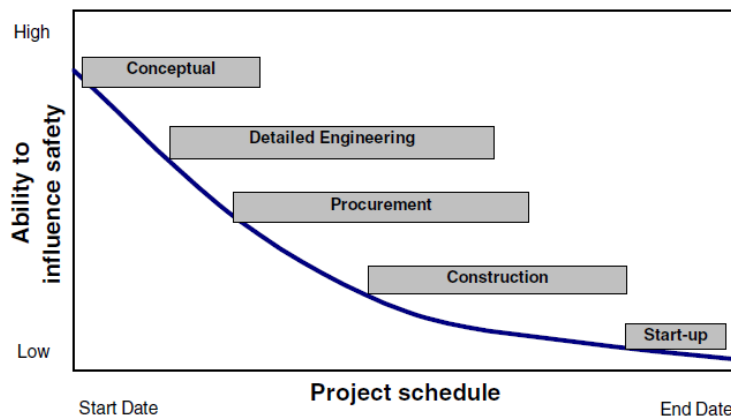


Figure 2 Time/safety influence curve

Source: Szymberski (31)

The HSE has produced ‘red, amber, green lists’ (RAG lists) to assist with hazard identification, which are described as practical aids for designers, highlighting what to avoid and what should be encouraged (32). The guides are often referred to during training sessions on CDM and designing for OSH as they are brief and simple to use. Curiously, the majority of the RAG recommendations relate to the detailed design stage of a project when the opportunity to achieve maximum impact has already passed. This could aid inexperienced designers who may not consider DfOSH during the design, but it is not as useful for earlier stages. Inexperienced designers may also use the RAG lists as a checklist without looking for additional hazards (33).

Notwithstanding the above discussions pertaining to the impact that design decisions have on the causation of accidents, it is important to remember that “It is incorrect to assume that simply by implementing the design for safety concept, construction site fatalities will automatically be eliminated.” (18) The designer cannot control risks that arise after their involvement in the project, but the premise of the current study is that they can influence them by either helping or hindering construction contractors, maintenance contractors and end users.

A further issue to consider is how far into the future life of the structure the designer needs to consider OSH, which affects the scope of any designer hazard database. Both Schulte et al. (34) and Hale et al. (35) consider the full life cycle of the structure from construction through to demolition; however, Behm (2) only refers to construction site OSH. The extent of designers’ DfOSH responsibility is not described consistently in the literature and could result in, for example, valuable designer input on OSH at demolition stage being missed. For the purposes of the current study, scope is limited to construction, maintenance and use, in line with current CDM 2015 requirements.

2.3 Building information modelling (BIM)

Building information modelling (BIM) is regularly cited as a means of (among other things) reducing OSH risks from a design and planning perspective (36) (22) (37). BIM is difficult to define due to the many stakeholders who use BIM for their own purposes and who, therefore,

have their own perceived definitions (38). Eastman et al. (39) choose to define what is not BIM: models that contain 3D data but no object attributes, non-parametric models, 2D drawings built into 3D models and models that allow editing in selective views without adjusting corresponding views. While accurate, it is important to remember that these definitions relate only to the 'technology' aspects of BIM.

Researchers in America have defined BIM as “an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information” (40).

On a similar theme Australian researchers define BIM as

“an IT enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository” (41)

McGraw Hill (42) suggests a BIM definition as “The process of creating and using digital models for design, construction and/or operations of projects.”

While focusing on the perspective of contractors, this definition is interesting as it starts to introduce the concept of a process, not just the use of digital technologies. The most succinct definition that encapsulates the main points of the previous section is probably the National BIM Standards-United States definition:

“A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward.” (43)

It is suggested that BIM differs from CAD in that BIM data contains syntax and semantics whereas CAD contains only syntax (44). It is the semantics, or meaning, combined with the parametric aspects of BIM models that allow rule checking of models to be undertaken. At the present time the UK adoption of BIM differs from other countries as the UK government has mandated the use of BIM level 2 on all centrally procured projects (45). Level 2 BIM is defined as a managed 3D environment using single discipline models and associated data (46). This is represented diagrammatically in Figure 3.

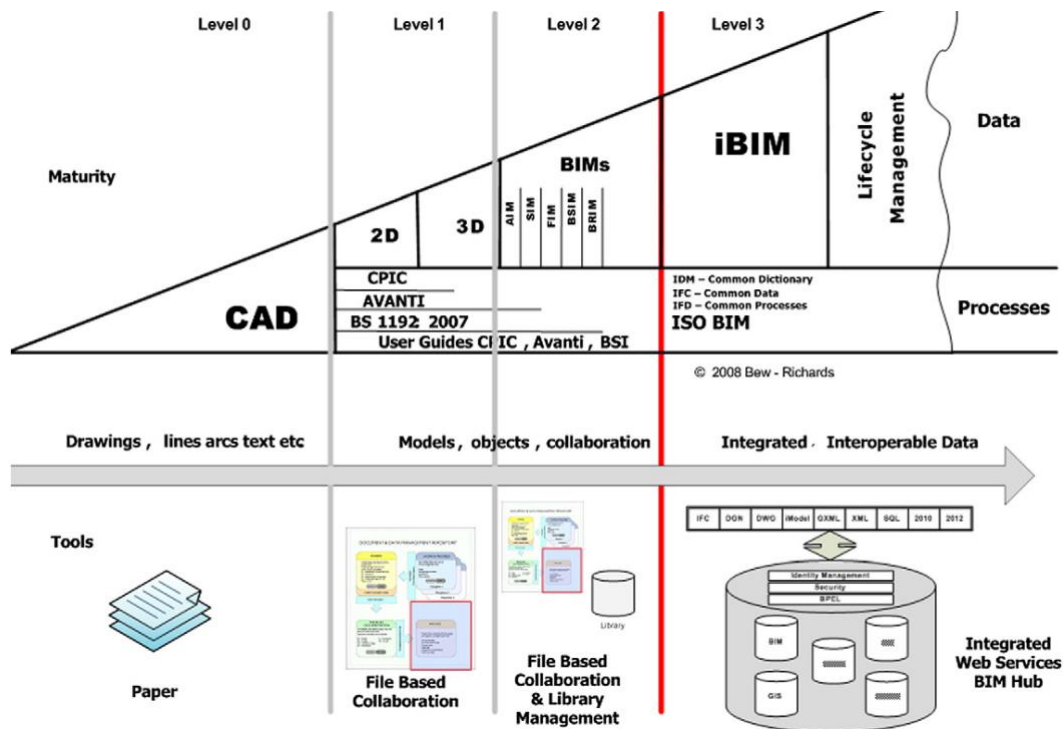


Figure 3 BIM maturing model
Source: BIS (46)

2.4 Present developments in design, BIM and OSH

The widespread use of BIM is a relatively new development within the architecture, engineering and construction (AEC) industries with the major software company Autodesk releasing the Revit Structure software in 2005. Research into how BIM and construction OSH could be integrated has been very limited with only a handful of studies being published. While some innovations include OSH, most are focused purely on safety, with 'fall from height' hazards receiving the most attention due to their prevalence in fatal accident statistics.

2.4.1 Example 1. Rule-based checking system

Benjaoran and Bhokha (47) undertook research utilising 3D CAD models linking the time schedule to form what they called 4D (including a time dimension) CAD models. The researchers acknowledged that a number of hazards can be eliminated, or at least significantly reduced, in the design and planning stage as noted by Gambatese et al. (18). They did, however, suggest that due to the nature of construction, some hazards would inevitably still be present on site and these hazards must be managed by identifying the risks, implementing protection measures and ensuring the time and resource schedules are adjusted to allow the implementation of these measures.

The research was undertaken in Thailand where construction methods and safety culture are often different from that seen in the UK. However, the issue of falls from height was identified as a significant cause of site-based accidents. The aim of the research was to develop a rule-checking model incorporating the following functions: hazard identification, safety (falls)

measure planning and control. The tool uses rule-based algorithms to identify areas of the project where falls from height may occur. When identified, safety measures such as edge protection are automatically inserted from a database of safe operating procedures (SOP). Importantly, the time schedule is adjusted to allow the installation of any protective measure and a bill of quantities produced.

A three-storey hotel project was used to validate the tool where it was found that the hazards were successfully identified with appropriate edge protection added in line with SOPs. The time schedule was accurately adjusted, allowing the site management team to efficiently manage the installation process. From the automatically generated quantities of edge protection, it could be seen that the original construction sequence required a large amount of protection. This quantity could be greatly reduced by adjusting the construction sequence without increased safety risk or delay to the overall programme.

The researchers suggested that the tool provided significant benefits but that it required projects to be modelled in 3D. A significant amount of additional time and effort was necessary if the project was not already designed in that medium. While this tool could undoubtedly be adjusted to operate in a true BIM environment, the tool was not specifically designed for BIM and may, therefore, not be utilising BIM's full capability.

The tool developed by Benjaoran and Bhokha (47) clearly brings some benefits to site planning and management, but it must be questioned why fall hazards are not identified by planners as a matter of course. It was also noted by the researchers that the tool allocated time not previously scheduled for the erection of edge protection measures. This raises a question over the general competence of the planners. These issues foster concerns that site managers and safety staff in particular may become over-reliant on this tool and stop reviewing the works manually, similar to safety problems encountered when drivers have become completely reliant on driverless technology (48). A significant amount of background information can be gleaned about a project through the review of drawings, and if this is now being omitted due to the use of checking software, other unintended problems could arise. This is an aspect which is not considered by Benjaoran and Bhokha (47).

2.4.2 Example 2. Safety planning and management

Kiviniemi et al. (49) undertook research between April 2009 and June 2011 to use available BIM technologies and 4D construction planning for OSH planning, management and communication. The researchers identified that BIM usage was spreading from architects and designers to construction companies and could therefore be utilised for site OSH planning activities. Several ideas were identified by the researchers: BIM-based OSH planning, risk analysis and safety evaluations of plans through BIM, 3D and 4D visualisations in OSH-related communications and other BIM-based plans at site. Field trials were carried out to test the effectiveness of the planning processes.

The researchers tested their methods on several live projects with varying degrees of success. Site layout plans were developed using 'Tekla Structures' software which was found to be effective as temporary features could be included in the model and the 4D planning illustrated the full site at any given period in time. The drawbacks encountered were that the program was developed for new build structures and as such the visualisation and animation tools were particularly weak.

A further pilot project that had been fully designed in Tekla Structures was used to test the placing and scheduling of edge protection to slab edges. It was established that there is a lack of tools to model the temporary edge protection. Additionally, the shortest time period for 4D modelling is a single day which was found to be far too long for effectively visualising the installation and removal of edge protection. Further pilot projects were used to model fall protection netting and to carry out safety analysis checking using the Solibri Model Checker.

The studies undertaken were all using commercially available software packages to carry out site-based safety planning with varying degrees of success. It was found that the programs were somewhat lacking when used for visualisation of temporary equipment and 4D scheduling. From the work undertaken by Kiviniemi et al. (49), it is evident that software developers were responding to their clients, primarily architects and civil engineers when developing the software capabilities. The research was carried out some years ago and it would be interesting to see if more contractors are using the software and making specific requests to the developers.

2.4.3 Example 3. Identification of hazards by designers

Research undertaken at the University of Florida by Qi et al. (22) explored how BIM could be used to improve site safety by assisting designers to identify hazards during the design process. Through a literature review the researchers identified that many designers in the USA had insufficient knowledge or education to be able to identify, eliminate or reduce hazards during the design phase of projects.

The development of the research tool was focused on the prevention of falls from height and falling objects and utilises best practice provisions identified by Gambatese et al. (50). The researchers divided the design suggestions into two groups: either “precise parameters” which could be checked by rule-checking software or “currently uncheckable” which tended to be subjective suggestions. This reasoning arose because while building codes contained explicit pass/fail rules, design for safety suggestions tended to be text-based suggestions that required many criteria to be considered. The developed tool allows designers to access the text version of the design for safety suggestions, although the model does not check these points for the reason noted above. The second function of the tool is to check the prescriptive rules such as roof pitches or heights of windowsills. Elements that fail the checks are highlighted and recommended actions are suggested.

Qi et al. (22) have identified a major difficulty with automatic model checking of BIM models as they are only effective for closed questions. While their tool is helpful for simple checks it does little to advance the dissemination of tacit knowledge to an inexperienced designer. The presentation of text-based rules is no more than an electronic database of rules.

2.4.4 Example 4. Rule-based checking system (2)

A further study of rule-based checking of models to identify potential falls from height was carried out by Zhang et al. (8). Acknowledging again that falls from height are a significant hazard within the construction industry, rule-based algorithms were established to identify holes in slabs and walls and unprotected edges of slabs. Occupational Safety and Health Administration (OSHA) safety rules were applied and protective measures of edge protection, window guardrails or the covering of holes in slabs were automatically added to the model.

The developed tool was tested on specially constructed models and then on complex industry models. In both cases the tool was found to operate accurately. Additionally, quantities were generated and the sequencing of the protective measures was added to the time schedule. The development by Zhang et al. (8) is a good example of a tool progressed to respond to the yes/no question noted by Qi et al. (22). The 3D visualisation, measurement of quantities and inclusion in the time schedule clearly has significant benefit to site safety planning. However, a total reliance on computer software can lead to “mindlessness” and the operators having a feeling of omniscience (51).

2.4.5 Example 5. HSE assessment of knowledge-based systems

The HSE publication RR173 (52) was commissioned to assess the form of a knowledge-based system (KBS) that was required by UK designers and, in particular, the type of information that the system should contain. The suggested approach would support the requirements and philosophy of the CDM regulations.

The report recognised that designers were often being proactive in some areas of OSH planning but also reiterated that many still see CDM regulations as form filling and a burden which is often not considered worthwhile. There was also a reluctance to change behaviour, and as such, any KBS must save designers time as well as provide information quickly and easily. The prototype developed had limitations in that if underlying data was not added to the design it could not be checked. While this is more of an issue for non-BIM applications, it still requires a culture change among designers. A further report was commissioned three years later to review the success of KBS in reducing accidents and to identify any lessons learned for the UK (53). The report identified the existence of 43 expert systems, none of which had any evidence to show their success or otherwise of impacting on OSH.

2.4.6 Example 6. Knowledge-based system (KBS) ToolSheD™

A KBS, sometimes referred to as an expert system, is defined as:

“a computer system that is programmed to imitate human problem solving by means of artificial intelligence and reference to a database of knowledge on a particular subject” (54).

KBSs have two specific purposes: in medicine they are widely used to support experienced users and remind them of all the options available; in other industries they are typically available to allow inexperienced operators to draw on the knowledge of industry experts when making decisions (55).

A KBS developed by Cooke et al. (54), ToolSheD™, while not designed for a BIM environment, utilised argument trees to disseminate knowledge to the designers. Cooke et al. recognise that there are few effective KBSs, which is often attributable to the method of collecting, storing and disseminating the knowledge, referred to as a “knowledge acquisition bottleneck” (56). The difficulty of open textual ‘duties’ required by designers under UK CDM regulations is highlighted as an additional problem. As noted earlier, these obligations are subjective and virtually impossible to resolve with yes/no or if/then questions and rules. The developers of the ToolSheD™ used facilities managers’ and designers’ inputs to produce details of the design factors that could contribute to falls during maintenance and operations of a building. This information was used to populate argument trees that linked all the relating factors in the branches of the trees, resulting in a single concept at the trunk.

The finished program asks a series of simple questions that populate the argument trees and feed through to the issue of a report. However, this can be a relatively long process as over 100 factors contribute to each tree. Conversely, it does allow inexperienced designers to exploit

a wealth of knowledge generated by experts in the field and indicates how the individual decisions are interrelated and affect the final safety rating. The output does not give prescriptive instructions to designers but allows them to understand the impact of the different elements of their design. This approach will gain favour with designers who often see OSH as an intrusion into their work. The research paper by Cooke et al. (54) was published in 2008 and ToolSheD™ is available online. It has not been developed beyond what was reported in 2008, which is perhaps an indication of the amount of knowledge and information that must be collected for each individual tree to be developed.

2.4.7 Example 7 BIM4H&S guidance

In the UK, a working group was established in 2014 to bring BIM and OSH experts together to help further the OSH benefits of BIM technologies. Known as BIM4H&S, it represents one of several other UK 'BIM4' working groups, such as BIM4REGS (57).

The working group has focused mainly on developing guidance and case studies, the most notable of which was the publication of a Publicly Available Specification (PAS) for managing OSH information in a BIM environment: PAS 1192-6 (2018) *Specification for collaborative sharing and use of structured Health and Safety information using BIM* (37). The PAS provides guidance on how OSH information is produced and flows through the lifecycle of construction assets. The PAS requires "the contextualization and filtering of hazards and risks to prioritize the elevated risks and aspects that are safety critical" (PAS 1192-6), and is structured around the PAS 1192 process framework (Figure 4).

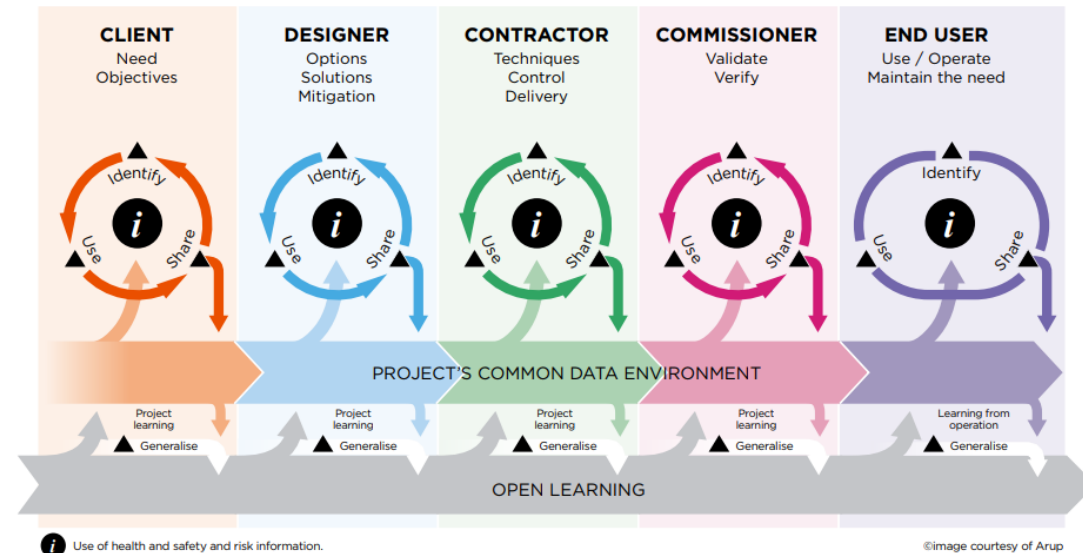


Figure 4 Progressive development of H&S information

Source: PAS 1192-6 2018 (37)

A key element of the PAS 1192-6 process is the 'Identify-Share-Use' cycle as illustrated in Figure 4. It would make sense for digital tools in this area of development to align with BIM in general and with PAS 1192-6 in particular. This includes the development of digital libraries to help identify OSH risks that can be shared in a 'common data environment', e.g. a software programme that all project members can use. Another important factor identified in the PAS is the need to attach relevant OSH risk information to one or more of the following 'attributes':

- Product;
- Activity;
- Location.

This acknowledges that 'products' (such as substances, materials, components and elements); 'activities' (such as working at height); and 'locations' (such as a confined crawl space) can all be associated with OSH risks. BIM technologies allow for such classifications, relying on some form of standard library that identifies unique codes for each (e.g. see COBie (58) or Uniclass (59)). The PAS also lists standard classifications that can help organise OSH risks into categories of harm. Together, these represent the most critical aspects to consider for developing any form of digital tool to assist with OSH if aligning with BIM and PAS 1192-6 (37).

2.5 Mixed-media communication of OSH information

A range of images can be used to communicate OSH information visually, including pictorial, cartoon, photograph and sketch. These images vary in their degree of representation to the referent. However, it is generally accepted that the more analogous an image is to a referent, the greater likelihood of correct interpretation (60) (61). This is because the image is more likely to evoke a concrete image in the mind of the viewer; however, age and culture can influence the strength of this association. This explains why abstract images have lower comprehension levels. For example, Wogalter and Sojourner (62) tested "easy" and "difficult" images and found that those classified as difficult (including abstract images) were not comprehended well, some with scores below 50%. Davies et al. (63) assessed 325 participants' comprehension of 13 product-related pictograms, and found that abstract images were very poorly understood, scoring between 2% and 29% completely correct answers. Cairney and Sless (64) found that two of the most poorly understood public information symbols they tested were also abstract images. In such cases, the viewer has to learn the meaning of the image. Chandler (65) emphasised that in such cases the only way to understand the meaning is by being privy to the codes (social, textual, interpretative) and conventions used by the creator.

McNairney (66) applied the Communication-Human Information Processing (C-HIP) model developed by Wogalter (67) to the assess images for OSH communication. The C-HIP model is a theoretical framework to assess the information processing variable, comprehension when dealing with OSH information, specifically images and warning signs. McNairney found photographs to be preferred by construction industry workers over pictorials, cartoons and sketches, and aided comprehension more effectively, which was attributed to their 'representational' nature (66). Photographs are effective and straightforward in depicting a construction scenario, yet maintain the richness of information needed to assess OSH risks. Photographs have been effectively used as stimuli-eliciting perceptions in landscaping studies (68) (69), also successfully used as experimental stimuli in areas such as industrial quality assurance (70) and construction hazard identification (6) (71).

Wogalter (67) claims that the main barrier to the use of images is that they are not necessarily applicable to all types of communication, such as detailed instructions or complex sequences. Therefore, if images are to be used, they should be limited to simple hazard and control scenarios.

In the context of instructing OSH information within a digital learning environment, it is imperative to ensure that learners are left without confusion when studying safety critical information. Therefore, it is important for the designers of digital content to consider how information is presented to their target audiences in ways that support cognitive processing and reduce the cognitive workload (72). The design principles of Schneiderman (73) ensure human cognition characteristics such as memory, perception, attention, learning and problem solving are supported. The main design feature centres around the use of images supported by text, its aim to use visual perception to support cognitive perception. Research indicates that when this design strategy is applied within multimedia learning environments, learning is better supported in terms of acquiring knowledge on the information presented (74).

2.6 Summary

Designing for Occupational Safety and Health (DfOSH) is known by various names in the research literature and the importance of designers in the management of OSH risks related to construction is well documented. While many attempts have been made to develop digital tools to aid designers in this respect, including those embedded within BIM technology, the need for the designer to be competent is a common thread. The nature and scope of education for designers, combined with relevant site experience, has been shown to be critical to successful DfOSH outcomes. Therefore, technology that seeks to remove the designer from the decision-making process around DfOSH – such as automated processes – could do more harm than good. A knowledge-based system seems to be the favoured method of giving designers the ability to make informed decisions on DfOSH. However, text-based systems have proven to be cumbersome, whereas visual (pictorial, multimedia) databases may be able to overcome the problems posed by overly word-based systems and provide a more effective solution.

3.0 Methods employed

3.1 Introduction

Discussed below is the primary research method along with a justification explaining why this was chosen. This section also covers the hypothesis, plus the details of the experiment, including the who, what, why and where. This is followed by an explanation of how the results were analysed.

The primary research of the project was acquired via an experimental focused evaluation method. An experiment is defined as a research strategy that aims to uncover a cause and effect behind something, and through this, an experiment is formed. The experiment itself is defined as a framework which can be either realistic or artificial in nature and 'controlled' in order to form reliable results related to the cause and effect. Researchers begin by forming a theory relating to their chosen area of focus which forms a statement relating to the theory that is to be tested by the experiment. The statement takes the form of "A causes B" and is commonly referred to as a hypothesis (75). Oates (75) details that experiments are undertaken as a means to prove/disprove the proposed hypothesis. Any elements or forces that could influence the results and outcomes are not considered and are removed from the experiment, keeping only the factors that cause the outcome itself. The experiment is then run and the results gathered carefully. If no other elements have caused the results that were expected, then the hypothesis is proven to be correct, but even the best designed experiments can have issues related to contamination. The gathered results also need to be analysed carefully in order to prove the hypothesis is indeed correct. A great deal of statistical knowledge is often required in order to analyse the data gathered.

3.2 Hypothesis

H-zero – Designers will not improve their ability to identify more 'project-specific' hazards after using the digital tool.

H1 – Designers will be able to identify more 'project-specific' hazards after using the digital tool.

H-zero – Designers will not improve their ability to recommend more effective design solutions to address hazards after using the digital tool.

H2 – Designers will be able to recommend more effective design solutions to address hazards after using the digital tool.

3.3 Experimental design

The methodology employed was one of exploratory action research, combined with the use of a strong and internally valid experimental design to evaluate the ability of a multimedia digital modelling intervention on designers' OSH knowledge and practices. This was expected to improve how designers can influence specific hazards (relating to construction, use and maintenance of structures). To achieve this, the methods described below were employed.

3.3.1 Literature review

Sector-specific hazards, which can be influenced by designers of buildings and structures, were identified through a systematic review of academic and industry literature. Academic sources included construction, civil engineering and architecture peer-reviewed journals; conference proceedings of the same; and research council and government-funded research reports. Industry literature included professional and trade publications, and Health and Safety Executive (HSE) guidance. Search terms included 'CDM', 'Safety in Design', 'Prevention through Design' and 'Design for Health'. This search also extended to occupational safety and health literature with the additional search terms 'construction', 'civil engineering' and 'architecture'. Qualitative filtering allowed relevant sources to be identified.

The literature search was supplemented by interviewing experienced (more than 10 years) HSE Construction Division inspectors, construction OSH professionals and facilities managers. Other experienced professionals were recruited from the research team's industry network. This included directors or senior managers. These interviews were open and exploratory, used to gain an understanding of current trends, HSE priorities, and as a means of directing the researchers towards any new databases not already identified in the literature. This led the researchers to the Construction Industry Training Board (CITB) work to create a designer application for CDM. At the time of writing, the app was shelved due to internal restructuring at CITB. However, the app was being developed on the basis of the HSE 'Red-Amber-Green' (RAG) lists (32).

Most design-influenced hazards found in the UK literature could be traced back to the HSE RAG lists. Therefore, this was used as the main framework or 'spine' of hazards that others (identified in the literature) were added to. The literature review identified mostly work at height hazards and these feature prominently in the hazards database (Appendix I). But use of the RAG list as the main source of literature ensured that a broad representation of both 'health' and 'safety' hazards were accounted for.

3.3.2 Development of the database

Examples of 'design-influenced hazards' were classified by industry sub-sectors, generic injury types, then in relation to specific design elements, using qualitative labelling (Appendix I: Hazards database). The literature review identified the importance of BIM technologies to the research. A database of the type developed for the research would be enhanced if it could be aligned with BIM. Therefore, the new BIM PAS 1192-6 (2018) (37) for OSH information was used as the main reference point. A consequence of this was to specifically label designer-related hazards in relation to the three 'attributes' of 'product', 'activity' and 'location'. Therefore, each hazard in the database could be labelled in relation to one or more of these attributes, e.g.:

- Products: such as substances, materials, components and elements;
- Activities: such as working at height; and
- Locations: such as a confined crawl space.

In addition to these labels, one of the features of BIM technology is its interoperability, achieved through the use of a common language or classification system. Therefore, to increase the database's interoperability, the most common unified classification system for construction

products, elements and locations was used for labelling, known as Uniclass (59). There are other classification systems available, e.g. COBie, but Uniclass is considered more universal, being able to cover both building and civil engineering projects.

Another critical step in classifying hazards in the database was to include the type(s) of injuries or harm resulting from each hazard. Again, the classifications in the new BIM PAS 1192-6 (2018) (37) were utilised, e.g. 'fall from ladder', 'electric shock' etc.

The final section of the database was the strategies for designers to address the hazards (Appendix II). This was classified in relation to a simplified version of the 'principles of prevention' (sometimes also described as 'hierarchy of controls') stipulated in the Management of Health and Safety at Work Regulations (1999), as developed by Hayne et al. (3), namely elimination, substitution, civil engineering controls, administration controls and PPE. Higher-level controls are interpreted as evidence of greater knowledge and understanding of how designer decisions can improve the overall management of OSH. This also provided a method of evaluating strategies to address the designer-influenced hazards, discussed later.

3.3.3 Hazard-test instruments

The hazards and corresponding designer actions allowed a series of hazard-test instruments to be developed, piloted and refined for each of two industry subgroups: commercial building (architects) and civil engineering. These instruments consisted of hazards embedded in 'design' solutions (CAD drawings), which knowledgeable designers can identify, following the method created by Hayne et al. (3).

A total of 15 CAD drawings were developed, based on a fictitious office development and external works (Appendix III). The drawings were carefully constructed to include as many of the hazards as possible that were identified in the database, while maintaining a realistic appearance. This resulted in 26 hazards being incorporated into the drawings (Appendix IV).

The drawings were accompanied by a feedback sheet to record the designers' responses. This included some demographic information (to confirm profession and level of experience) and essentially two columns: 'hazards' and 'alternatives' (Appendix V). This allowed comparison of designers' reasoning and responses in relation to OSH hazards in the designs. The test instrument also facilitated a method to evaluate them, i.e. determine if they are generic/specific; and high/low 'hierarchy of control' solutions.

3.3.4 Digital multimedia tool

The hazards and corresponding designer actions above also allowed a series of multimedia materials to be developed within a digital web-tool. These included photographs and videos in which the constructors and end users of designs talk about and show how design decisions can impact OSH during construction, maintenance or subsequent operation of a facility.

The tool was developed iteratively, with pilot testing and refinement until it was deemed ready for the experiment. A critical change to the appearance of the tool was to hide the original Uniclass codes. The designers who participated in the pilots found the Uniclass codes confusing and complicated. Indeed, the main refinement that resulted from the pilots was to simplify the filter options in the tool to the three shown in Figure 5–7. Note, the original PAS 1192-6 codes have been retained within the architecture of the tool, hidden from the user but available for future use with BIM technology.

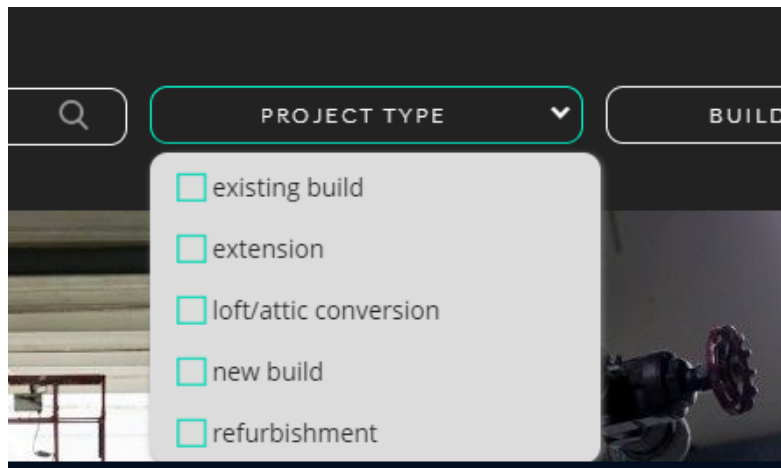


Figure 5 Filter 1 – project type

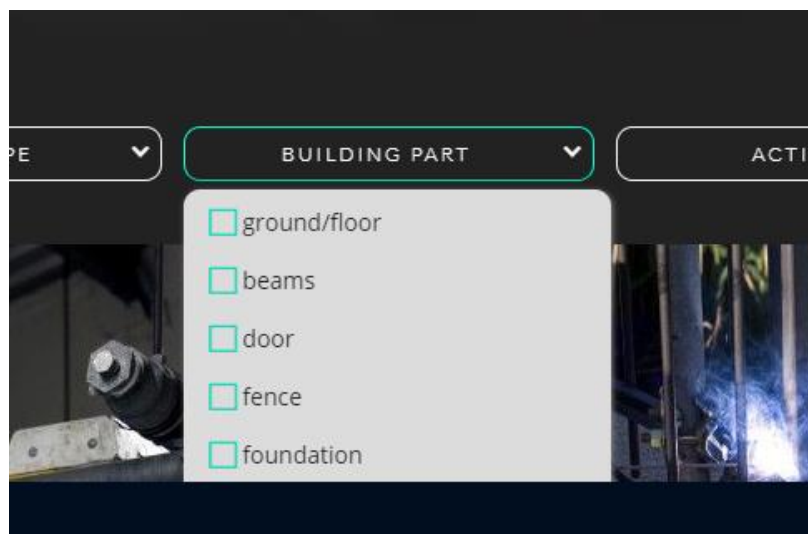


Figure 6 Filter 2 – building part

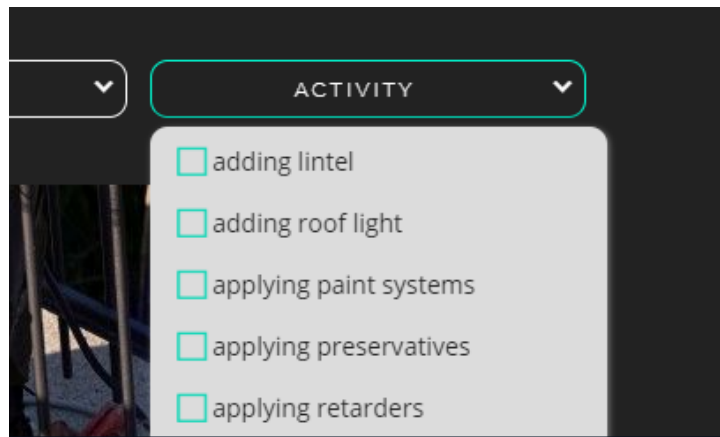


Figure 7 Filter 3 – activity

The tool homepage lists each of the main hazards using photographs and a short description (Figure 8). Filtering provides a shorter list of specific hazards. Clicking on the photo leads to designer options, classified as ‘eliminate’, ‘reduce’ and ‘inform’ in relation to the possible designer actions available to address the hazard (as opposed to contractor controls). These alternative options also include visual examples (photographs) and include links to external photos and video clips if further explanation is required.

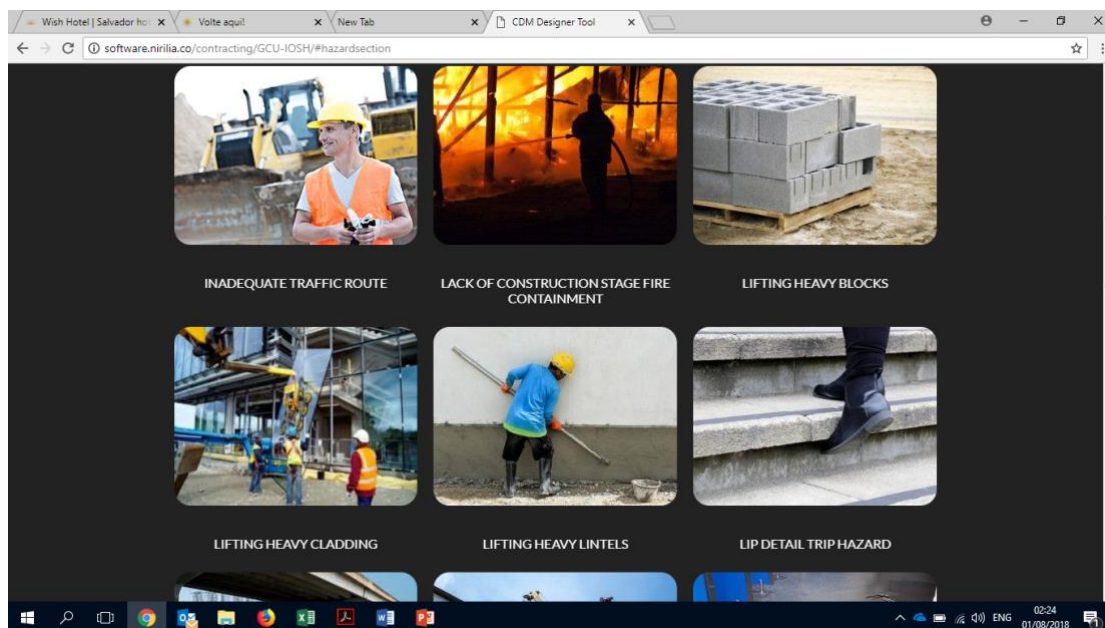


Figure 8 Screenshot of hazards on homepage

3.3.5 Experimental procedure

A sample of 40 designers (based on the timeframe for the study) from the two industry groups (architects/civil engineers) were recruited for the experimental work. These categories of designer were chosen because they represent the two main industry categories of ‘building’ and ‘civil engineering’ as described by the ONS¹ and are the two main ‘traditional’ designer

¹ 79,000 civil engineers and 54,000 architects

groups under CDM who generally work throughout the whole 'pre-construction phase' of projects. These were recruited via the network of designers who have attended GCU/ICE CDM courses and the network of designers known to the research team. The sample was purposefully chosen using the following criteria: half (20) expert (deemed as more than 5 years' experience, which must include site experience) and half (20) novice (less than two years after graduation). Each of these two groups consisted of half (10) architects and half (10) civil engineers. Table 1 shows the composition of the sample.

Table 1 Sample

		Expert	Novice	Total
Experimental Groups	Architect	5	5	10
	Civil Eng.	5	5	10
Control Groups	Architect	5	5	10
	Civil Eng.	5	5	10
		20	20	40

Designers were invited to engage with the developed materials in a carefully controlled experiment. The experiment evaluated the effects of the multimedia materials on decision-making and users' capability in designing for OSH. The experiment determined whether use of the multimedia materials improved users' ability to foresee OSH hazards in designs by measuring both the quantity of specific hazards identified and the quality of design outcomes (design controls) recommended.

The 20 novice and 20 experienced design professionals were randomly assigned into multimedia user (experimental) and non-user (control) groups attending one of several sessions depending on their availability. Participants were asked to review the set of 15 CAD drawings to identify hazards and make decisions about designing for OSH. The expectations were explained to the participants, and they were given an opportunity to ask any questions. For the first part of the experiment, all participants were asked to use their own knowledge to identify hazards and alternative solutions. In the second part of the experiment, participants were split into two groups: those who used the tool to identify hazards and alternatives and those who used their own resources, for example the HSE website. Participants were allowed to use the second half of the experiment to not only add new hazards and alternatives but to also edit their current ones if they wanted. The pre-intervention responses were written with a red pen and the post-intervention responses with a green pen to distinguish between them.

The experiments took place in one of the GCU computer labs (either Glasgow or London campus) so that participants could have their own space and use the computers with ease. These labs were specifically chosen as they had a large number of computers and each had an adequate amount of spacing, which meant that participants were not copying each other's answers and that the data gathered was exclusive to the individuals themselves, therefore valid and free from contamination.

3.3.6 Analysis of results

Data was compared for experimental and control groups and also between novice and experienced designers. It was also possible to compare between architects and civil engineers. The ability to identify 'generic' hazards is associated with a basic or superficial understanding of how design impacts on OSH, whereas being able to link specific hazards to particular design choices is seen as indicative of a more knowledgeable designer (3). This informed the framework for structuring the data for analysis.

The two main units for analysis were:

- Number of project-specific hazards identified;
- 'Hierarchy of controls' score.

The average (mean) number of project-specific hazards identified per group was measured. Following the method used by Hayne et al. (3), generic hazards were ignored. Out-of-scope items included general references to, for example, work at height (if not related to a project-specific item); general good practice to comply with building control/standards, such as fire protection; or those considered out of scope for not being OSH related.

The hierarchy of controls score also followed the method devised by Hayne et al. (3) as shown in Table 2. This utilised a simple weighting depending on what alternative options were recommended by designers. In some cases, more than one alternative option was listed by designers. In these cases, the highest-ranked option in the response was used.

Table 2 'Hierarchy of controls' score-card

Type of control	Score
Eliminate (through design)	5
Reduce (through design)	4
Reduce (engineering controls)	3
Inform of procedure (contractor's system of work)	2
Control (contractor PPE)	1

Three researchers reviewed the results to ensure reliability. An initial cross reference of the first five participant scores was performed to check inter-rater reliability. This was shown to be between 0.85 and 0.96 for the five participant scores (number of controls x weighting). The following examples were used to inform decisions around weightings:

1. Eliminate (through design): prefabrication; locate item at ground level;
2. Reduce (through design): design in edge protection; substitution of lesser hazard;

3. Reduce (civil engineering controls): local exhaust ventilation; temporary edge protection;
4. Inform of administrative procedure: 'contractor to provide method statement';
5. Control through PPE: 'contractor to provide PPE'.

The resulting quantifiable data allowed visual graphical analysis to detect any rise in frequency of hazards identified or 'hierarchy' score among the participants. While the data is quantitative, it should not be analysed using parametric tests as it violates the required assumptions for such tests. It is more appropriate to check for statistically significant changes and differences using non-parametric tests as data of this nature is rarely normally distributed and the hierarchy scores in particular are not true scales.

Comparisons between experimental and control groups used the Mann-Whitney between-group test. This tests for statistically significant differences between two separate groups (experimental/control). Changes before and after interventions within the same groups used the Wilcoxon Signed-Ranks Test, commonly associated with 'within group' 'pre-post' tests.

4.0 Findings

4.1 Introduction

The findings are presented in two parts: a detailed description of the numbers and types of hazards identified by each group, followed by statistical analysis of the before and after measures. A total of 43 designers participated in the experiments. Three of the most extreme outliers in each group were removed to leave 40 so equal numbers could be used for analysis (as described in the Methods Section). The nature of the data dictated non-parametric statistical tests. These tests rely on ranking differences between measured data. A consequence of this is that 'tied' ranks (e.g. where designers failed to add any further project-specific hazards to their score after the intervention) are ignored. This happened with six designers (one from the experimental group; five from the control group). The reasons (and implications) for this are discussed later.

4.2 Sample

The method employed required a total of 40 designers. The breakdown of the sample (per Table 3) consisted of half architects (n. 20) and half civil engineers (n. 20). These, in turn, were split: half 'novice' and half 'expert'. Table 3 lists the 40 participants in terms of experience. For architects, 'novice' included those who had achieved 'RIBA Part 2' (which requires an undergraduate degree) but no more than two years' practical experience. 'Expert' architects were required to be at least five years post 'Part 3' (final RIBA exam). There are many routes to becoming a Chartered Civil Engineer, and therefore a simplified method was employed based on the RIBA model of 'novice' being up to two years after graduation and expert being either at least five years after graduation or at least 10 years' practical experience with full chartered 'MICE'.

Table 3 Breakdown of sample

1	Arch.	Novice	Pt2	21	Eng.	Novice	Grad+1
2	Arch.	Novice	Pt2 + 2Yr	22	Eng.	Novice	Grad+1
3	Arch.	Novice	Pt2 +1.5Yr	23	Eng.	Novice	New Grad
4	Arch.	Novice	Pt2 + 2Yr	24	Eng.	Novice	New Grad
5	Arch.	Novice	Pt2 +1.8Yr	25	Eng.	Novice	New Grad
6	Arch.	Novice	Pt2 Stud.	26	Eng.	Novice	New Grad
7	Arch.	Novice	Pt2 + 2Yr	27	Eng.	Novice	New Grad
8	Arch.	Novice	Pt2 + 1.5Yr	28	Eng.	Novice	New Grad
9	Arch.	Novice	Pt2 + 2Yr	29	Eng.	Novice	New Grad
10	Arch.	Novice	Pt2 + 1.5Yr	30	Eng.	Novice	New Grad
11	Arch.	Expert	Pt3 5 Yrs	31	Eng.	Expert	MICE 10Yr
12	Arch.	Expert	Pt3 10 Yrs	32	Eng.	Expert	AMICE 8Yr
13	Arch.	Expert	13 Yrs	33	Eng.	Expert	MICE 13Yr
14	Arch.	Expert	15 Yrs	34	Eng.	Expert	MICE 4Yr
15	Arch.	Expert	Pt3 12 Yrs	35	Eng.	Expert	MICE 6.5
16	Arch.	Expert	21 Yrs	36	Eng.	Expert	AMICE 5Yr
17	Arch.	Expert	19 Yrs	37	Eng.	Expert	MICE 10+
18	Arch.	Expert	18 Yrs	38	Eng.	Expert	CEng 10Yr

19	Arch.	Expert	33 Yrs	39	Eng.	Expert	MICE 10+
20	Arch.	Expert	Pt3 5 Yrs	40	Eng.	Expert	MICE 10+

4.3 Findings: hazards

4.3.1 Overall project-specific hazards

The hazards identified by all designers were filtered to eliminate generic hazards (e.g. 'work at height' but not specified on the drawings); those following building regulation procedures; or those deemed out of scope (e.g. aesthetics). A list of rejected examples is included in Appendix VI. Once this was completed a total of 599 hazards had been identified – cumulatively before and after intervention – by all designers. A breakdown of these, per groups, is shown in Appendix VII. A summary of the totals is shown in Table 4.

Table 4 Hazard types

Hazard types	Before	After (additional)	Total (cumulative)
wet in-situ concrete	23	3	26
structural openings	30	2	32
lifting operation risks	28	2	30
high-level light	14	10	24
clean glazing	25	1	26
piling risks	31	3	34
open edges	35	0	35
handling of cladding	12	5	17
flooring COSHH	10	10	20
plant maintenance at height	18	4	22
traffic route	19	3	22
fire spread during build	11	6	17
emergency escape during build	3	7	10
heavy blocks/lintels	24	8	32
man holes in traffic route	22	2	24
single-step trip hazard	31	2	33
foyer entrance slip risk	3	3	6
clean/maintenance pitched roof	5	1	6
welding steel frame	3	8	11
cutting dust	10	12	22
buried services	14	1	15
slip/trip on stairs	7	2	9
column layout risks	8	0	8
large floor-ceiling heights	2	0	2
fragile roof light	17	5	22
temporary works	17	7	24
paint COSHH	3	11	14
excavations	15	1	16
misc.	27	13	40

TOTALS	467	132	599
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The full 599 hazards are shown by type in Figure 9. This illustrates where the main increases in hazards identified has taken place.

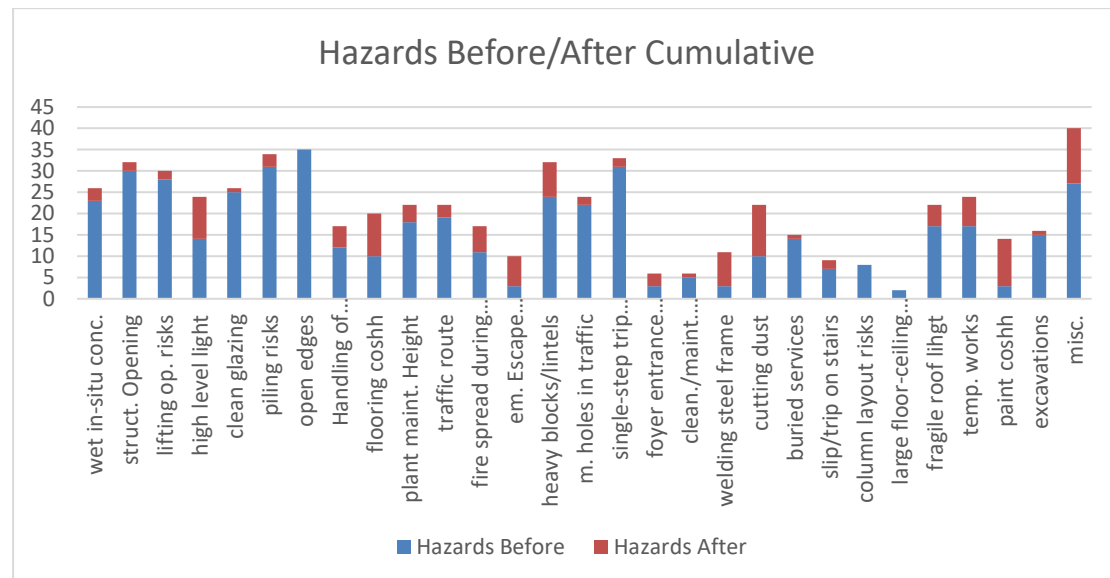


Figure 9 All hazards before/after

The most commonly identified hazards (excluding miscellaneous) were open edges (n. 35), piling risks (n. 34), single-step trip (n. 33), heavy blocks/lintels (n. 32) and structural openings (n. 32). This indicates that the most common types of hazards identified relate to work at height (n. 67) aligning with the work of most previous studies, identified in the literature, focusing solely on this one issue.

The greatest rise in hazards identified after intervention (for both experimental and control groups) were cutting dust (n. 12), paint COSHH (n. 11), flooring COSHH (n. 10) and high-level lighting (n. 10). This indicates that designers have added to their list of hazards post-intervention with mainly health-related hazards. This may be due to them uncovering mostly health-related guidance. However, a further breakdown of experimental –v– control group comparisons will shed more light on this.

4.3.2 Experimental –v– control group hazards

The experiment and control groups consisted of 20 designers each. The hazards identified by the experimental group (before/after) are shown in Figure 10. This constitutes a total of 339 hazards (234 before + additional 105 after) for this group. The greatest increases in hazards identified were high-level lighting (n. 9), flooring COSHH (n. 8), paint COSHH (n. 8) and welding steel frame (n. 8). The uplift in number of hazards identified by the experimental group amounts to 45% of the original number as a result of using the digital tool.

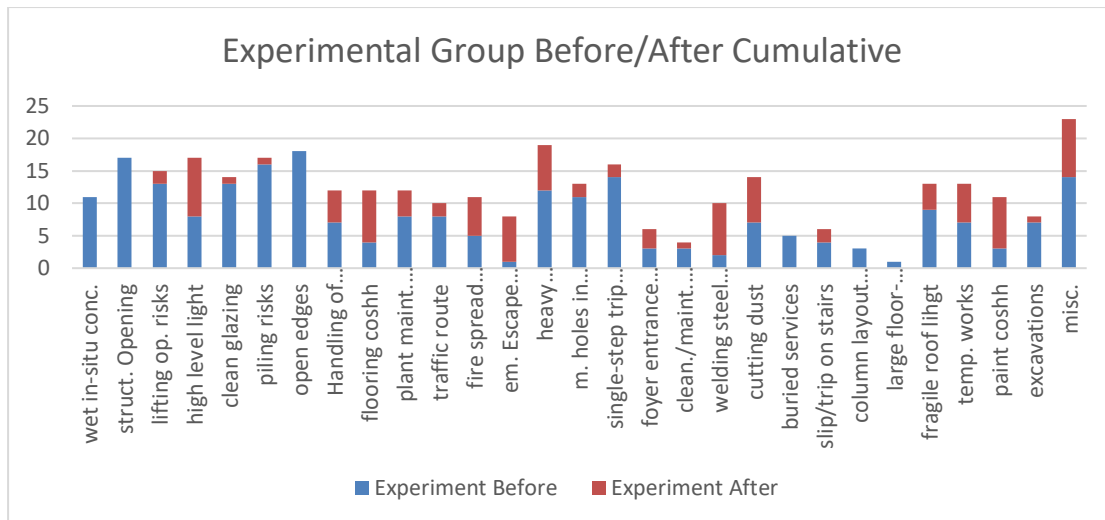


Figure 10 Experimental group number of hazards, before/after, cumulative

The hazards identified by the control group (before/after) are shown in Figure 11. This constitutes a total of 260 hazards (233 before + additional 27 after). The greatest increases in hazards identified for this group were cutting dust (n. 4), wet in-situ concrete (n. 3) and paint COSHH (n. 3). The uplift in number of hazards identified by the control group amounts to 12% of the original number as a result of searching the web. This compares to the 45% rise for the experimental group.

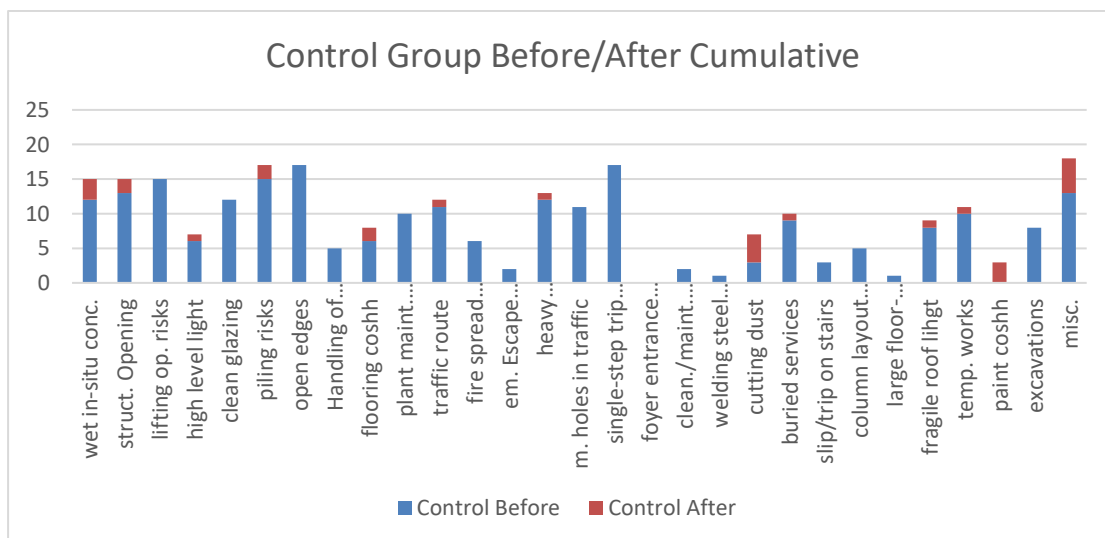


Figure 11 Control group number of hazards, before/after, cumulative

4.3.3 Architects –v– civil engineers hazards

There were 20 architects (10 novice + 10 expert) in the sample, with an equal number and composition of civil engineers. The hazards identified by the architects (before/after) are shown in Figure 12. This constitutes a total of 281 hazards (212 before + additional 69 after) for this group. The profile of hazards identified pre-intervention was dominated by work at height issues, including open edges (n. 20), structural openings (n. 16) and single-step trip hazard (n. 14). The greatest increases in hazards identified after intervention were cutting dust (n. 7),

heavy blocks/lintels (n. 6), fire spread during build (n. 5), temporary works (n. 5) and paint COSHH (n. 5). These figures are useful for comparison with the civil engineers, but a further breakdown, in terms of experimental group –v– control group should reveal more.

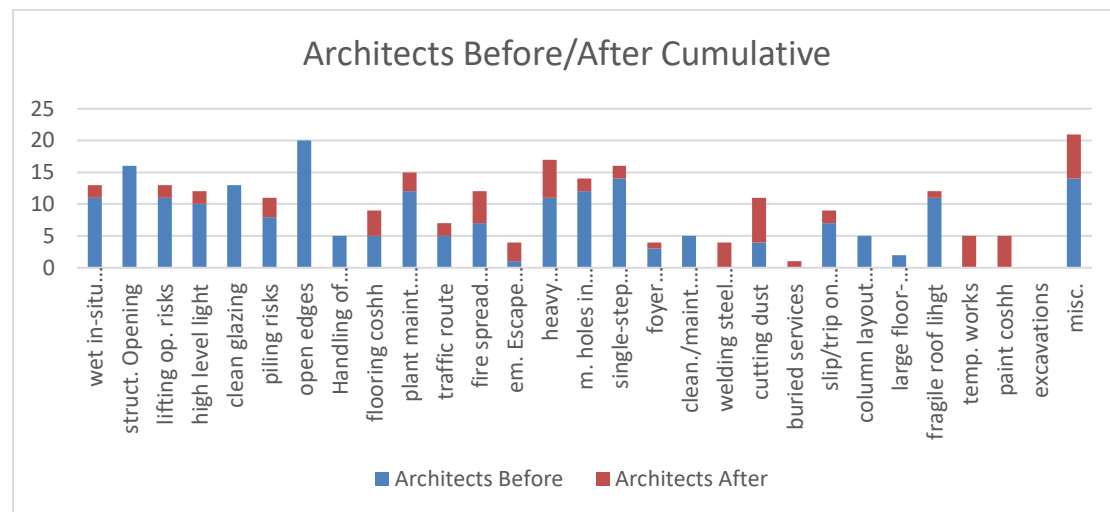


Figure 12 Architects number of hazards, before/after, cumulative

Hazards identified by the civil engineers (before/after) are shown in Figure 13. This constitutes a total of 318 hazards (255 before + additional 63 after) for this group. These figures are higher than those for architects by 13% (n. 37), due to more hazards being identified before interventions. The profile of hazards identified pre-intervention ranked the following top three: piling risks (n. 23), temporary works (n. 17) and single-step trip hazard (n. 17). This shows a different profile when compared to the architects, with the exception of the single-step trip hazard. In addition, the civil engineers have identified lifting operations (n. 17), buried services (n. 14), excavations (n. 15) and traffic routes (n. 14) to a greater extent than the architects. The greatest increases in hazards identified after intervention were high-level light (n. 8), flooring COSHH (n. 6) and paint COSHH (n. 6). Only the increase in 'paint COSHH' matched those of the architects. A further breakdown of hazards for architects and civil engineers, in terms of experimental group –v– control group, may be useful, but the number of hazards to compare will diminish as the groups are filtered further.

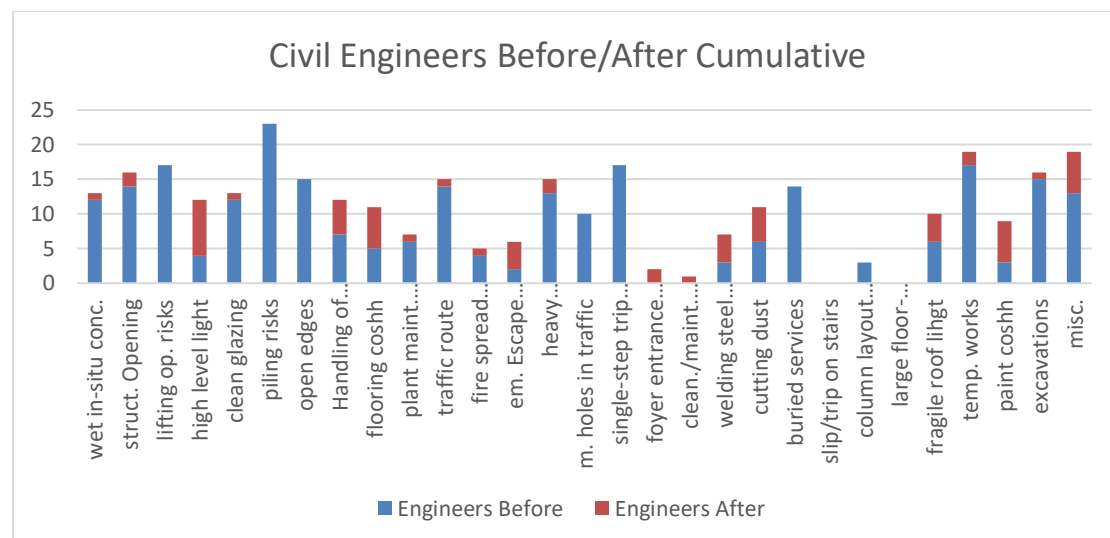


Figure 13 Civil engineers number of hazards, before/after, cumulative

4.3.4 Novice –v– expert hazards

There were 20 novice designers (10 architects + 10 civil engineers) in the sample, with an equal number and composition of expert designers. The hazards identified by the novice designers (before/after) are shown in Figure 14. This constitutes a total of 293 hazards (188 before + additional 105 after) for this group. The bars in Figure 14 show most hazard types with increases post-intervention. The greatest increases in hazards identified were high-level light (n. 9), flooring COSHH (n. 8), welding steel frame (n. 8) and paint COSHH (n. 8). These figures are useful for comparison with the expert designers and a further breakdown into experimental group –v– control group.

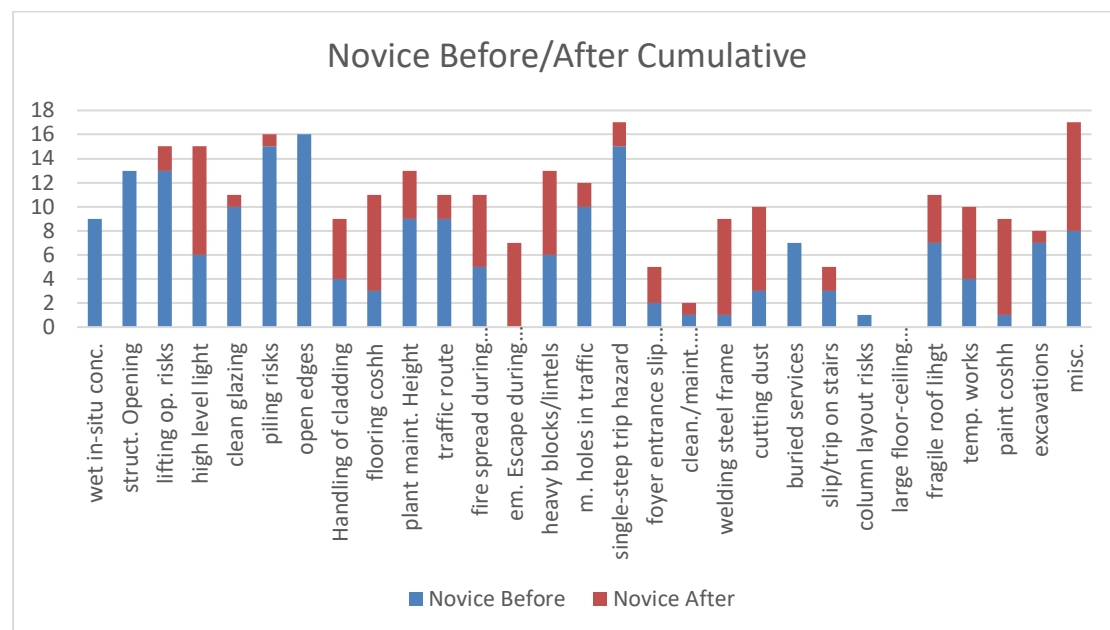


Figure 14 Novice number of hazards, before/after, cumulative

Hazards identified by the expert designers (before/after) are shown in Figure 15. This constitutes a total of 306 hazards (279 before + additional 27 after) for this group. These figures are marginally higher than those for novice designers by 4% (n. 13); however, 91 more hazards were identified by the expert designers before intervention, meaning the novice designers have improved to be nearer expert levels post-intervention. Further filtering of the data will confirm to what extent novice/experimental and novice/control groups have contributed to this increase.

The greatest increases in hazards identified after intervention for the expert designers were cutting dust (n. 5), wet in-situ concrete (n. 3) and paint COSHH (n. 3). Compared to novice designers, there were very few additional hazards identified post-intervention. Analysis of the group, subdivided by experimental group and control group, may reveal further differences, but the low numbers post-intervention may prevent any meaningful results.

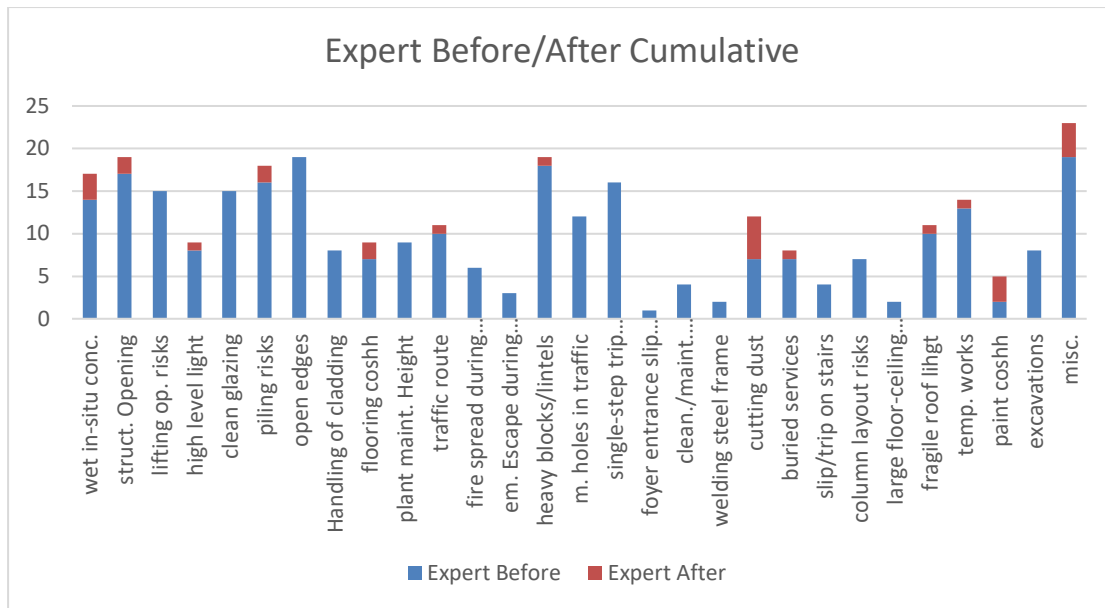


Figure 15 Expert number of hazards, before/after, cumulative

4.3.5 Filtered groups hazards

Filtering different groups (novice/expert & architect/civil engineer) by experimental and control groups can provide further insights. However, some filters at this level of analysis may not produce much data for comparison. Specifically, the expert designers seem to have demonstrated a comprehensive understanding of the hazards presented in the drawings. But comparing the groups still proved interesting.

Figure 16 shows additional hazards identified by novice designers post-intervention. This includes twin bars for each hazard-type, comparing the novice experimental group (n. 70 hazards) with the novice control group (n. 35 hazards). Visually, the bars for the novice experimental group show better results, with more hazard types (n. 16 more) identified post-intervention than the novice control group. Conversely, hazard types for the novice control group improved at a better level than the novice experimental group on only two occasions. There were four occasions where increases are tied between the two groups.

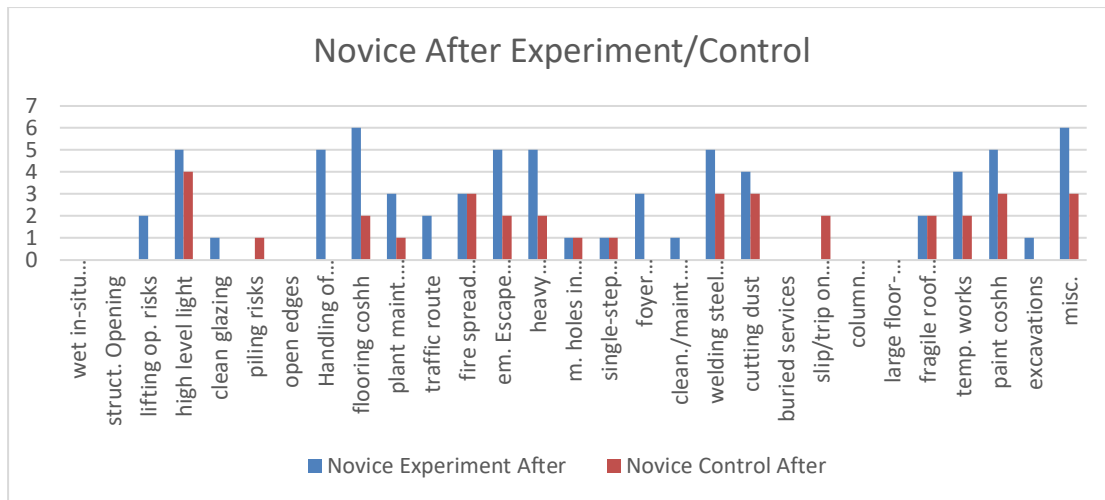


Figure 16 Novice number of hazards after, experiment/control groups

Figure 17 shows additional hazards identified by expert designers post-intervention, comparing the expert experimental group with the expert control group. The experimental group identified 18 hazards post-intervention, compared to the control group who only identified a further nine hazards. Although there are few examples to compare at this level of filtering, it can be seen that there are more bars for the expert experimental group (n. 10) than the expert control group (n. 7), indicating a wider spread of hazards identified for those using the digital tool during the intervention.

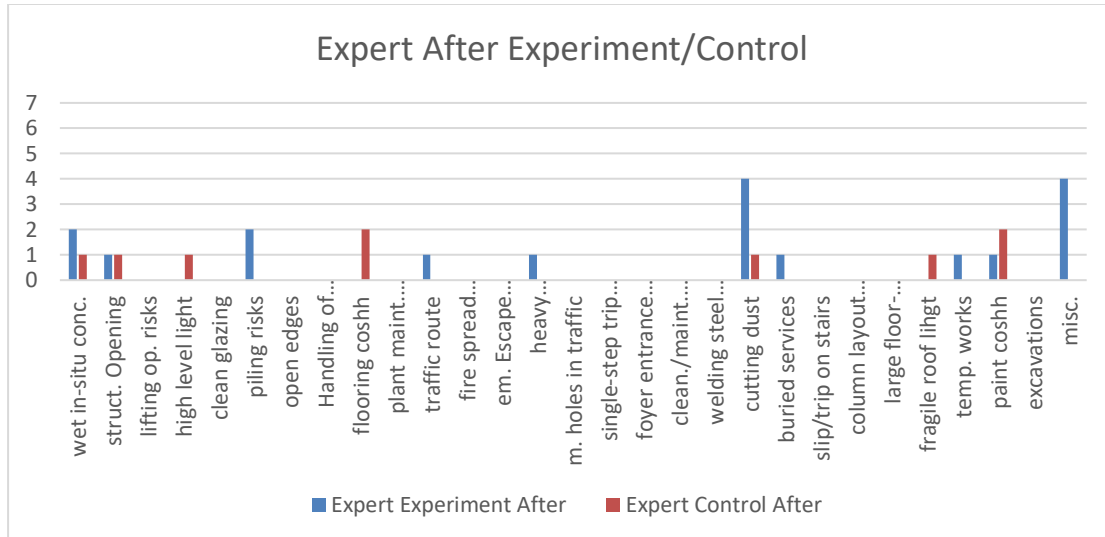


Figure 17 Expert number of hazards after, experiment/control groups

Similar filtering was possible with the architects and civil engineers. Figure 18 shows the additional hazards identified by architects post-intervention, subdivided between experimental and control groups. The experimental group identified 53 additional hazards, which is over three times the number for the control group (n. 16). In addition to this, the architect experimental group has nearly twice as many bars (n. 18) as the architect control group (n. 10), indicating a greater spread of hazard types identified post-intervention. The greatest increases in hazard types identified post-intervention for the architect experimental group were heavy blocks/lintels

(n. 6), fire spread during build (n. 5) and cutting dust (n. 5). There were no notable increases for the corresponding control group.

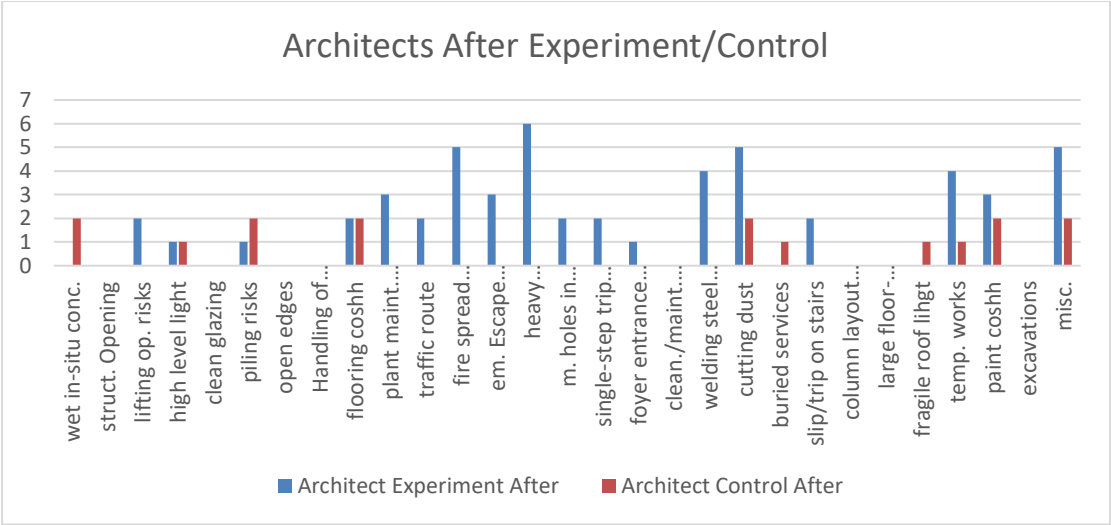


Figure 18 Architects number of hazards after, experiment/control groups

Figure 19 shows additional hazards identified by civil engineers post-intervention, subdivided between experimental and control groups. The experimental group identified 52 additional hazards, which is nearly five times the number for the control group (n. 11). In addition to this, the civil engineer experimental group has over twice as many bars (n. 17) as the civil engineer control group (n. 7), indicating a greater spread of hazard types identified post-intervention. The greatest increases in hazard types identified post-intervention for the civil engineer experimental group were high-level light (n. 8), flooring COSHH (n. 6) and paint COSHH (n. 5). The corresponding control group had cutting dust (n. 3) as the most notable improvement.

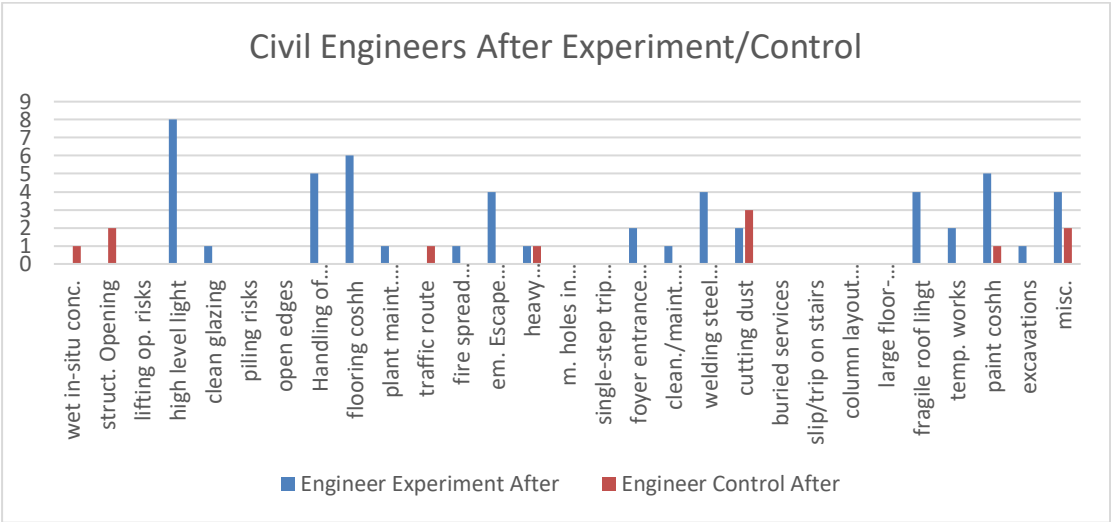


Figure 19 Civil engineers number of hazards after, experiment/control groups

4.4 Findings: before/after measures

4.4.1 Data used for statistical tests

The overall changes in performance pre- and post-intervention were analysed using average (mean) figures per group. This included not just the number of hazards identified by designers, but also a weighted score for the actions (controls) recommended (see Section 3.3). The multiplication of a weighted control score by the number of controls identified by designers gave the overall 'control score' (as described in the Methods Section). It should also be noted that in some cases designers were able to identify a hazard but not a suitable control. Therefore, the hazard would have been counted in the data but a zero recorded for the control. A table with individual scores is included in Appendix VIII.

Two statistical tests were used to compare the means: Mann-Whitney for tests between groups (e.g. between experimental and control groups) and Wilcoxon Signed-Ranks for pre/post-intervention measures within the same groups. In all cases the usual convention was followed of rejecting the null hypothesis if $p < 0.05$.

4.4.2 Hazard numbers before/after

The average (mean) number of project-specific hazards identified per designer was analysed for various groups. Figure 20 shows the change, from pre- to post-intervention, for all designers in the sample. This shows a clear rise in the mean hazard numbers for the experimental group, above that of the control group. The pre-intervention mean values for experimental and control groups were 11.7 and 11.75 respectively (not statistically different). However, the experimental group increased to 16.95 post-intervention, while the control group increased to only 13.1. A Mann-Whitney statistical test for the difference between the two groups post-intervention returned a p-value of 0.017 (1-tailed). A Wilcoxon Signed-Ranks for the experimental group confirms a statistically significant change ($Z = -3.829$, $p < 0.001$), rejecting the null hypothesis.

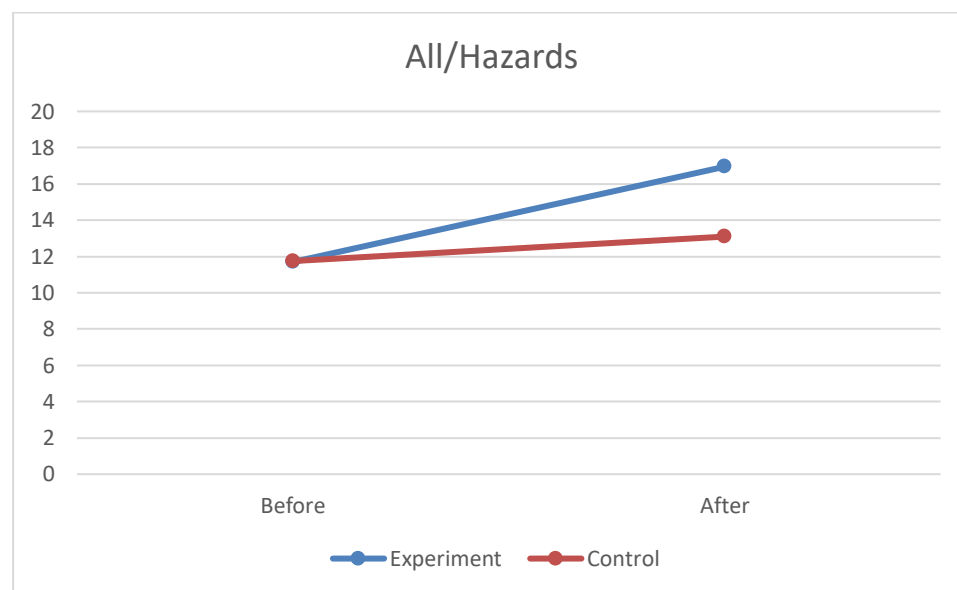


Figure 20 Mean hazard numbers, experiment/control

The data for novice and expert groups are shown in Figure 21. The graphs indicate what was anticipated, i.e. novice designers identify (on average) fewer hazards than expert designers

pre-intervention but increase post-intervention to near-expert levels, whereas experienced designers show little increase as their average was already high to start with.

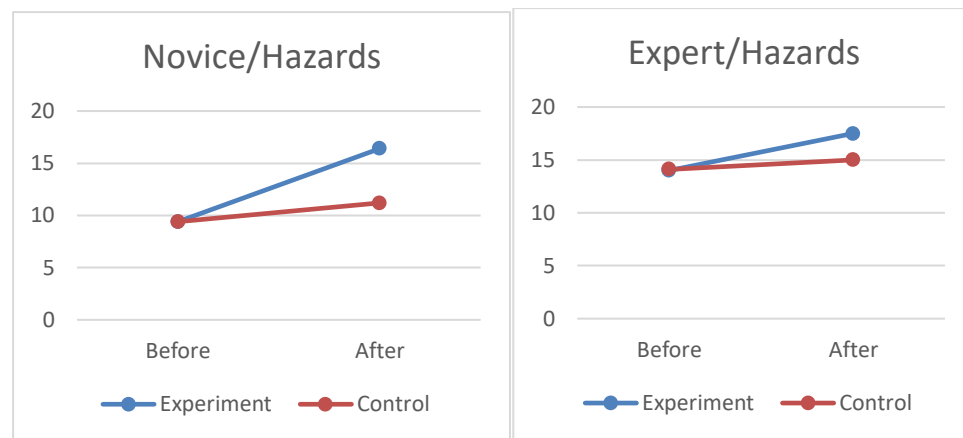


Figure 21 Mean hazard numbers, novice & expert experiment/control

The novice groups (experimental and control) both had a mean of 9.4 pre-intervention. The novice experimental post-intervention mean was 16.4 (within group: $Z = -2.810$, $p = 0.001$) and the corresponding control group was only 11.2 (between groups: $p = 0.018$), being statistically significant. Pre-intervention, the expert groups (experimental and control) were 14 and 14.1 respectively, rising to 17.5 and 15. This small post-intervention rise was still statistically significant ($Z = -2.670$, $p = 0.002$). However, the difference between experimental and control groups was not ($p = 0.152$) meaning the null hypothesis could not be rejected. This could mean the difference was not great enough to satisfy the test for the sample size, but another plausible explanation could be that expert designers didn't gain the same level of benefit as novice designers to distinguish them enough from the control group (as demonstrated by the small gap between experimental and control groups in the right-hand graph of Figure 21).

The main reason for the two graphs in Figure 21 being side by side is to show that the novice experimental group's mean value surpassed the expert control group post-intervention. It was also closer to the higher expert experimental group mean than pre-intervention, as anticipated.

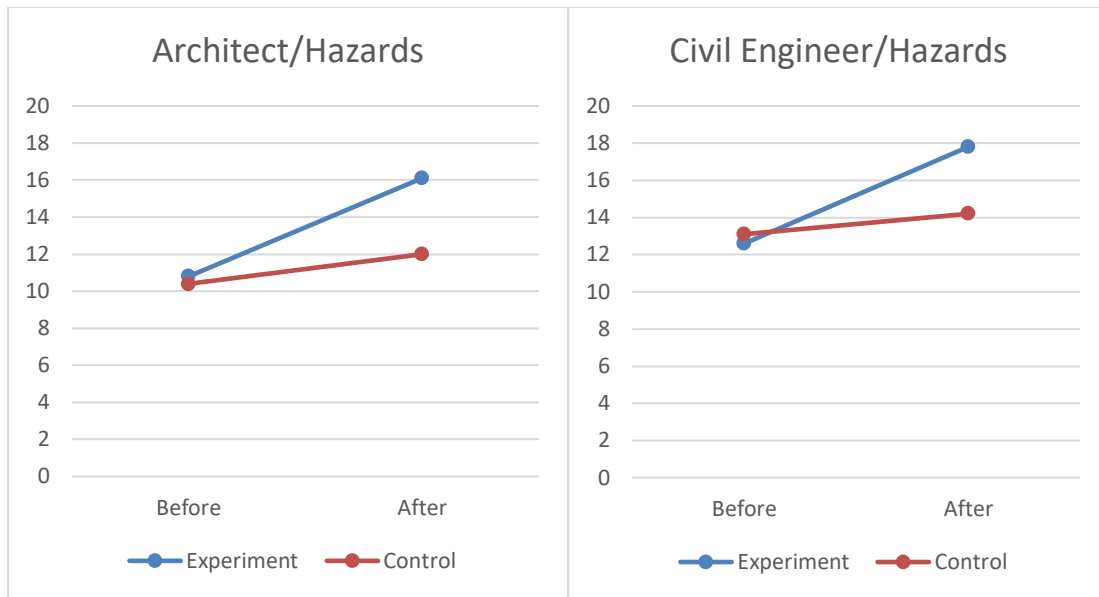


Figure 22 Mean hazard numbers, architect & civil engineer, experiment/control

Figure 22 shows that both architects and civil engineers in the experimental group achieved higher means than their corresponding control groups post-intervention. These comparisons were statistically tested although the numbers were smaller due to sub-dividing the sample.

The architects' pre-intervention means were 10.8 for experimental and 10.4 for control group, increasing to 16.1 and 12 respectively. The within-group statistical test was significant ($Z = -2.812$, $p = 0.001$), but the between-group test was not ($p = 0.091$).

The civil engineers' pre-intervention means were 12.6 for experimental and 13.1 for control groups, increasing to 17.8 and 14.2 respectively. The within-group statistical test was significant ($Z = -2.670$, $p = 0.002$), as was the between-group test ($p = 0.050$).

The civil engineers' statistical results indicate that the reason for the architects' between-group test being rejected may be merely due to the smaller numbers, as the graphs in Figure 22 show similar patterns across both groups of designers. The only discernible difference being civil engineers identify, on average, more hazards than architects.

4.4.3 Control scores before/after

The mean scores for project-specific controls recommended by designers were analysed for the same groups as Section 4.4.2. Figure 23 shows the change, from pre- to post-intervention, for all designers in the sample. This shows a clear rise in the mean risk control scores for the experimental group, above that of the control group (predictably, a similar result to the mean hazard numbers). The pre-intervention mean scores for experimental and control groups were 34 and 35.6 respectively (not statistically different). However, the experimental group increased to 55.85 post-intervention, while the control group increased to only 39.1. The between-groups test post-intervention returned a p-value of 0.002 (1-tailed). The within-group test confirms a statistically significant change ($Z = -3.825$, $p < 0.001$), rejecting the null hypothesis.

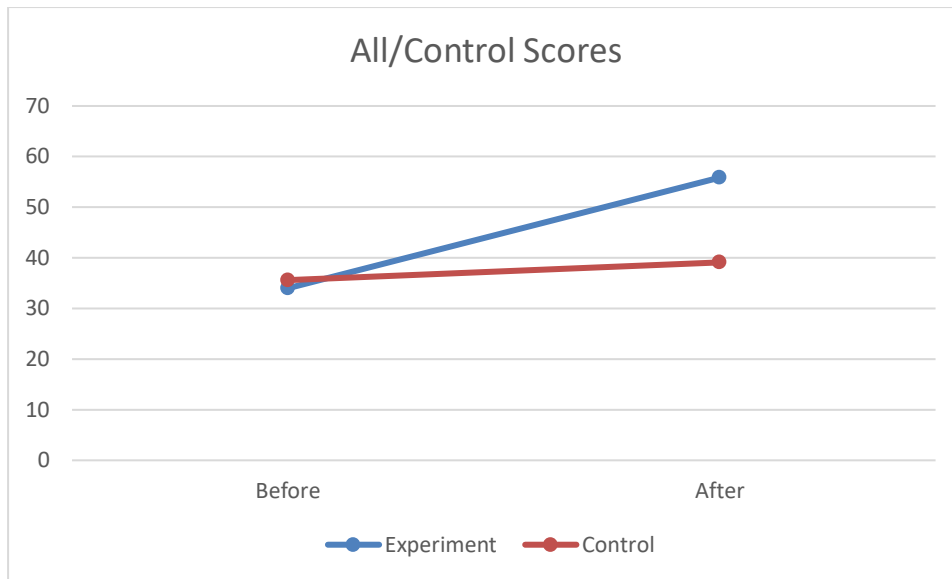


Figure 23 Mean control scores, experiment/control

The data for novice and expert groups are shown in Figure 24. The graphs indicate what was anticipated in line with the hazard results, i.e. novice designers had (on average) lower risk control scores than expert designers' pre-intervention but increase post-intervention to near-expert levels, whereas experienced designers show less of an increase as their average was already high to start with.

The novice groups (experimental and control) had means of 24.9 and 28.5 pre-intervention. The novice experimental post-intervention mean was 53.8 (within group: $Z = -2.805$, $p = 0.001$) and the corresponding control group was only 32.1 (between groups: $p = 0.007$), being statistically significant. Pre-intervention, the expert groups (experimental and control) were 43.1 and 42.7 respectively, rising to 57.9 and 46.1. This post-intervention rise was statistically significant ($Z = -2.670$, $p = 0.002$). However, the difference between experimental and control groups was not ($p = 0.074$) meaning the null hypothesis could not be rejected. This repeats the result experienced with the hazard means and could likewise mean the difference was not great enough to satisfy the test for the sample size, or (per the hazards) that expert designers didn't gain the same level of benefit as novice designers to distinguish them enough from the control group (as demonstrated by the smaller gap between experimental and control groups in the right-hand graph of Figure 24).

The two graphs in Figure 24, side by side, show again (per the hazard graphs) that the novice experimental group's mean score surpassed the expert control group post-intervention. It was also closer to the higher expert experimental group mean than pre-intervention, as anticipated.

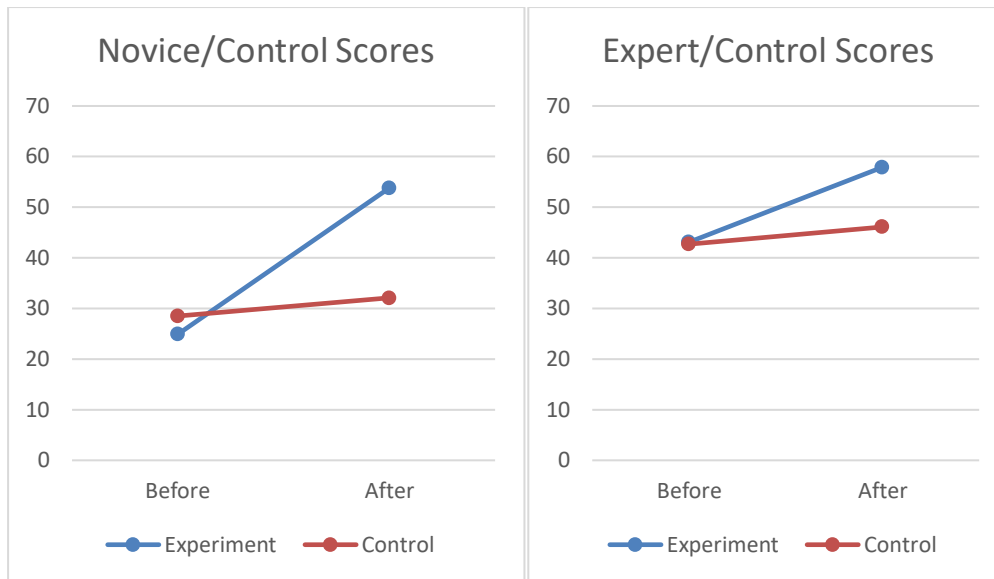


Figure 24 Mean control scores, novice & expert, experiment/control

Figure 25 shows that both architects and civil engineers in the experimental group achieved higher means than their corresponding control groups post-intervention, repeating the results for the hazards data. These comparisons were statistically tested although, again, the numbers were smaller due to sub-dividing the sample.

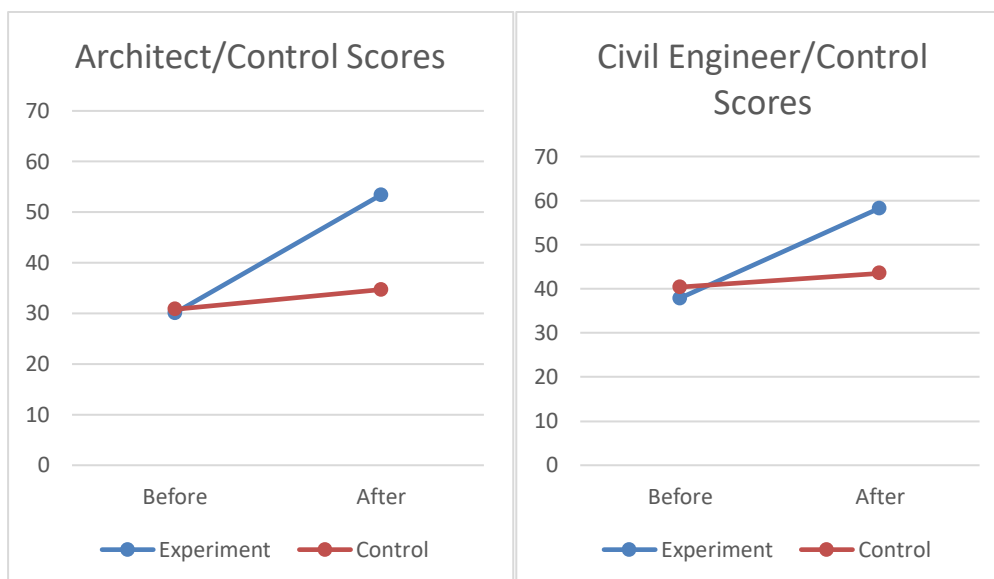


Figure 25 Mean control scores, architect & civil engineer, experiment/control

The architects' pre-intervention means were 30.1 for the experimental group and 30.8 for the control group, increasing to 53.4 and 34.7 respectively. The within-group statistical test was significant ($Z = -2.807$, $p = 0.001$), as was the between-group test ($p = 0.025$), in contrast to the between-group test for the hazards data.

The civil engineers' pre-intervention means were 37.9 for the experimental group and 40.4 for the control group, increasing to 58.3 and 43.5 respectively. The within-group statistical test was significant ($Z = -2.666$, $p = 0.002$), as was the between-group test ($p = 0.021$).

The complete agreement between architects' and civil engineers' statistical tests seems to confirm the previous assumption that the reason for the architects' between-group test for mean hazard numbers being rejected may be merely due to the smaller numbers. As with the hazard graphs in Figure 22, similar patterns across both groups of designers are seen with the risk control graphs in Figure 25. Also, like the hazard graphs, civil engineers score, on average, higher than the architects.

4.5 Findings: summary

4.5.1 Hazards identified

After filtering for generic hazards, the 40 designers identified hazards a total of 599 times. These were sorted into 29 categories. The most common types of hazards identified by all designers related to work at height. But this was supplemented by mostly health-related hazards post-intervention. The experimental group (who used the digital tool) identified 339 hazards in total, whereas the control group only identified 260. This difference was due to the post-intervention differences: experimental group 105; control group 27. The largest increases in the experimental group related to issues highlighted in the tool, e.g. high-level lighting, flooring and paint COSHH, and welding steel frame. The smaller increase in the control group (using the internet) included hazards relating to dust and hazardous substances.

Civil engineers identified more hazards than architects: 318 and 281 respectively. Architects tended to identify more building-related hazards – open edges and structural openings, trip hazards etc. – whereas civil engineers gravitated towards civil engineering issues such as piling, temporary works and excavations. Novice designers identified 293 hazards while experts identified 306. However, these figures constitute an increase of 105 post-intervention for novice and only 27 for expert designers. This increase in the novice figure was due to 70 additional hazards identified by the experimental group. The novice experimental group also improved the scope of hazards identified, with increases in 21 categories compared to only 16 in the control group. Filtering architects and civil engineers into experimental and control groups revealed a similar pattern: architects using the tool identified over three times the hazards as their control group post-intervention; for civil engineers the figure was five times, and in both cases the scope of hazards identified was double the control group.

4.5.2 Before/after measures

Mean averages were used to measure changes pre- and post-intervention. Hazard data was used, which was supplemented by a weighted score for the level of controls recommended by designers to address the hazards identified. The average number of hazards identified by designers pre-intervention was almost identical for experimental (11.7) and control (11.75) groups. However, post-intervention figures were 16.95 and 13.1 respectively, which were statistically significant. This pattern was repeated throughout the subgroups of novice, expert, architect and civil engineer. The number of cases reduced with this filtering of subgroups, but the statistical tests generally returned results to reject the null hypothesis even with the smaller numbers. As anticipated, novice designers improved to a greater extent than experts, with the

experimental novice group gaining a higher average (16.4) than the expert control group (15) post-intervention. The split between architects and civil engineers followed the same pattern for the number of hazards identified, i.e. civil engineers' averages pre- and post-intervention were higher than the architects. At this level of analysis most statistical tests were significant but not all.

5.0 Discussion and conclusions

5.1 Discussion on findings

5.1.1 The sample

The sample represents two of the most common types of designers working in the UK construction industry: architects and civil engineers (76). All but one of the 10 novice architects in the sample had experience in a design practice. This compares to eight of the civil engineering novices who were new graduates with limited practical experience and two with up to one year's experience. This may seem like the novice architects had an advantage, but the novice civil engineers had some practical experience included in their education, in the form of work placements.

The selection criteria for both architects and civil engineers included a prerequisite for some level of exposure to site operations (3). This criterion was easier to satisfy for the civil engineers than the architects and resulted in having to source a greater number of more experienced architects. Therefore, on the face of it, if length of experience is related to performance, the architects may have had a slight advantage. However, as the data has shown, the civil engineers were able to identify more hazards and recommend, on average, a higher level of controls than the architects. This point is discussed in more detail later in this section.

5.1.2 Hazards identified

The overall results clearly demonstrate that use of the multimedia digital tool (compared to merely using the internet) leads to improved hazard identification, in terms of number and scope of hazards. It is important to note that the pre-intervention hazard numbers were almost identical for experimental and control groups (not statistically different) but were statistically different post-intervention.

Many of the hazards illustrated in the digital tool were identified post-intervention. The most prolific were high-level lighting, COSHH relating to flooring and painting, and welding of steel frame. However, others (not identified post-intervention by control groups) were:

- lifting operations (cladding);
- cleaning glazing;
- maintaining plant at height;
- fire spread during build;
- emergency escape during build;
- manholes in traffic routes;
- single-step hazard;
- foyer entrance slip;
- excavations (temporary works shoring).

Note that what is being stated here is that all but one of these hazards (foyer entrance slip) were identified by at least one designer pre-intervention in the control group but no further

designers in the control group post-intervention. Of the 26 hazards illustrated in the digital tool and captured in the drawings, only one was not identified by the experimental group: 'curtain wall systems with no anchor points for scaffold'. This may have been due to lack of context from the concept in the tool to the drawings, especially if it did not make sense to the designers. Its relevance to the drawings may have also been missed if designers have no previous experience of the issue (3). A reassessment of the digital tool's images and the description for this hazard reveals that the main issue was glass cladding with no anchor points for scaffold. However, the solution was presented with a photo of opaque cladding (rather than glazed cladding) with an anchor point. Therefore, this may have confused the designers and been the source of this one omission in the results.

Notwithstanding this one item, the digital tool has performed better for the experimental group in relation to pre-intervention scores than the control group. However, it may be argued that the tool could be replaced by a checklist of items, and indeed some of the more experienced architects made this very comment. But the existing literature would seem to refute this claim, citing limitations with text-based rules (22) and the level of information needed to complete structured text-based 'argument trees' (54) being too cumbersome. However, it would seem a visual knowledge-based tool may not be perceived as useful by experienced designers to help identify hazards. This is discussed in more detail later in relation to the comparisons of novice and expert designers.

The next issue worth discussing is the types of hazards identified by the control group as this provides a comparison for what could be identified by other means. Firstly, there were many generic hazards listed by the control group designers (Appendix VI). These generic lists were not produced to the same extent by the experimental group. Appendix VI can easily be cross-referenced to the HSE construction division web pages and explains many of the items, e.g. the web page for construction safety topics (77) lists many of the generic items stated predominately by the control group. It is interesting, however, to note the improved numbers for the control group in relation to 'cutting dust'. This is an area that, during the data collection phase of the research, was receiving much attention from the UK construction industry (78). This may have been the reason for web searches returning such results. The improvement in wider health hazards by the control group has also coincided with a sustained effort to improve awareness of health issues in construction (79). Therefore, while the control group has seen a slight rise in project-specific hazard identification numbers, this may be the result of current industry initiatives. As trends come and go, it is clear from the findings that a structured knowledge database for the long term is more effective.

The contrast between civil engineers and architects, in terms of hazards identified, demonstrates a potential difference in ability to perceive and visualise project-specific construction process and maintenance hazards. The criteria for participant selection was carefully designed to take account of site-based experience as this was important for previous studies (3). This factor has been controlled for, so there must be some other reason for civil engineers identifying 13% more hazards than architects. The answer may lie in the different methods of education for each profession. Civil engineering education in the UK tends to focus on both theory and practice, and invariably includes some level of industry practice, either as part of a student placement or a requirement of graduate membership of the ICE (80). Further, around 10 years ago, the study *Integrating risk concepts into undergraduate civil engineering courses* provided a precedent for individual higher education courses to embed OSH into their core activities in innovative ways (81). The current syllabus of all civil engineering degrees accredited by the Joint Board of Moderators (JBM) must include a defined "thread" on "Health and Safety Risk Management" (82). By contrast, the Royal Institute of British Architects' (RIBA) criteria for accredited courses merely require students to have an understanding of "health and safety legislation" (83). Research published in 2012 on the approaches to OSH teaching in undergraduate schools of architecture in the UK found pockets of good practice and made

recommendations for a more consistent approach (84). The work was partly funded by RIBA; however, based on the current criteria for accredited courses, no action seems to have been taken to implement these recommendations.

Another subtler difference between architects and civil engineers was the scope of hazards identified. The types of hazards that topped the architects' list were open edges and structural openings, high-level lighting (work at height issues in and on the building) and slips and trips (although a 100mm single step in the drawings may have been one of the easier hazards to spot). Civil engineers were also able to spot work at height hazards to a similar extent as the architects, as well as the 100mm trip hazard. However, these were supplemented by numerous instances of hazards relating to piling, temporary works, excavations, buried services and transport route. These constitute subject matter covered in typical civil engineering courses in the UK. Therefore, it may be assumed that education on construction technology and methods possibly enables the civil engineers to interpret and transfer the hazards they have been exposed to as part of their education to drawings for analysis. While some architects were able to identify the more 'civil engineering' hazards after exposure to the digital tool, most civil engineers did not need to be shown these and identified them pre-intervention.

The difference in approach and content within the educational framework of these two professions, and the implications for Design for OSH (DfOSH), could very well be the underlying reason for this gap in the number of hazards identified. In the absence of any other plausible explanation, this may be (for now) considered the most reasonable assumption. In Australia, Zhang et al. (6) did not report any statistically significant differences between architects' and civil engineers' perceptions of OSH risk when viewing images of construction products and processes. Their study included mechanical, electrical and structural engineers (as opposed to civil engineers). However, this shows that elsewhere in the world the gap between architects and civil engineers may be narrower, and further investigation may reveal useful insights.

The narrowing of the gap in hazards identified between novice and experienced designers was as expected. The theoretical change anticipated was to see the novice designers, who were exposed to the digital tool, move closer to the experienced designers in terms of number and scope of hazards identified. This is what happened, however, to a greater effect than expected, i.e. post-intervention novice numbers were 293 compared to experts' 306. The expert designers identified 91 more hazards than novice designers before, but the novice designers increased by 105 post-intervention. These figures include all designers, which may mask the true result. Therefore, comparable data with those novice designers who were in the experimental group (i.e. exposed to the digital tool) need to be isolated and compared to pre-intervention experienced designers. Pre-intervention, the experts identified 140 hazards, compared to 139 for the control group. The novice experimental group figures were 94 pre-intervention and a further 70 post-intervention. This confirms that 164 hazards were identified in total by novice designers exposed to the digital tool, which surpasses the experts' pre-intervention figures (140). Such a result seems, *prima facie*, extremely compelling. However, a number of factors need to be considered before jumping to any conclusions: there was a limited number of hazards that could be found in the hazard-test drawings and the experts had mostly reached the ceiling point; the test has been designed to find hazards matching the content of the digital tool, so it is in some respects artificial (but still a useful learning tool); and finally, a comparison of averages may reveal more useful information. This is explored in the next section.

The final level of analysis for hazard identification numbers continued to reveal greater numbers for the experimental groups than for the control groups. The previous analysis compared architects with civil engineers. This final layer of analysis compares each designer type with

their individual control groups. Architects using the tool identified over three times the hazards as their control group post-intervention; for civil engineers the figure was five times, and in both cases the scope of hazards identified was double the control group. The greater increase in the absolute number of hazards identified by civil engineers using the digital tool (compared to architects) reinforces the notion that they performed better. It can be concluded from this analysis that civil engineers used the tool to greater effect; essentially, they got better use out of the tool. That is not to say that the tool is useless for architects. Possibly with more usage, architects could reach similar levels to the civil engineers.

5.1.3 Before/after measures

The hazard numbers provided useful insights to assess the impact of the digital tool. It is not necessary to go over these same issues again in relation to average scores, but the added dimension of 'control measures' data provides opportunities for further discussion on how the designers have interpreted the tool's guidance. The theoretical standpoint in relation to the control measures is that those designers who understand the OSH implications of their design decisions are able to articulate higher-level controls. This translates to recommending options to either eliminate or reduce risk through designer choices, whereas less knowledgeable designers revert to asking contractors to provide method statements or PPE for their workers as a means of controlling risks. These 'low-level' measures may very well be recommended by knowledgeable designers, but their ability to first recommend alternatives means the 'highest level' option offered by designers can be recorded for analysis.

Calculating the mean hazard scores pre- and post-intervention allowed non-parametric tests for significance to be applied. The increase in mean hazards identified in the experimental group proved statistically significant and the null hypothesis (that designers will not improve their OSH effectiveness after using the digital tool) when compared to the control group was rejected. This analysis provides confirmation of what the absolute hazard numbers suggest: the post-intervention results are not down to chance but are most likely the result of exposure to the digital tool.

Statistical analysis of the mean control scores for experimental and control groups proved significant for both tests. This shows that designers using the digital tool were able to, on average, recommend higher-level controls than those merely accessing the internet. The benefit of having a control group guards against the weighting of control options, creating a multiplier effect linked to merely identifying more hazards. Therefore, the between-group test provides confidence that a real improvement has occurred. However, what this shows is that the majority of experimental designers can merely identify more hazards and articulate what higher-level controls can be applied. It does not guarantee they will be addressed. Further, designers still need to compare options against time, effort and cost, i.e. what is deemed 'reasonably practicable' before applying the guidance contained in the tool. A consequence of this, though, is that designers make the final (informed) decision on what action to take, rather than relying on automated results. This would ensure that designers understand the links between their design decisions and the management of OSH, and do not become further distanced from the reality of their design implications.

The findings in relation to the tool's impact on mean hazard numbers for novice designers compared to experts showed conclusively that novice users benefited from using the tool. However, the tests for expert users were not so clear cut, i.e. differences between experts in the experimental group (using the tool) and the control group (using the internet) were not statistically significant. Similar test results were replicated for the mean risk controls score, and once again there were uniform results for novice designers but not for experts. The expert

experimental group still showed visible increases on both mean hazards/controls graphs compared to the control group, and therefore it can be concluded that it is still of use to expert designers but not to the same extent as for novice users. It may actually be worthwhile, if the digital tool is developed further, for expert designers to contribute to the content of the tool for the benefit of new graduate (novice) designers as discussed by Metaxiotis and Samouilidis (55).

Both statistical tests proved significant for civil engineers' mean hazard numbers. However, this was not the case for architects; differences pre- and post-intervention were significant but not between experimental and control groups. The higher average for civil engineers reflects the absolute numbers post-intervention returned for the sample (also higher for civil engineers), showing that civil engineers gained the most from use of the tool. These results, in combination with the scope of hazards identified (wider for civil engineers), reinforce the argument for embedding OSH risk management more consistently in architectural undergraduate degrees. The digital tool could have limitations if architects lack the underpinning technical knowledge generally possessed by civil engineers, particularly in relation to piling, excavations, ground works etc.

The one anomaly regarding architects' and civil engineers' data was that the mean control measure scores were statistically significant for all tests, contradicting the inconclusive architects' hazard data. This means that while hazard identification figures for architects were not statistically significant, compared to the control group, the control measures put forward were statistically higher. The inference that can be drawn from this is that where architects understand and can relate hazards viewed in the digital tool to the drawings, they can also articulate higher-level controls (i.e. designer actions).

There are further implications in relation to how best to use the digital tool that will now be discussed. The tool has been predominately built around the HSE 'Red-Amber-Green' guidance (32). One of the limitations of this is many examples relate to issues that will be addressed by designers at a relatively late stage in a typical construction project lifecycle, e.g. detailed design. This means there may be missed opportunities to greatly enhance DfOSH impact at earlier stages of projects (33). Further, the 'eliminate' options presented in the digital tool may need earlier intervention than detailed design stage. Therefore, if the tool is to be developed further for industry use, critical timelines need to be established for when and how the tool can be used, possibly linked to the PAS 1192-6 framework (37).

Appendix IX presents a 'future report' to consider for further development of the tool to take it from prototype to a fully functioning digital tool. Some further refinement has already been identified as a result of the research findings. The tool is at prototype level, meaning that it can be used but isn't at a level suitable for publishing, but it was never intended to be a fully finished tool. It is for research purposes at this stage, created to test the concept.

Finally, the drawings developed for the hazard tests can be used on their own or integrated with the digital tool as a training aid for designers – especially novice designers – of both architecture and civil engineering, for the purpose of improving their knowledge and understanding of construction hazards flowing from their designs. In all cases the researchers delivered CPD training on DfOSH and CDM 2015 after completion of the experiments. This was deemed ethically necessary and also engaged the research participants in a meaningful way.

5.2 *Conclusions and recommendations*

5.2.1 Conclusions

The aim of this research was to improve how designers involved in construction projects learn about how their design influences the management of occupational safety and health (OSH) once the design is implemented. The main conclusions are presented in relation to the research objectives as follows:

1. Identify sector-specific hazards that can be influenced (either mitigated or aggravated) by designers of construction.

The core sector-specific hazards were developed from the HSE 'Red-Amber-Green' (RAG) lists. These were supplemented by others identified in the literature, predominately based around work at height. This limited the types of hazards used in the research to those discussed at a relatively late stage in a typical construction project lifecycle. This means the subsequent digital tool and 'hazard-test' drawings in their current state may miss opportunities to greatly enhance DfOSH impact at earlier stages of projects. The 'eliminate' options presented in the digital tool may need earlier intervention than at, for example, detailed design stage. However, the database is a very useful starting point to build from and has obvious uses as a training and educational resource. Its use as a project resource should be considered and developed further before implementation as it is still very much a prototype.

2. Evaluate strategies on how the hazards (identified in objective 1) can be prevented or mitigated by designers of construction.

Strategies for preventing and mitigating the design-influenced hazards developed for objective 1 were identified from HSE and industry guidance, before being classified into a hierarchical list: eliminate (through design), reduce (through design), reduce (engineering controls), inform of procedure (contractor's system of work) and control (contractor PPE). This hierarchy was developed from a combination of HSE guidance on risk controls and previous research methods found within the literature. The hierarchical framework allowed the development of the digital tool with structured categories of controls, and provided a weighted method of assessing the effectiveness of controls recommended by designers during experiments. This method can be used as an industry tool for assessing strategies put forward by designers in relation to DfOSH. It provides a quick and easy way to measure DfOSH as was demonstrated by the high inter-rater results for the researchers who used the method.

3. Develop a 'hazards test' for designers, tailored to sector-specific hazards (based on the findings of objectives 1+2).

'Hazard-test' drawings were created, based around a fictitious office building. This allowed typical hazards associated with architecture and civil engineering to be incorporated from the RAG database. These drawings can be used on their own or integrated with the digital tool (discussed later) as a training aid for designers – especially novice designers – of both architecture and civil engineering, for the purpose of improving their knowledge and

understanding of construction hazards flowing from their designs. Civil engineers responded best to the hazard drawings (in terms of identifying hazards), possibly reflecting the content and structure of their education, whereas architects were not as prolific, likewise reflecting their own profession's approach to education on DfOSH. The drawings will therefore make a very useful educational (and training) aid for students and new graduates, although students of architecture may need further explanatory material regarding construction technology and methods.

4. Develop mixed-media strategies to fill the 'experiential knowledge gap' of designers who work on construction projects, to improve their ability to complete the 'hazards test', thereby improving their ability to identify, prevent and mitigate hazards.

A multimedia digital tool was developed as a prototype in response to objective 3. Like the hazard-test drawings, the content was drawn from the RAG database. Several iterations of piloting and development resulted in the tool being exclusively photo-based, with external links to video-sharing websites. The logic of the tool flows as follows: project type, building part, activity, hazard, controls, web links to further resources. However, the (digital) architecture of the tool contains much more information, which includes BIM attributes for 'products', 'activities' and 'locations' as well as Uniclass codes for these attributes, as recommended by PAS 1192-6. However, the designers who participated in the pilots found these terms and codes confusing and too complicated. While it seems that the designers in the sample were not quite ready for BIM terminology, the tool has been 'future-proofed' for possible incorporation into BIM technologies at a later date.

5. Validate the mixed-media strategies (of objective 4).

Validation was undertaken via a series of experiments with a sample of 20 architects and 20 civil engineers. These were further subdivided equally between novice and expert designers and placed randomly into experimental (using the digital tool) and control (merely accessing the internet) groups.

The overall results clearly demonstrate that use of the multimedia tool (compared to merely using the internet) leads to more hazards being identified, a greater scope of hazards being identified, and a higher level of controls being recommended by designers. At this level of analysis, all tests were statistically significant and the null hypothesis can be rejected.

With the null hypothesis rejected it can be stated with confidence that:

H1 – Designers will be able to identify more 'project-specific' hazards after using the digital tool.

H2 – Designers will be able to recommend more effective design solutions to address hazards after using the tool.

As the sample is filtered by the various subgroups (novice, expert, architect, civil engineer), the differences between experimental and control groups could not be rejected for 'experts' and 'architects'. However, visual inspection of the graphs and within-group statistical tests were still

significant. Therefore, either the sample was too small to detect these changes as significant, or some other reason exists, which is discussed further in the following pages.

The results of the experiments demonstrated that at least nine categories of hazards were identified post-intervention using the tool that were not identified by the control group. While this may be expected, it confirms that this method of sharing knowledge allows ideas and concepts around hazards and controls to be communicated effectively. Only one hazard from the digital tool was not identified in the hazard-test drawings which can be easily remedied. However, this demonstrates the need for continual monitoring and updating of the tool if it is to become a fully functioning aid for designers.

Validation of the tool uncovered limitations of architects compared to civil engineers (in terms of numbers/scope of hazards and controls). The source of this may lie with the respective educational systems, and while the materials developed for the purposes of the research will prove beneficial for educational purposes, it is acknowledged that the RIBA has been slow to act upon research it commissioned several years ago which made recommendations similar to those employed by the ICE (for civil engineers) to improve OSH risk management in undergraduate degrees. It cannot be concluded that the architects' lower results (compared to the civil engineers) are related to the format and/or content of the tool, as the architects demonstrated statistically valid improvements when using the tool compared to the control group. As mentioned previously, technical content of their educational syllabus may be the reason.

6. Develop a pilot database of mixed-media materials to aid designers of construction in their statutory duty to identify, prevent and mitigate hazards flowing from their design.

As a prototype tool, it can be used but it won't be at a level suitable for publishing. It was never intended to be a fully finished tool. It is for research purposes at this stage, created to test the concept. In its current format, it still has value as a teaching and training aid, but further development is needed before utilising it in a project environment.

5.2.2 Limitations of the study

The research had the typical constraints of a 12-month study, which limited the scope to only two types of designers and a maximum of 40. This had implications for statistical tests once filtering was performed to the point where only five cases per group could be used. This was still valid to a point but not when there were ties (no increases in project-specific hazards/controls from pre- to post-intervention), which have to be ignored by the statistical tests used. This happened with six designers: once with the experimental group and five times with the control group. However, visual differences were obvious in all cases, which was encouraging.

The same constraints limited the size and scope of the hazard database developed, and a deeper investigation of how well the digital tool performs with a larger database should be considered for any future research.

5.2.3 Recommendations

The following recommendations are based on the conclusions drawn from the study:

1. The sector-specific hazards database should be recommended for use as an educational and training resource, helping tutors to develop scenarios for teaching and training purposes for architects and civil engineers related to the construction industry.
2. The hazard-test drawings should be recommended for use as an educational and training resource, per recommendation number 1. These can be used as stand-alone materials or as part of a suite with the digital tool.
3. The digital tool should be recommended for use as an educational and training tool, per recommendation number 2.
4. The recommendations (1–3) should be carefully considered with respect to architects and consultation with the RIBA (RIAS in Scotland) should be sought to ensure recommendations made by previous RIBA-funded research (in relation to education) are implemented.
5. The digital tool should be developed and expanded for eventual use as a project tool, aligned with BIM PAS 1192-6 as a means to helping designers identify hazards and recommend suitable controls when developing and reviewing designs and specifications.
6. The digital tool should be owned by an organisation capable of monitoring, updating and sharing its contents in a transparent way. It is anticipated that its future success will depend on an 'open' format, with gatekeepers, so that experienced designers can continue to share their experiential knowledge with novices. This way, the content will grow and remain relevant.

Improved industry practice

The research has demonstrated that the digital tool (and related materials) is of most use to novice designers, such as students and new graduates. Adoption of the research outputs should foster long-term improvements in how new designers approach their designs with regard to DfOSH and their duties under the CDM regulations. The digital tool and hazard drawings need to be shared with tutors and trainers of architectural and civil engineering professions. However, architects will improve to a greater extent if the findings of this research are shared with and reciprocated by the RIBA.

In addition to the educational uses for the outputs of the research, the training benefits should not be underestimated. There are many CDM-related courses available to the construction designer community. It is expected that the hazard-test drawings in particular will be of significant use and other industry-specific versions could be developed based on the methods employed by this research.

The hazards database and digital tool also provide a format more accessible than other similar databases on the internet for sharing good practice. The recommended 'open' format (like a wiki) with designated gatekeepers, e.g. IOSH Construction Group, will allow experienced designers to share their knowledge and help the next generation of designers so that such knowledge is not lost.

Further academic study

The recommendations made regarding development of the digital tool for industry project application are dependent on further research to develop the size and scope of the tool before validating its use. By doing this, the scalability of the tool can be determined. Further data collection with a larger sample will also allow more confidence in its validity and reliability.

Future integration of the tool with BIM technology would provide an ideal opportunity to further develop and test the theories around visualisation and the application of knowledge databases through visual means. This may also help to determine additional strategies to help architects in particular gain more from use of the tool.

Finally, a logical development would be to monitor use of the materials developed and assess their impact on live projects. However, this would be only after the proposed research mentioned above is completed.

This study has not only contributed to research-led knowledge in the OSH discipline, but it has also delivered practical tools to help improve industry practice. DfOSH is a moral and legal obligation for designers and the research reported here can help novice designers in particular to improve their effectiveness in this regard.

References

1. Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., & Atkinson, S. (2005). Contributing factors in construction accidents. *Applied Ergonomics*, 36(4), 401–415.
2. Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. *Safety Science*, 43(8), 589–611.
3. Hayne G., Kumar B., & Hare B (2015). Evaluating the effectiveness of modern building engineering studios to deliver design for safety (DfS). In *CIB W099* (pp. 160–168). Belfast.
4. Hare, Cameron, Real & Maloney (2013). Exploratory case study of pictorial aids for communicating health and safety for migrant construction workers. *Journal of Construction Engineering and Management*, 139(7), 818–825.
5. Lingard, H., Zhang, R., Blismas, N., Wakefield, R., & Kleiner, B. (2015). Are we on the same page? Exploring construction professionals' mental models of occupational health and safety. *Construction Management and Economics*, 33(1).
6. Zhang, R, Lingard, H., Blismas, N., Wakefield, R., & Kleiner, B. (2015). Work-health and safety-risk perceptions of construction-industry stakeholders using photograph-based Q methodology. *Journal of Construction Engineering and Management*, 141(5), 1–13.
7. Liu, R., & Issa, R. (2014). Design for maintenance accessibility using BIM tools. *Facilities*, 32, 153–159.
8. Zhang, S., Teizer, J., Lee, J-K., Eastman, C., & Venuggopal, M. (2013). Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules. *Automation in Construction*, 29, 183–195.
9. Gambatese. (1998). Liability in designing for construction worker safety. *Journal of Architectural Engineering*, 4(3), 107–112.
10. Hecker & Gambatese. (2003). Safety in design: A proactive approach to construction worker safety and health. *Applied Occupational and Environmental Hygiene*, 18(5), 339–342.
11. Larsen & Whyte. (2013). Safe construction through design: Perspectives from the site team. *Construction Management and Economics*, 31(6), 675–690.
12. Schultz & Jorgensen. (2014). Integrated safety in design. In *CIB W099 Achieving sustainable construction health and safety*.
13. Sherrard. (2017). *Safety in design: A study of designers' motivation in Canberra, Australia* (PhD thesis). University of Canberra, Canberra.
14. Trethewy & Atkinson. (2003). Enhanced safety, health and environment outcomes through improved design. *Journal of Engineering, Design and Technology*, 1(2), 187–201.
15. Toole & Gambatese. (2008). The trajectories of prevention through design in construction. *Journal of Safety Research*, 29, 225–230.
16. Gibb, A., Haslam, R., Gyi, D., Hide, S., & Duff, R. (2006). What causes accidents? *Civil Engineering*, 159, 46–50.

17. Martínez Aires, M. D., Rubio Gámez, M. C., & Gibb, A. (2010). Prevention through design: The effect of European directives on construction workplace accidents. *Safety Science*, 48(2), 248–258.
18. Gambatese, J. A., Behm, M., & Rajendran, S. (2008). Design's role in construction accident causality and prevention: Perspective from an expert panel. *Safety Science*, 46, 675–691.
19. Directive 92/57/EEC. *Temporary or mobile construction sites*. Retrieved from <https://osha.europa.eu/en/legislation/directives/15>.
20. Howarth, T., Stoneman, G., & Hill, C. (2000). A review of the construction (design and management) regulations. *Association of Researchers in Construction Management*, 1, 433–441.
21. Gambatese, J., & Hinze, J. (1999). Addressing construction worker safety in the design phase: Designing for construction worker safety. *Automation in Construction*, 8(6), 643–649.
22. Qi, J., Issa, R., Hinze, J., & Olbina, S. (2011). Integration of safety in design through the use of building information modeling. *Computing in Civil Engineering*, 698–705.
23. Morrow, S., Cameron, I., & Hare, B. (2015). The effects of framing on the development of the design engineer: framing health and safety in design. *Architectural Engineering and Design Management*, 11(5), 338–359.
24. Gangoilells, M., Casals, M., Forcada, N., Roca, X., & Fuertes, A. (2010). Mitigating construction safety risks using prevention through design. *Journal of Safety Research*, 41(2), 107–122.
25. Hadikusumo, B. H. W., & Rowlinson, S. (2004). Capturing safety knowledge using design-for-safety-process tool. *Journal of Construction Engineering and Management*, 130, 281–289.
26. Hadikusumo, B. H. W., & Rowlinson, S. (2002). Integration of virtually real construction model and design-for-safety-process database. *Automation in Construction*, 11(5), 501–509.
27. Scheer, D. R. (2014). *The death of drawing architecture in the age of simulation*. New York: Routledge.
28. Bronowski, J. (1979). *The origins of knowledge and imagination*. New Haven: Yale University Press.
29. Suddendorf, T. *Foresight and evolution of the human mind*. (2006). *Science*, 312(5776), 1006–1007.
30. Lingard, H.C., Cooke, T., & Blismas, N. (2012). Designing for construction workers' occupational health and safety: A case study of socio-material complexity. *Construction Management and Economics*, 30(7), 599–599.
31. Szymberski, R. (1997). Construction safety planning. *TAPPI Journal*, 80(11), 69–74.
32. CITB. (2015). *CDM 2015 industry guidance for designers*. Retrieved from <https://www.citb.co.uk/documents/cdm%20regs/2015/cdm-2015-designers-printer-friendly.pdf>.
33. Hayne, G. R. (2016). *The assessment of the impact of site experience on designers' ability to identify and mitigate hazards in designs* (PhD thesis). Glasgow Caledonian University, Glasgow.
34. Schulte, P. A., Rinehart, R., Okun, A., Geraci, C. L., & Heidel, D. S. (2008). National prevention through design (PtD) initiative. *Journal of Safety Research*, 39(2), 115–121.

35. Hale, A., Kirwan, B., & Kjellén, U. (2007). Safe by design: Where are we now? *Safety Science*, 45(1–2), 305–327.
36. Finch, R., & Mordue, S. (2014). *BIM for construction health and safety*. s.l.: NBS/RIBA Enterprises.
37. BSi. (2018). *Specification for collaborative sharing and use of structured health and safety information using BIM* (PAS 1192–6:2018).
38. Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM – A case study approach. *Automation in Construction*, 24, 149–159.
39. Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2018). *BIM handbook* (3rd ed.). New Jersey: John Wiley and Sons.
40. Woo, J., Wilsmann, J., & Kang, D. (2010). Use of as-built building information modelling. *Construction Research Congress*, 1, 538–547.
41. Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in AEC industry. *Automation in Construction*, 19, 988–999.
42. McGraw Hill. (2009). *The business value of BIM: Getting to the bottom line*.
43. NBIMS. (2015). *National BIM standard – United States*.
44. Kumar, B. (2015). *A practical guide to adopting BIM in construction projects*. Dunbeath: Whittles Publishing.
45. Cabinet Office. (2011). *Government construction strategy*.
46. BIS. (2011). *A report for the government construction client group building information modelling (bim) working party strategy paper*.
47. Benjaoran, V., & Bhokha, S. (2010). An integrated safety management with construction management using 4D CAD model. *Safety Science*, 48(3), 395–403.
48. Noy, I. Y., Shinar, D., & Horrey, W. J. (2018). Automated driving: Safety blind spots. *Safety Science*, 102, 68–78.
49. Kiviniemi, M., Sulankivi, K., Kähkönen, K., Mäkelä, T., & Merivirta, M. (2011). *BIM-based safety management and communication for building construction* (Research notes 2597). Espoo: Technical Research Centre of Finland.
50. Gambatese, J. A., Hinze, J. W., & Haas, C. T. (1997). Tool to design for construction worker safety. *Journal of Architectural Engineering*, 1, 32–41.
51. Keick, K. E. (1985). Cosmos vs chaos: Sense and nonsense in electronic contexts. *Organisational Dynamics*, 14(2), 51–64.
52. HSE. (2003). *The development of a knowledge based system to deliver health and safety information to designers in the construction industry* (Research Report 173). London: HMSO.
53. HSE. (2006). *Evaluation into the success of occupational health and safety regulators and organisations use of expert systems* (Research Report 508). London: HMSO.
54. Cooke, T., Lingard, H., & Blismas, N. (2008). ToolSHeD (TM) 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.

55. Metaxiotis, K. S., & Samouilidis, J. E. (2000). Expert systems in medicine: Academic illusion or real power? *Information Management & Computer Security*, 8(2), 75–79.
56. Lenat, D. B. (1983). The role of heuristics in learning by discovery. In R. Michalski, J. Carbonell, & T. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (pp. 243–306). Palo Alto: Tioga Publishing Co.
57. BIM4REGS Software Group. (2013). *About BIM4REGS*.
58. NBS. (2011). *Construction operations building information exchange (COBie)*.
59. NBS. (2015). *Introducing Uniclass 2015*.
60. Dewar, R. E. (1999). Design and evaluation of public information symbols. In H. J. G Zwaga, T. Boersema, & H. C. M Moonhout (Eds.) *Visual information for everyday use: Design and research perspectives* (p. 285). London: Taylor & Francis.
61. Lehto, M. R. (1992). Designing warning signs and warning labels: Part II – scientific basis for initial guidelines. *International Journal of Industrial Ergonomics*, 10(1–2), 115–138.
62. Wogalter, M. S., Sojourner, R. J., & Brelsford, J. W. (1997). Comprehension and retention of safety pictorials. *Ergonomics*, 40(5), 531–542.
63. Davies, S., Haines, H., Norris, B., & Wilson, J. R. (1998). Safety pictograms: are they getting the message across? *Applied Ergonomics*, 29(1), 15–23.
64. Cairney, P., & Sless, D. (1982). Communication effectiveness of symbolic safety signs with different user groups. *Applied Ergonomics*, 13(2), 91–97.
65. Chandler, D. (2002). *Semiotics: The basics*. London: Routledge.
66. McNairney, F. (2012). *Using images to overcome communication hurdles posed by foreign site operatives* (PhD thesis). Glasgow Caledonian University, Glasgow.
67. Wogalter, M. S. (2006). *Communication-human information processing (C-HIP) model*. New Jersey: Lawrence Erlbaum Associates.
68. Green, R. (2005). Community perceptions of environmental and social change and tourism development on the island of Koh Samui, Thailand. *Journal of Environmental Psychology*, 25(1), 37–56.
69. Fairweather, J. R., Swaffield, S. R., & Simmons, D. G. (1998). *Understanding visitors' experiences in Kaikoura using photographs of landscapes and Q method*. Lincoln, New Zealand: Tourism Research and Education Centre (TREC).
70. Kleiner, B. M., & Shewchuk, J. P (2001). Participatory function allocation in manufacturing. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 11(3), 195–212.
71. Albert, A., Kleiner, B. M., & Hallowell, M. R. (2014). Enhancing construction hazard recognition and communication with energy-based cognitive mnemonics and safety meeting maturity model: Multiple baseline study. *Journal of Construction Engineering and Management*, 140(2).
72. Ware, C. (2008). *Visual thinking for design*. s.l.: Morgan Kaufmann.
73. Shneiderman, B., Plaisant, C., Cohen, M., & Jacobs, S. (2009). *Designing the user interface: strategies for effective human-computer interaction* (5th ed.). s.l.: Pearson.

74. Anglin, G. J., Vaez, H., & Cunningham, K. L. (2004). Visual representations and learning: The role of static and animated graphics. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (2nd ed.) (pp. 865–916). Mahwah, NJ: Lawrence Erlbaum Associates.
75. Oates, Briony J. (2006). *Researching information systems and computing*. London: SAGE.
76. ONS. (2017). *Construction statistics annual tables*. s.l.: Office for National Statistics.
77. HSE. (2018). *HSE construction safety topics*. s.l.: Health and Safety Executive.
78. CITB (2017). *Construction dust partnership*. s.l.: Construction Industry Training Board.
79. Health in construction leadership group. (2014). *Health in construction leadership group*.
80. ICE. (2018). *Graduate membership of ICE*. s.l.: Institution of Civil Engineers.
81. HSE. (2009). *Integrating risk concepts into undergraduate engineering courses* (Research Report 702). London: HMSO.
82. JBM. (2017). Health and safety risk management in degree programmes. In *Guidelines for developing degree programmes*. s.l.: Joint Board of Moderators.
83. RIBA. (2014). *RIBA procedures for validation and validation criteria for UK and international courses and examinations in architecture*. s.l.: Royal Institute of British Architects.
84. HSE. (2012). *Healthy design, creative safety – Approaches to health and safety teaching and learning in undergraduate schools of architecture* (Research Report 925). London: HMSO.

Appendix I Hazard database

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Ground	Piling	Ss_20_05_15_71 * Reinforced Concrete Pilecap And Ground Beam Foundation systems	Vibration	1	Using a hand-held breaker on concrete	Using a hand-held breaker for long periods of time to create a rough surface on concrete can cause hand arm vibration syndrome	Image of worker using a breaker on concrete
Basement	Piling	Ss_15_10_28_15 * Contiguous Bored Pile Embedded Retaining Wall Systems	Vibration	1	Using a hand-held breaker on concrete	Using a hand-held breaker for long periods of time to create a rough surface on concrete can cause hand arm vibration syndrome	Image of worker using a breaker on concrete
Basement	Piling	Ss_15_10_28_80 * Secant Pile Embedded Retaining Wall Systems	Vibration	1	Using a hand-held breaker on concrete	Using a hand-held breaker for long periods of time to create a rough surface on concrete can cause hand arm vibration syndrome	Image of worker using a breaker on concrete
Floor	Concrete finishing	Ss_30_12_85_18 * Concrete Floor Or Roof Deck Systems	Vibration	2	Using a vibrating hand-held scabbling tool	Using a hand-held scabbling tool for long periods of time can cause hand arm vibration syndrome	Image of someone scabbling

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Wall (internal & external)	Concrete finishing	Ss_25_11_16 * Concrete Wall Systems	Vibration	2	Using a vibrating hand-held scabbling tool	Using a hand-held scabbling tool for long periods of time can cause hand arm vibration syndrome	Image of someone scabbling
Ceiling	Concrete finishing	Ss_30_12_85_18 * Concrete Floor Or Roof Deck Systems	Vibration	2	Using a vibrating hand-held scabbling tool	Using a hand-held scabbling tool for long periods of time can cause hand arm vibration syndrome	Image of someone scabbling
Stairs	Concrete finishing	Ss_35_10_85_15 * Concrete Stair Or Ramp Systems	Vibration	2	Using a vibrating hand-held scabbling tool	Using a hand-held scabbling tool for long periods of time can cause hand arm vibration syndrome	Image of someone scabbling
Ramp	Concrete finishing	Ss_35_10_85_15 * Concrete Stair Or Ramp Systems	Vibration	2	Using a vibrating hand-held scabbling tool	Using a hand-held scabbling tool for long periods of time can cause hand arm vibration syndrome	Image of someone scabbling
Flat roof	Roof-light installation & maintenance	Ss_30_30_72_70 * Roof-Light Systems	Fall through fragile surface	3	Working on a fragile roof light	Working on a roof with a fragile roof light can result in workers falling through it and injuring themselves	Image of someone working on a roof light
Pitched roof	Roof-light installation & maintenance	Ss_30_30_72_70 * Roof-Light Systems	Fall through fragile surface	3	Working on a fragile roof light	Working on a roof with a fragile roof light can result in workers falling through it and injuring themselves	Image of someone working on a roof light

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Wall (internal & external)	Chase/raggle and drilling	Ss_25 * Wall And Barrier Systems	Silica	4	Using a powered tool to chisel out masonry	The dust created from chiselling or drilling into masonry and concrete causes respiratory illness, which can be terminal	Image of worker using a powered chisel on a brick/block/concrete wall
Wall (internal)	Cutting and drilling	Ss_25_10_30_35 * Gypsum Board Partition Systems	Silica	5	Using a powered tool to cut plasterboard	The dust created from cutting plasterboard causes respiratory illness, which can be terminal	Image of worker using a powered saw to cut a sheet of plasterboard
External path	Cutting brick/block	Ss_30 * Roof, Floor And Paving Systems	Silica	6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	The dust created from cutting bricks, blocks or paving causes respiratory illness, which can be terminal	Image of worker cutting a block with cut-off saw
Flat roof	Cutting brick/block	Ss_30 * Roof, Floor And Paving Systems	Silica	6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	The dust created from cutting bricks, blocks or paving causes respiratory illness, which can be terminal	Image of worker cutting a block with cut-off saw
Floor	Cutting brick/block	Ss_30 * Roof, Floor And Paving Systems	Silica	6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	The dust created from cutting bricks, blocks or paving causes respiratory illness, which can be terminal	Image of worker cutting a block with cut-off saw

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Wall (internal & external)	Cutting brick/block	Ss_25_13_50 * Masonry Wall Systems	Silica	7	Using a powered tool to cut bricks or blocks creates dust	The dust created from cutting bricks or blocks causes respiratory illness, which can be terminal	Image of worker cutting a block with cut-off saw
Confined space	Timber treatment	Ss_15_30_32_90 * Timber Fungus Treatment Systems	Liquids/ vapours/ gases	8	Application of preservatives, paint systems and retarders	Brush or spray application of preservatives, paints and retarders increases the risk of inhaling or absorbing toxic substances into the body	Image of worker painting timber with preservative
Structural frame	Working on structural frame	Ss_20_10_75 * Structural Framing Systems	Fall from open edge	9	Working on a steel frame	Working on a steel frame without any protection could lead to a fall from height	Image of a worker on a steel beam
Flat roof	Maintenance of plant on roof	Ss_55 * Piped Supply Systems	Fall from open edge	10	Working on a flat roof with no fall protection	Working on a flat roof could lead to a fall over the edge	Image of a worker close to the edge of a roof
Flat roof	Maintenance of plant on roof	Ss_60 * Heating, Cooling And Refrigeration Systems	Fall from open edge	10	Working on a flat roof with no fall protection	Working on a flat roof could lead to a fall over the edge	Image of a worker close to the edge of a roof
Flat roof	Maintenance of plant on roof	Ss_65 * Ventilation And Air Conditioning Systems	Fall from open edge	10	Working on a flat roof with no fall protection	Working on a flat roof could lead to a fall over the edge	Image of a worker close to the edge of a roof

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Wall (external)	Maintenance/cleaning of glazing	Ss_25_20 * Wall Cladding Systems	Fall from open edge	11	Working from abseil ropes for too long	Worker cleaning glazed cladding from abseil ropes for long periods of time increases the risk of injury or a fall	Image of worker cleaning windows from an abseil rope
Wall (external)	Maintenance/cleaning of glazing	Ss_25_30_95 * Window Systems	Fall from ladder	12	Working on a ladder for too long	Worker cleaning windows from a ladder for long periods of time could lead to a fall	Image of worker cleaning windows from a ladder
Building entrance	End user/during use	Ss_30_20 * Flooring And Decking Systems	Slip trip fall	13	Walking into building from rain	Users of the building walking in from rain, onto a slippery surface	Slippery surface sign
Ceiling	Access for maintenance	Ss_70_80 * Lighting Systems	Fall from ladder	14	Working on a ladder for too long	Working from a ladder for long periods of time could lead to a fall	Image of worker changing a lightbulb from a ladder
Wall (internal & external)	Access for maintenance	Ss_70_80 * Lighting Systems	Fall from ladder	14	Working on a ladder for too long/Installing a light on a ladder	Working from a ladder for long periods of time could lead to a fall	Image of worker changing a lightbulb from a ladder
Wall (internal & external)	Fire-proofing	Ss_25_60_30 * Fire Stopping Systems	Fire/explosion	15	Lack of construction stage fire containment	Failure to specify fire containment during construction can lead to a site fire	Image of cavity wall with no fire stopping
Floor	Access for maintenance	Ss_35_13_50 * Manhole And Access Shaft Systems	Fall from open edge	16	Open manhole fall	End users can easily fall down an open manhole in a busy area	Image of open manhole in a busy pedestrian walkway
Ground	Access for maintenance	Ss_50_30_06 * Below-Ground Drainage Inspection Systems	Struck by plant/vehicle	17	Manhole in traffic route	Vehicles can easily run over workers around manholes in traffic routes	Image of open manhole in traffic route

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Stairs	Stair installation	Ss_35_10_85_15 * Concrete Stair Or Ramp Systems	Slip trip fall	18	Lip detail trip hazard	Specifying a lip detail at top of precast concrete stairs can be a trip hazard	Image of lip at top of stairs
External path	End user/during use	Ss_30 * Roof, Floor And Paving Systems	Slip trip fall	19	Small step trip hazard	Specifying a small change in height, e.g. step, can be a trip hazard	Image of small step, e.g. 50mm
Wall (internal & external)	Laying blocks	Ss_25_13 * Unit Wall Structure Systems	Manual handling	20	Lifting heavy blocks	Lifting blocks weighing over 20kg	Image of worker lifting a heavy block
Basement	Laying blocks	Ss_25_13 * Unit Wall Structure Systems	Manual handling	20	Lifting heavy blocks	Lifting blocks weighing over 20kg	Image of worker lifting a heavy block
Wall (external)	Installing cladding	Ss_25_20 * Wall Cladding Systems	Manual handling	21	Lifting heavy cladding	Lifting heavy, large or long cladding panels	Image of worker handling large cladding panel
Wall (internal & external)	Installing lintels	Pr_20_85_48 * Lintels	Manual handling	22	Lifting heavy lintels	Lifting heavy lintels to install at height	Image of several workers lifting heavy lintel
Wall (external)	Installing curtain walling	Ss_25_10_20 * Curtain Walling Systems	Fall from scaffold	23	Unstable scaffold	If curtain wall systems (especially glass) do not allow anchor points for scaffold it will be difficult to keep it stable	Scaffold tilting over
Traffic route	Traffic and vehicle movements	Ss_15_95_80 * Temporary Transport Works Systems	Struck by plant/vehicle	24	Inadequate traffic route	Site traffic routes that do not allow for one-way systems and/or vehicular traffic segregated from site personnel	Image of workers mixed with site vehicles

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Crane	Lifting large heavy elements	Ss_80_30 * Crane And Hoist Systems	During crane ops	25	No space for crane	Failure to design for crane location can lead to locating crane outside the site endangering members of the public	Image of crane dropping materials on street
Structural frame	Welding	Ss_20_10_75_35 * Heavy Steel Framing Systems	Liquids/ vapours/ gases	26	Fumes from welding	Welding causes fumes which are harmful to health	Image of worker welding
Structural frame	Welding	Ss_20_10_75_45 * Light Steel Framing Systems	Liquids/ vapours/ gases	26	Fumes from welding	Welding causes fumes which are harmful to health	Image of worker welding
Fence	Welding	Ss_25_14 * Fence Systems	Liquids/ vapours/ gases	26	Fumes from welding	Welding causes fumes which are harmful to health	Image of worker welding
Confined space	Welding	Ss_55 * Piped Supply Systems	Liquids/ vapours/ gases	26	Fumes from welding	Welding causes fumes which are harmful to health	Image of worker welding
Plant room	Access for maintenance	Ss_60 * Heating, Cooling And Refrigeration Systems	Manual handling	27	Handling/moving plant	No space to mechanically move plant in/out of plant room causes manual handling problems	Image of plant room with tight space for access to equipment
Plant room	Access for maintenance	Ss_65 * Ventilation And Air Conditioning Systems	Manual handling	27	Handling/moving plant	No space to mechanically move plant in/out of plant room causes manual handling problems	Image of plant room with tight space for access to equipment

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Plant room	Access for maintenance	Ss_70 * Electrical Systems	Manual handling	27	Handling/moving plant	No space to mechanically move plant in/out of plant room causes manual handling problems	Image of plant room with tight space for access to equipment
Stairs	Stair installation	Ss_35_10 * Fixed Access Structure Systems	Fall from open edge	28	Working at height open edge	Risers for staircases can cause a fall from height and require needless temporary works	Image of open stair riser with no staircase
Plant room	Access for maintenance	Ss_60 * Heating, Cooling And Refrigeration Systems	Fall from open edge	29	Working at height open edge	If equipment in plant rooms needs to be accessed at height, workers can fall from the equipment or from a temporary structure	Image of plant equipment with a valve up high
Plant room	Access for maintenance	Ss_65 * Ventilation And Air Conditioning Systems	Fall from open edge	29	Working at height open edge	If equipment in plant rooms needs to be accessed at height, workers can fall from the equipment or from a temporary structure	Image of plant equipment with a valve up high
Plant room	Access for maintenance	Ss_70 * Electrical Systems	Fall from open edge	29	Working at height open edge	If equipment in plant rooms needs to be accessed at height, workers can fall from the equipment or from a temporary structure	Image of plant equipment with a valve up high
Wall (internal & external)	Installing temporary works	Ss_15_95 * Temporary Works Systems	Collapse/fall of structure/part of structure	30	Stability of temporary works (scaffold)	Scaffolding can become unstable if not designed properly	Image of scaffold

Location	Activity	Product Code (Uniclass)	Hazard Category	Hazard ID	Hazard Name	Hazard Description (the action)	Hazard Media
Ground	Installing temporary works	Ss_15_95 * Temporary Works Systems	Collapse/fall of structure/part of structure	31	Stability of temporary works (shoring)	Shoring can become unstable if not designed properly	Image of trench with shoring
Structural frame	Installing temporary works	Ss_15_95 * Temporary Works Systems	Collapse/fall of structure/part of structure	32	Stability of temporary works (rebar)	Rebar can become unstable if not designed or supported properly	Image of tall vertical rebar

Appendix II Designer control measures database

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
1	Using a hand-held breaker on concrete	An alternative option to workers using a hand-held breaker for long periods of time is to precast concrete or steel pile driven or vibrated by machine. This removes the need to break out the concrete and eliminates the risk of HAVS	Another different solution to workers using a hand-held breaker for long periods of time is to coordinate with a contractor to specify a hydraulic breaker suspended from an excavator (space is needed for the plant). This removes the need to break out the concrete and eliminates the risk of HAVS			
1	Using a hand-held breaker on concrete	An alternative option to workers using a hand-held breaker for long periods of time is to precast concrete or steel pile driven or vibrated by machine. This removes the need to break out the concrete and eliminates the risk of HAVS	Another different solution to workers using a hand-held breaker for long periods of time is to coordinate with a contractor to specify a hydraulic breaker suspended from an excavator (space is needed for the plant). This removes the need to break out the concrete and eliminates the risk of HAVS			
1	Using a hand-held breaker on concrete	An alternative option to workers using a	Another different solution to workers			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		hand-held breaker for long periods of time is to precast concrete or steel pile driven or vibrated by machine. This removes the need to break out the concrete and eliminates the risk of HAVS	using a hand-held breaker for long periods of time is to coordinate with a contractor to specify a hydraulic breaker suspended from an excavator (space is needed for the plant). This removes the need to break out the concrete and eliminates the risk of HAVS			
2	Using a vibrating hand-held scabbling tool	An alternative to a worker using a hand-held scabbling tool for long periods of time is to design dapped mould into the formwork, which eliminates the need to scabble	Another alternative solution to a worker using a hand-held scabbling tool for long periods of time is paint-on chemical retardant, which will create a scabbled effect without the need to scabble	An alternative to a worker using a hand-held scabbling tool for long periods of time is water-jetting the surface which will eliminate the need to scabble		
2	Using a vibrating hand-held scabbling tool	An alternative to a worker using a hand-held scabbling tool for long periods of time is to design dapped mould into the formwork, which eliminates the need to scabble	Another alternative solution to a worker using a hand-held scabbling tool for long periods of time is paint-on chemical retardant, which will create a scabbled effect without the need to scabble	An alternative to a worker using a hand-held scabbling tool for long periods of time is water-jetting the surface which will eliminate the need to scabble		

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
2	Using a vibrating hand-held scabbling tool	An alternative to a worker using a hand-held scabbling tool for long periods of time is to design dapped mould into the formwork, which eliminates the need to scabble	Another alternative solution to a worker using a hand-held scabbling tool for long periods of time is paint-on chemical retardant, which will create a scabbled effect without the need to scabble	An alternative to a worker using a hand-held scabbling tool for long periods of time is water-jetting the surface which will eliminate the need to scabble		
2	Using a vibrating hand-held scabbling tool	An alternative to a worker using a hand-held scabbling tool for long periods of time is to design dapped mould into the formwork, which eliminates the need to scabble	Another alternative solution to a worker using a hand-held scabbling tool for long periods of time is paint-on chemical retardant, which will create a scabbled effect without the need to scabble	An alternative to a worker using a hand-held scabbling tool for long periods of time is water-jetting the surface which will eliminate the need to scabble		
2	Using a vibrating hand-held scabbling tool	An alternative to a worker using a hand-held scabbling tool for long periods of time is to design dapped mould into the formwork, which eliminates the need to scabble	Another alternative solution to a worker using a hand-held scabbling tool for long periods of time is paint-on chemical retardant, which will create a scabbled effect without the need to scabble	An alternative to a worker using a hand-held scabbling tool for long periods of time is water-jetting the surface which will eliminate the need to scabble		
3	Working on a fragile roof light	An alternative to a worker working on a fragile roof light is to use a non-fragile roof	Another alternative solution to help reduce accidents while working on a	Another option to help reduce accidents while on a fragile roof light is to		

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		light (at least Advisory Committee for Roof Safety Category C) that is strong enough to take the weight of a person standing on it	fragile roof light is to use a fixed barrier above the roof light to prevent workers falling if they stumble or trip	use netting below the roof light to catch a falling worker and mitigate the consequences of a fall		
3	Working on a fragile roof light	An alternative to a worker working on a fragile roof light is to use a non-fragile roof light (at least Advisory Committee for Roof Safety Category C) that is strong enough to take the weight of a person standing on it	Another alternative solution to help reduce accidents while working on a fragile roof light is to use a fixed barrier above the roof light to prevent workers falling if they stumble or trip	Another option to help reduce accidents while on a fragile roof light is to use netting below the roof light to catch a falling worker and mitigate the consequences of a fall		
4	Using a powered tool to chisel out masonry	An alternative to prevent workers from using a powered tool to chisel out masonry is prefabricated wall panels that have pre-drilled and integrated service channels, which eliminate the need to chisel	For refurbishments, an alternative solution to prevent workers from using a powered tool to chisel out masonry is wall-mounted trunking. Drilling holes for fixings is less hazardous than chiselling long channels into the wall			
5	Using a powered tool to cut plasterboard	An alternative to prevent workers from using a powered tool	An alternative solution to prevent workers from using a			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		to cut plasterboard is prefabricated walls with gypsum board already attached, which eliminates the need to cut on site	powered tool to cut plasterboard is to use 900mm wide boards, which leads to less cutting and increased productivity			
6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	An alternative to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to specify dimensions for full bricks/blocks – an accurate BIM model will help with accuracy. This eliminates the need to cut on site	An alternative solution to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to pre-cut bricks/blocks – this can be done in a factory in a controlled environment, which removes the risk from the site			
6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	An alternative to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to specify dimensions for full bricks/blocks – an accurate BIM model will help with accuracy. This eliminates the need to cut on site	An alternative solution to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to pre-cut bricks/blocks – this can be done in a factory in a controlled environment, which removes the risk from the site			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
6	Using a powered tool to cut bricks, blocks or paving slabs creates dust	An alternative to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to specify dimensions for full bricks/blocks – an accurate BIM model will help with accuracy. This eliminates the need to cut on site	An alternative solution to prevent workers from using a powered tool to cut bricks, blocks or paving slabs is to pre-cut bricks/blocks – this can be done in a factory in a controlled environment, which removes the risk from the site			
7	Using a powered tool to cut bricks or blocks creates dust	An alternative to prevent workers from using a powered tool to cut bricks or blocks is prefabricated brick/block wall panels. These are usually lifted into place by a crane which is faster and eliminates the need to individually cut bricks or blocks				
8	Application of preservatives, paint systems and retarders	An alternative to prevent workers from using preservatives, paint systems and retarders is the off-site treatment or coating of materials	An alternative to prevent workers from using preservatives, paint systems and retarders is less harmful products e.g. water-based			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		or products, e.g. timber preservatives which is done in a controlled environment	products which will reduce or eliminate the risk			
9	Working on a steel frame	Specify structural steelwork with anchor points for safety nets				
10	Working on a flat roof with no fall protection	Design the plant to be located elsewhere, such as ground level or contained within the structure. This will eliminate the risk of working on the outside of the roof, but is subject to logistical and cost issues. However Zaha Hadid Architects achieve this on many of their buildings	If there is enough space, locate the plant away from the edge of the roof to reduce the risk of a fall	Specify a barrier round the edge of the roof to prevent a fall over the edge. This may be subject to planning approval and impact the aesthetics. A discreet design may be possible, e.g. a glazed barrier	Specify anchor points for attachment of a lanyard, to use in conjunction with a work restraint harness. This will prevent a fall, but only for those trained and wearing a harness; anchor points will also need to be regularly inspected	
10	Working on a flat roof with no fall protection	Design the plant to be located elsewhere, such as ground level or contained within the structure. This will eliminate the risk of working on the outside of the roof,	If there is enough space, locate the plant away from the edge of the roof to reduce the risk of a fall	Specify a barrier round the edge of the roof to prevent a fall over the edge. This may be subject to planning approval and impact the aesthetics. A discreet design may be	Specify anchor points for attachment of a lanyard, to use in conjunction with a work restraint harness. This will prevent a fall, but only for those trained and wearing a	

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		but is subject to logistical and cost issues. However Zaha Hadid Architects achieve this on many of their buildings		possible, e.g. a glazed barrier	harness; anchor points will also need to be regularly inspected	
10	Working on a flat roof with no fall protection	Design the plant to be located elsewhere, such as ground level or contained within the structure. This will eliminate the risk of working on the outside of the roof, but is subject to logistical and cost issues. However Zaha Hadid Architects achieve this on many of their buildings	If there is enough space, locate the plant away from the edge of the roof to reduce the risk of a fall	Specify a barrier round the edge of the roof to prevent a fall over the edge. This may be subject to planning approval and impact the aesthetics. A discreet design may be possible, e.g. a glazed barrier	Specify anchor points for attachment of a lanyard, to use in conjunction with a work restraint harness. This will prevent a fall, but only for those trained and wearing a harness; anchor points will also need to be regularly inspected	
11	Working from abseil ropes for too long	Design permanent access platforms or gantries to access and clean internal glazed surfaces. This saves time, money (whole-life costs), and is safer	Design a permanent cradle access system to access and clean external glazed surfaces. This saves time, money (whole-life costs), and is safer	Design enough flat space at ground level to allow equipment to be used (e.g. a MEWP or extending poles) for cleaning the facade. Speak to the equipment supplier to ensure enough space is allowed, there are no	Specify self-cleaning glass, which eliminates the need to work at height. There will be cost implications, but this may be a useful option for lower whole-life cost. This solution works best for vertical glazing	

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
				obstacles and the ground is strong enough		
12	Working on a ladder for too long	Design openable windows so they can be cleaned from the inside. This removes the risk of cleaning them from the outside	Specify anchor points and eye bolts for securing harnesses and ladders to. This will help prevent a fall from ladders	Design enough flat space at ground level to allow equipment to be used (e.g. a MEWP or extending poles) for cleaning the facade. Speak to the equipment supplier to ensure enough space is allowed, there are no obstacles and the ground is strong enough	Specify self-cleaning glass, which eliminates the need to work at height. There will be cost implications, but this may be a useful option for lower whole-life cost. This solution works best for vertical glazing	
13	Walking into building from rain	Specify absorbent non-slip surface at building entrances and where fluid is expected regularly				
14	Working on a ladder for too long	Position lighting at a lower level to reduce the distance to travel or fall, avoiding or mitigating the need to work at height	Position lighting above fixed platforms such as mezzanine floors to allow easier access instead of climbing tall ladders or temporary scaffolds	Specify long-life bulbs that require less maintenance, and therefore less exposure time working at height	Specify fibre-optic lighting, which can beam a light-source from a safe base position to any point at height. This eliminates the need to change bulbs at height	Specify lighting that can be lowered by a pulley system or slide along a channel to a safe place for maintenance and replacement
14	Working on a ladder for too	Position lighting at a lower level to reduce the distance to travel	Position lighting above fixed platforms such as mezzanine	Specify long-life bulbs that require less maintenance,	Specify fibre-optic lighting, which can beam a light-source	Specify lighting that can be lowered by a pulley system or

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
	long/Installing a light on a ladder	or fall, avoiding or mitigating the need to work at height	floors to allow easier access instead of climbing tall ladders or temporary scaffolds	and therefore less exposure time working at height	from a safe base position to any point at height. This eliminates the need to change bulbs at height	slide along a channel to a safe place for maintenance and replacement
15	Lack of construction stage fire containment	Consider the sequence of construction in conjunction with specifying fire stopping and containment. Consult with the contractor and, if in doubt, a fire safety civil engineer. The aim is to ensure adequate fire prevention measures are in place for each stage of the build				
16	Open manhole fall	Try to position manhole access points away from busy areas if possible. This will reduce the risk of end users falling down manhole shafts during maintenance operations				
17	Manhole in traffic route	Try to position manholes and inspection chambers				

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		away from traffic routes if possible (e.g. entrance gate; car-park lane). This will reduce the risk of vehicles running over workers around manholes during maintenance operations				
18	Lip detail trip hazard	Try to design top of concrete stair to finish flush with finished floor level. Consult with contractor to ensure finished floor level is achieved as soon as possible so no lip is exposed during construction				
19	Small step trip hazard	Try to design paths, walkways and paving to be same level throughout. This will reduce the risk of tripping				
20	Lifting heavy blocks	Try to specify repeat-lift items, like blocks, to be no more than 20kg. Ask contractor to justify if they propose use of heavier blocks				

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
20	Lifting heavy blocks	Try to specify repeat-lift items, like blocks, to be no more than 20kg. Ask contractor to justify if they propose use of heavier blocks				
21	Lifting heavy cladding	Try to specify dimensions and weights that can be installed easily by hand from a Mobile Elevated Working Platform (MEWP). Liaise with the cladding contractor to agree sizes and available space for materials and equipment	Try to design cladding panels – especially heavy glass cladding – with lifting method in mind. Liaise with cladding contractor, consider weight, size and site space available for lifting equipment. If space is not available outside, cladding may be installed by equipment from the inside – but the design must allow this			
22	Lifting heavy lintels	Try to specify a lighter lintel, e.g. slim metal or hollow concrete. This will reduce the risk of causing injury	Try to design lintels with lifting method in mind. Liaise with the contractor, consider weight, size and site space available for lifting equipment			
23	Unstable scaffold	Try to design the structural frame to	Try to allow enough space round the			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		allow anchor points, e.g. between some panels, or similar innovation. Collaboration with the structural designer and temporary works (scaffold) designer/contractor will help to find a solution	building for scaffold to be stabilised by raking supports, spread outwards. This will stabilise the scaffold without the need for ties, but will be a limited solution as the structure increases in height. Collaboration with the temporary works (scaffold) designer/contractor will help to decide if this is possible			
24	Inadequate traffic route	Try to allow enough space on the site for a circular one-way traffic route for plant, deliveries etc., with enough space for barriers to separate pedestrians. The design and positioning of structures will dictate this, but will reduce the risk of being run over. Liaison with the contractor and/or traffic management contractor early on will help				

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
25	No space for crane	Try to allow enough space on the site for a crane, hoist or other lifting equipment. The design and sequence of construction will dictate this, but will reduce the risk of heavy materials falling outside the site, onto the street and possibly hitting members of the public. Liaison with the structural civil engineer and contractor early on will help				
26	Fumes from welding	Try to specify an alternative to welding connections, e.g. bolt connections. This will reduce health risks as well as fire risks. Liaise with the structural designer	Try to specify prefabrication if possible. A factory environment will be able to control welding hazards better. Liaise with the structural designer			
26	Fumes from welding	Try to specify an alternative to welding connections, e.g. bolt or other fastener connections. This will reduce health risks as well as fire risks.	Try to specify prefabrication if possible. A factory environment will be able to control welding hazards			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		Liaise with the structural designer	better. Liaise with the structural designer			
26	Fumes from welding	Try to specify modular fencing that does not need welding. This will reduce health and fire risks. Liaise with the fencing supplier				
26	Fumes from welding	Try to specify non-weld connections, e.g. push-fit piping. This will reduce health and fire risks. Liaise with the contractor responsible for piped services (e.g. mechanical, plumbing, heating etc.)				
27	Handling/moving plant	Try to specify enough space around plant and equipment in plant rooms to access and replace it. This includes doors large enough for transportation equipment to get through and routes to outside. Liaise with				

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		equipment suppliers and installers				
27	Handling/moving plant	Try to specify enough space around plant and equipment in plant rooms to access and replace it. This includes doors large enough for transportation equipment to get through and routes to outside. Liaise with equipment suppliers and installers				
27	Handling/moving plant	Try to specify enough space around plant and equipment in plant rooms to access and replace it. This includes doors large enough for transportation equipment to get through and routes to outside. Liaise with equipment suppliers and installers				
28	Working at height open edge	Specify design to allow early installation of permanent				

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		staircases. This allows easier access to upper floors and reduces the risk of falling through the open space				
29	Working at height open edge	Try to locate access points for plant (e.g. valves) at low level. This will eliminate the need to work at height. Liaise with equipment suppliers and installers	Try to design fixed access stairs and working platforms with edge protection where regular access to plant is necessary. Liaison with plant suppliers and installers will help			
29	Working at height open edge	Try to locate access points for plant (e.g. valves) at low level. This will eliminate the need to work at height. Liaise with equipment suppliers and installers	Try to design fixed access stairs and working platforms with edge protection where regular access to plant is necessary. Liaison with plant suppliers and installers will help			
29	Working at height open edge	Try to locate access points for plant (e.g. valves) at low level. This will eliminate the need to work at height. Liaise with equipment suppliers and installers	Try to design fixed access stairs and working platforms with edge protection where regular access to plant is necessary. Liaison with plant suppliers and installers will help			

Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
30	Stability of temporary works (scaffold)	Liaise with temporary works designer/coordinator. There may be interfaces and overlaps between the permanent works and temporary works, e.g. scaffold ties into a building. Early liaison will reduce the risk of problems later, including collapse				
31	Stability of temporary works (shoring)	Liaise with temporary works designer/coordinator. There may be interfaces and overlaps between the permanent works and temporary works, e.g. the method of shoring excavations may become part of the final structure. Early liaison will reduce the risk of problems later, including collapse				
32	Stability of temporary works (Rebar)	Liaise with temporary works designer/coordinator.				

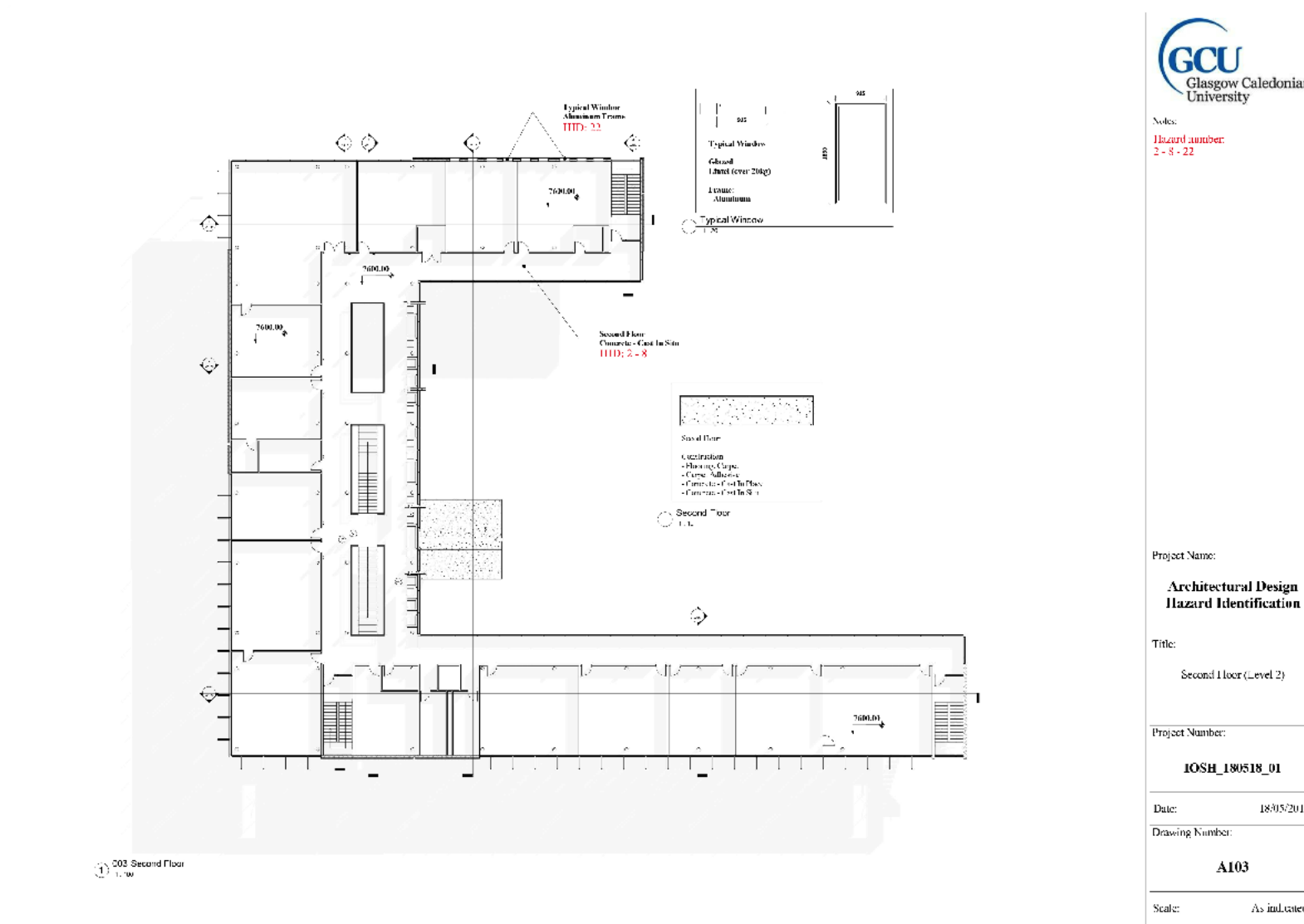
Hazard ID	Hazard Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		There may be interfaces and overlaps between the permanent works and temporary works, e.g. rebar thickness and spacing may prevent temporary support. Early liaison will reduce the risk of problems later, including collapse				

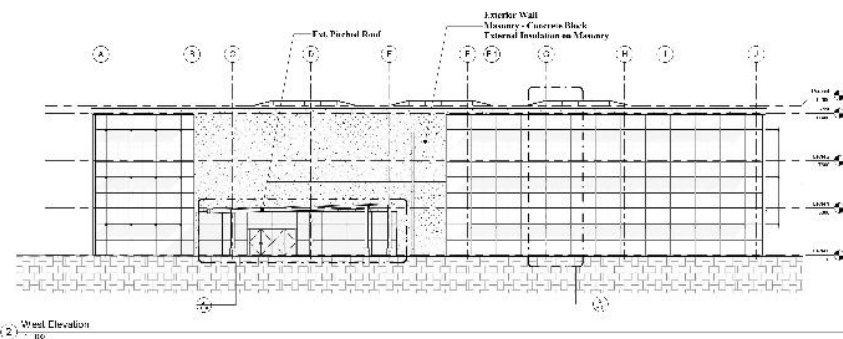
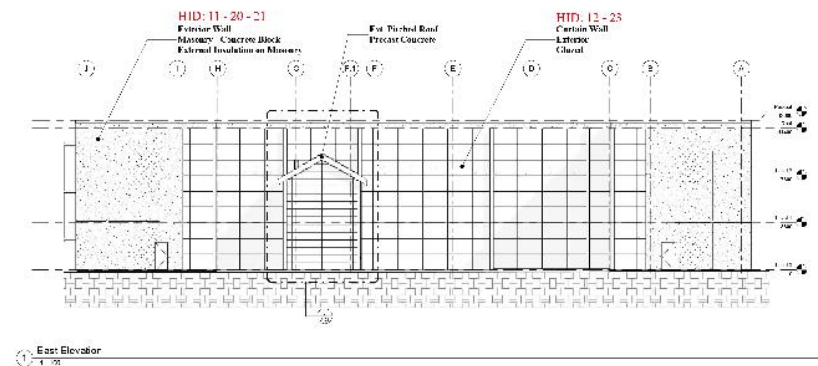
Appendix III Hazard drawings

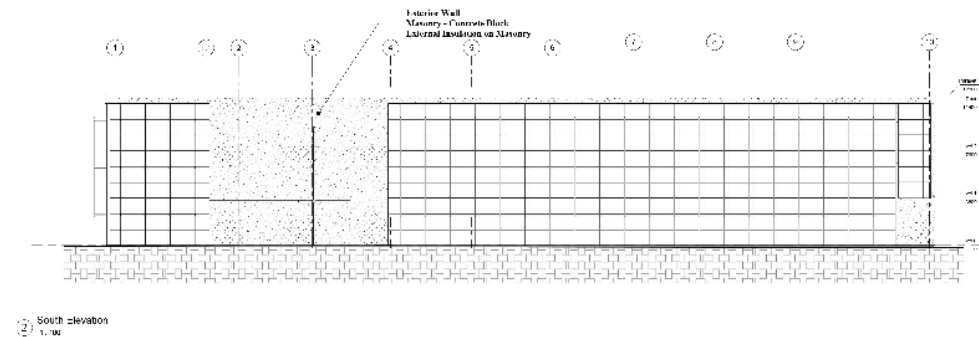
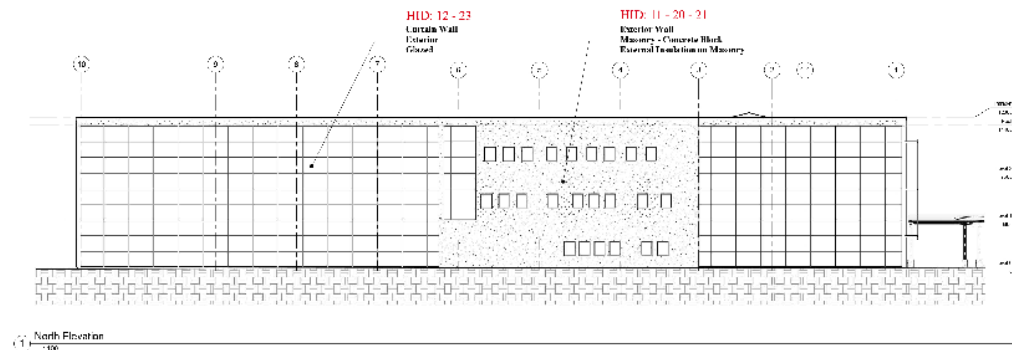
Available to download from:

https://drive.google.com/open?id=1jxHy2JLFvzIsiMdYN8pxqOvxk-qO54_r









Notes:

Hazard number
11 - 12 - 20 - 21 - 23

Project Name:

**Architectural Design
Hazard Identification**

Title:

North & South Elevations

Project Number:

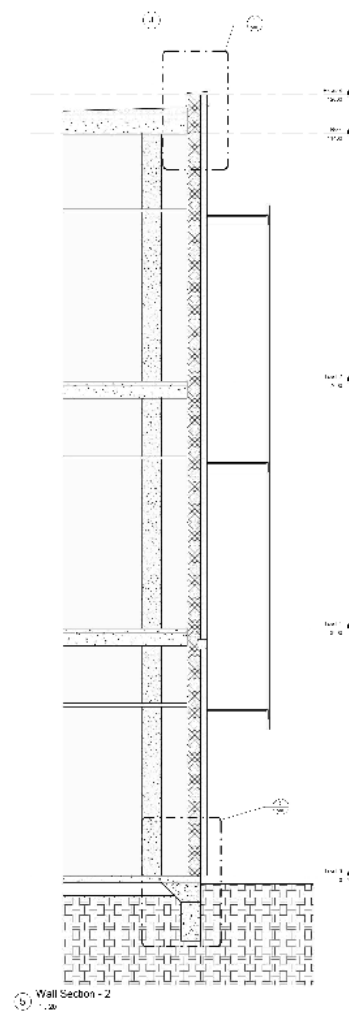
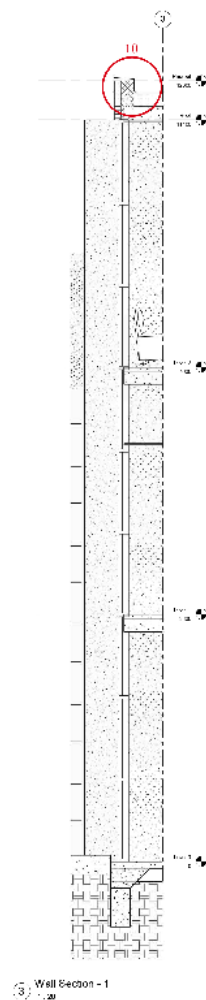
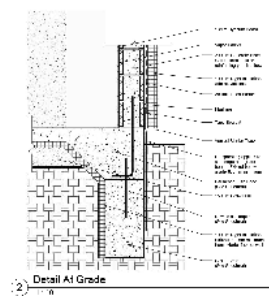
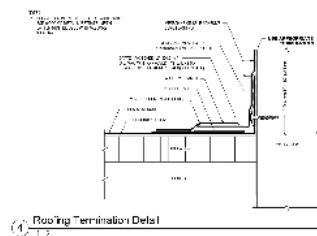
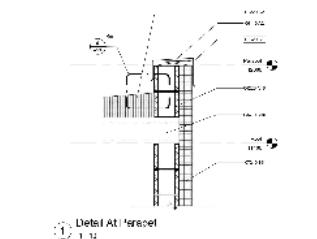
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Date: 18/05/2018

Drawing Number:

A105

Scale: 1 : 100



Notes:
Hazard number:
10

Project Name:

**Architectural Design
Hazard Identification**

Title:

Details - Architectural

Project Number:

IOSH_180518_01

Date:

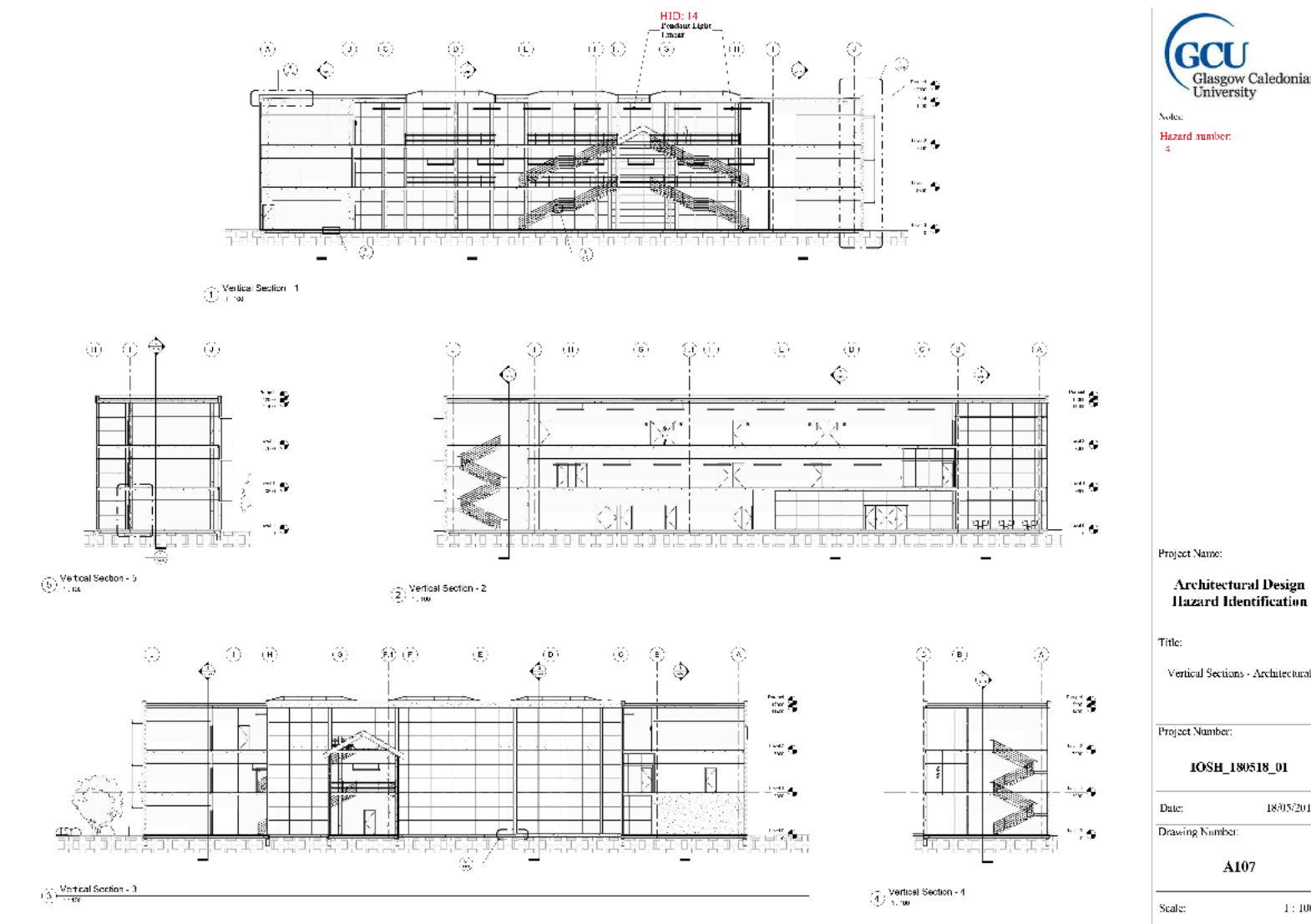
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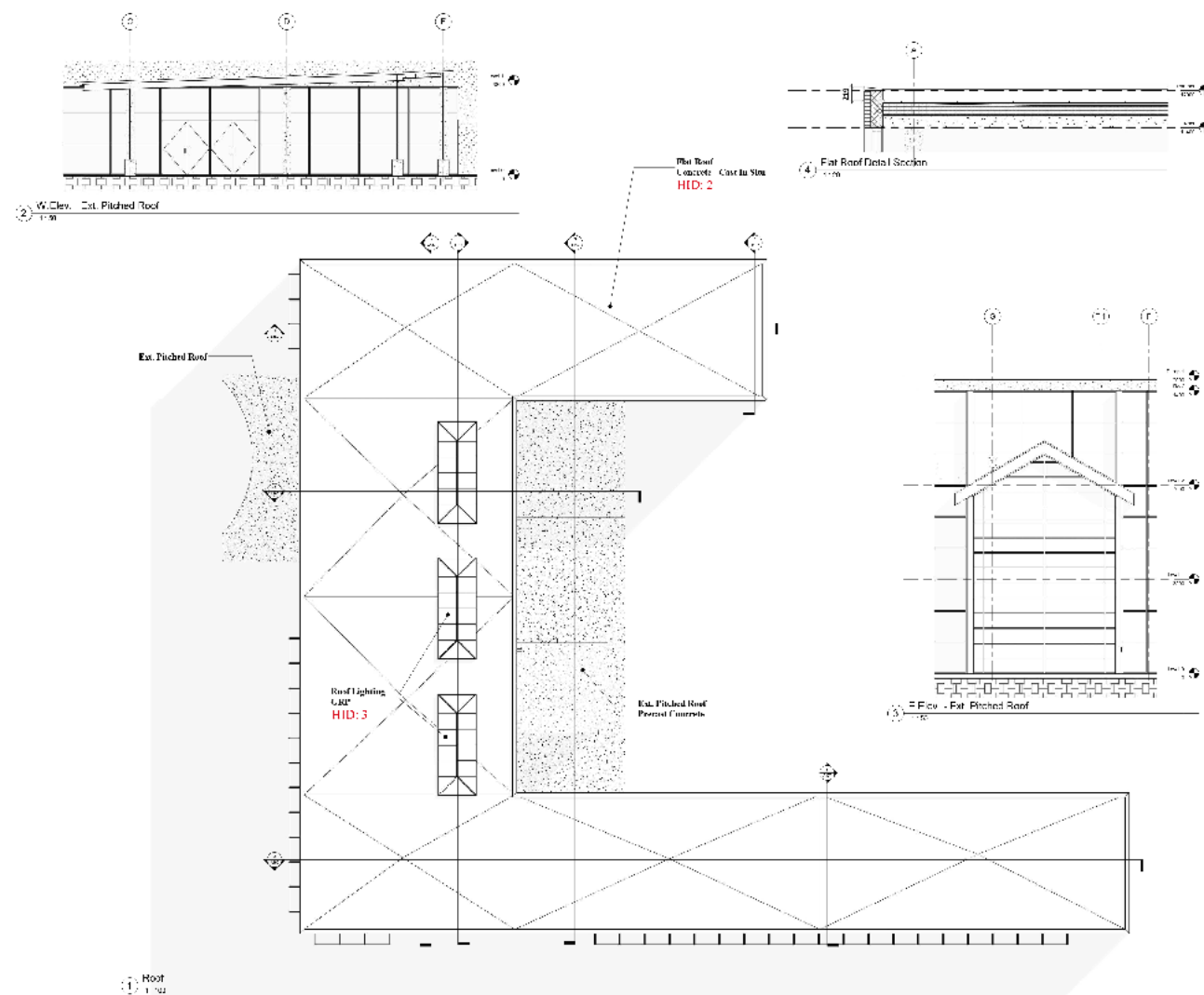
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A106

Scale:

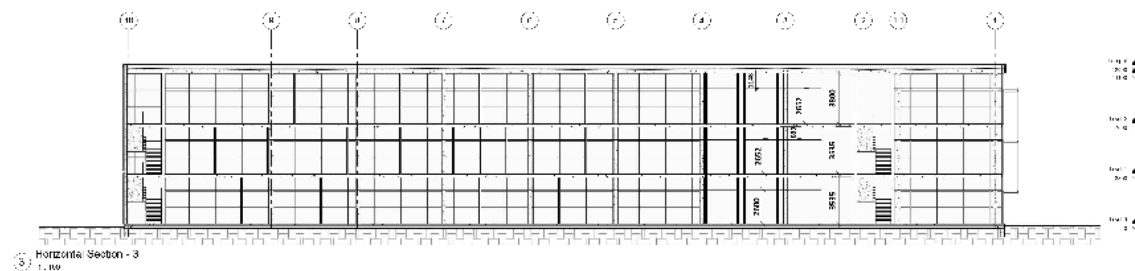
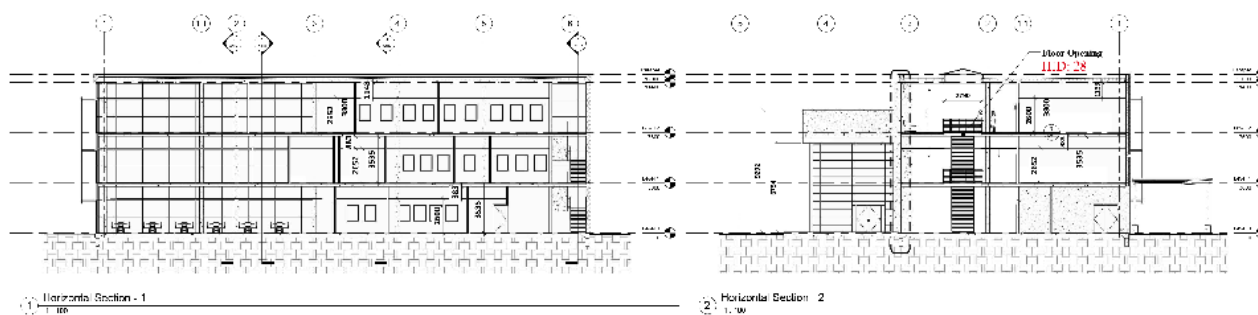
As indicated





Notes:

Hazard number:
28



Project Name:

**Architectural Design
Hazard Identification**

Title:

Horizontal Sections - Architectural

Project Number:

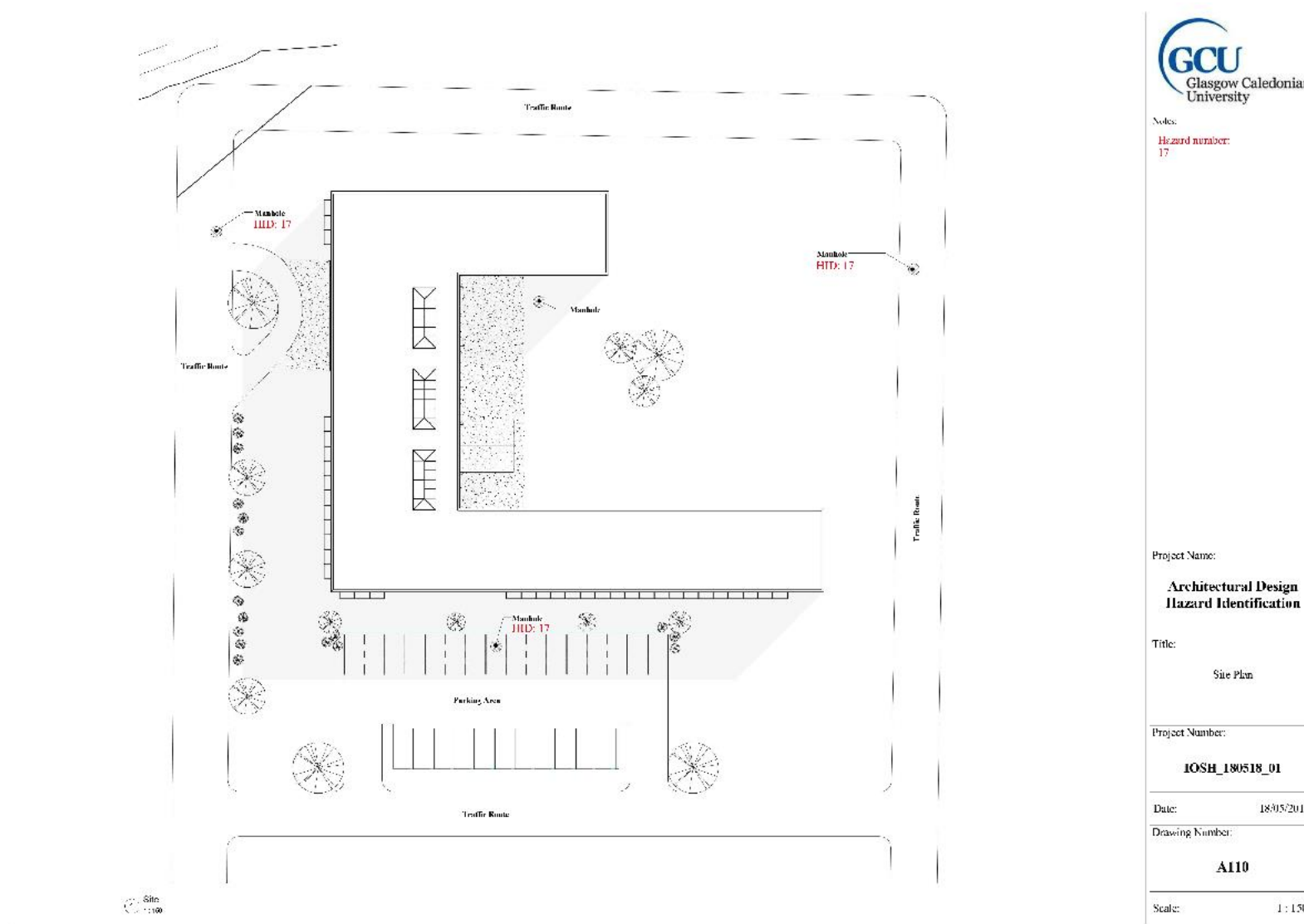
IOSH_180518_01

Date: 18/05/2018

Drawing Number:

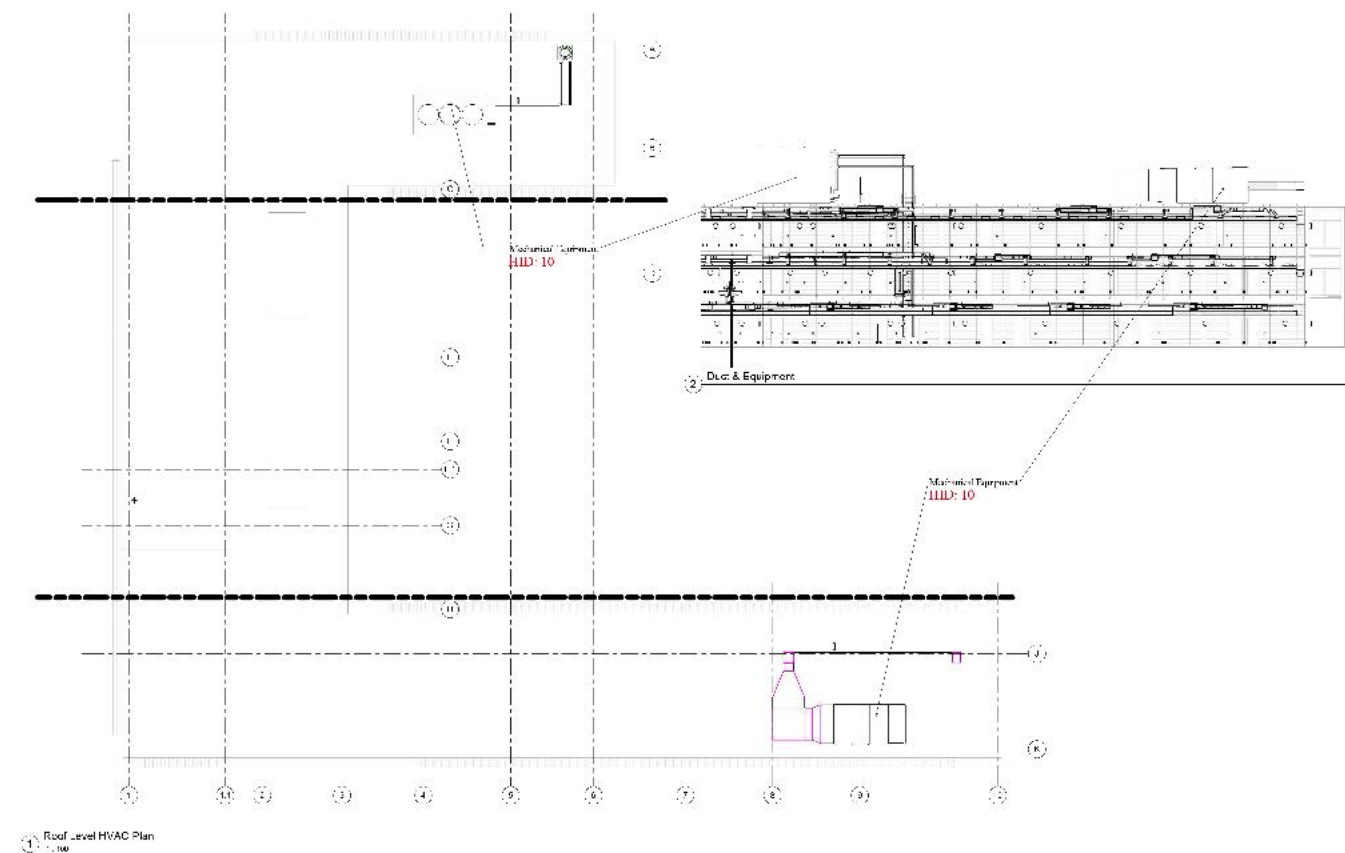
A109

Scale: 1 : 100



Notes:

Hazard number:
10



Project Name:

**Architectural Design
Hazard Identification**

Title:

Roof - HVAC Plan

Project Number:

IOSH-180518-01

Date:

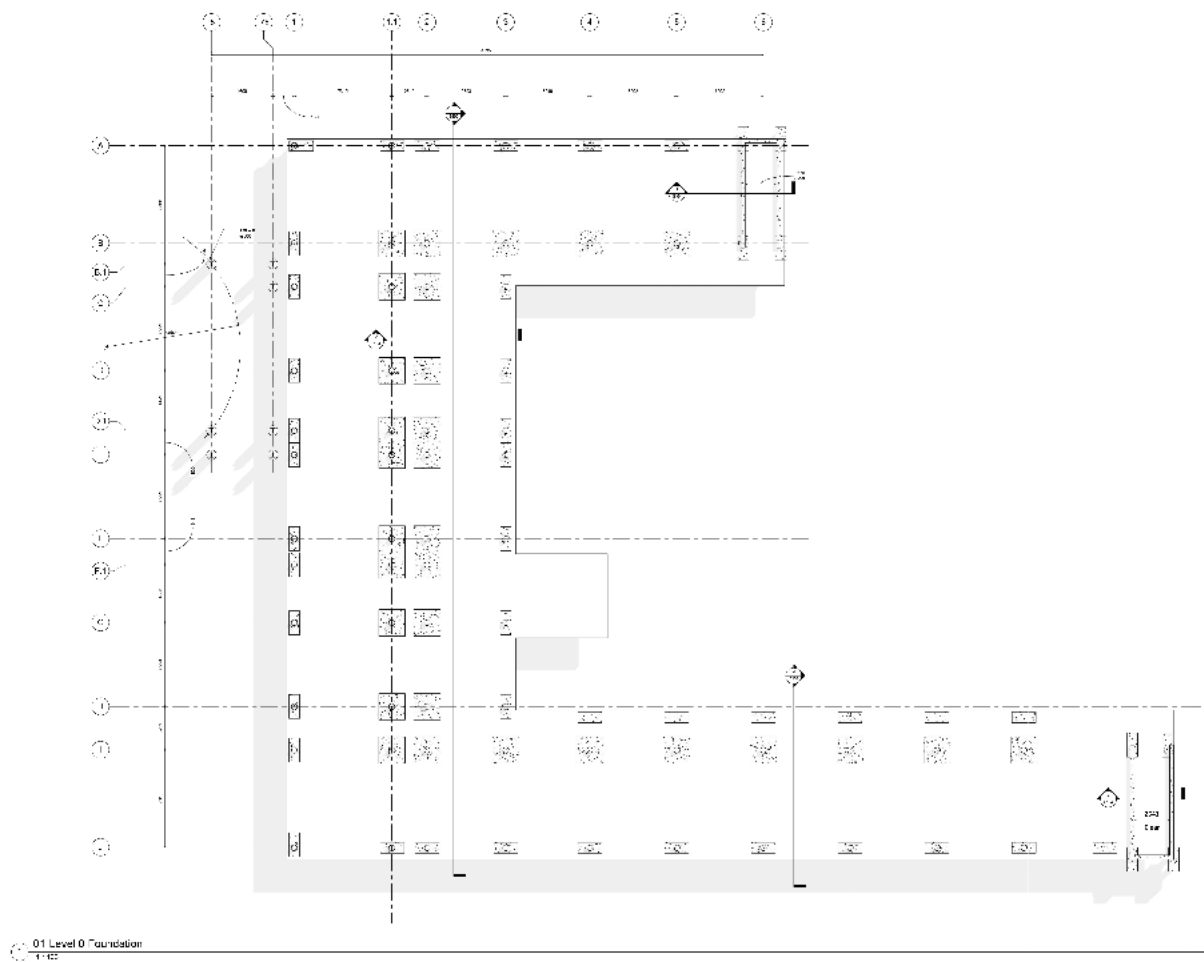
18/05/2018

Drawing Number:

M101

Scale:

1:100



Notes:

Hazard number:
1
Piling

Project Name:

**Architectural Design
Hazard Identification**

Title:

Foundation Plan - Structural

Project Number:

IOSH-180518-01

Date:

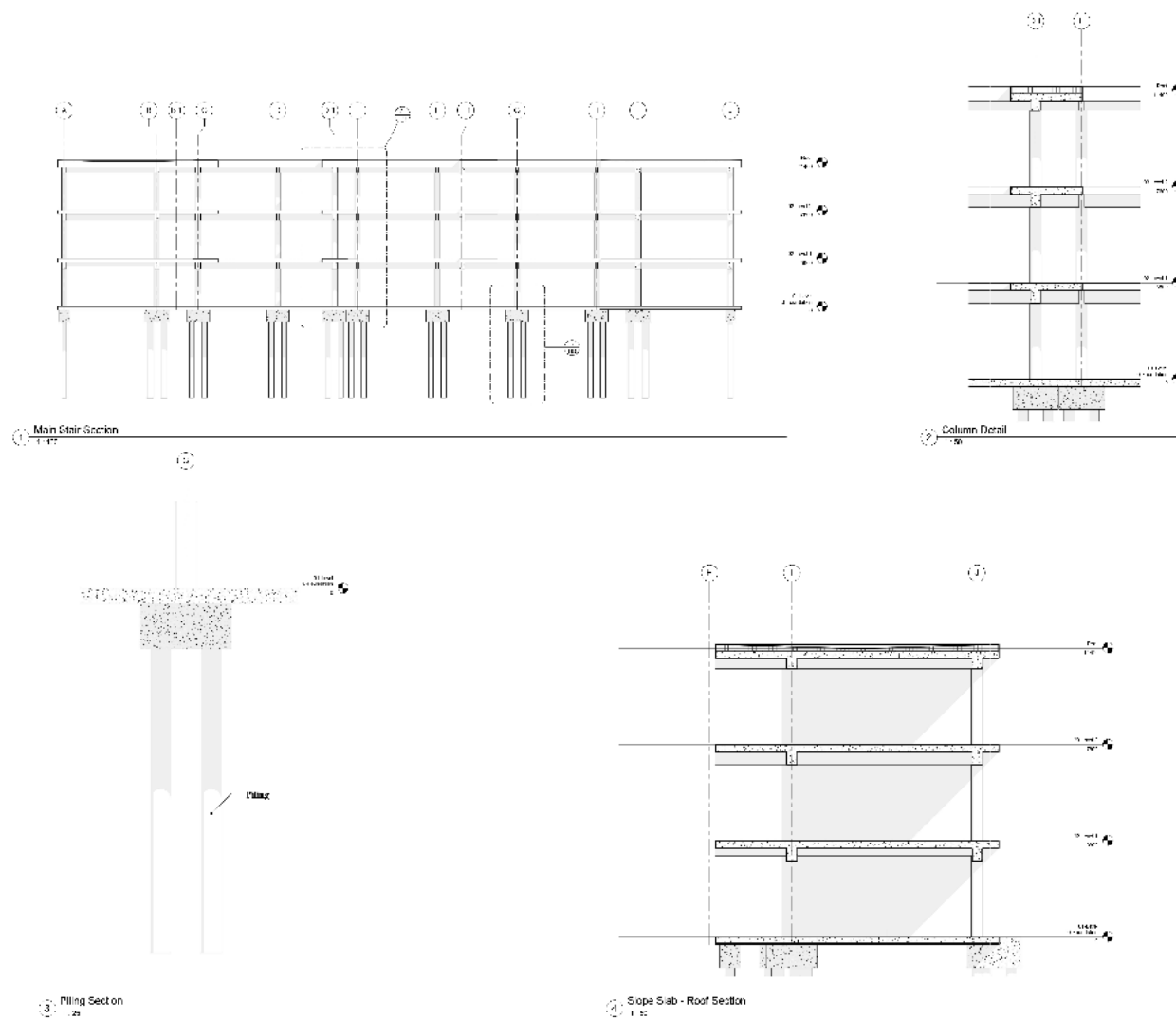
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Drawing Number:

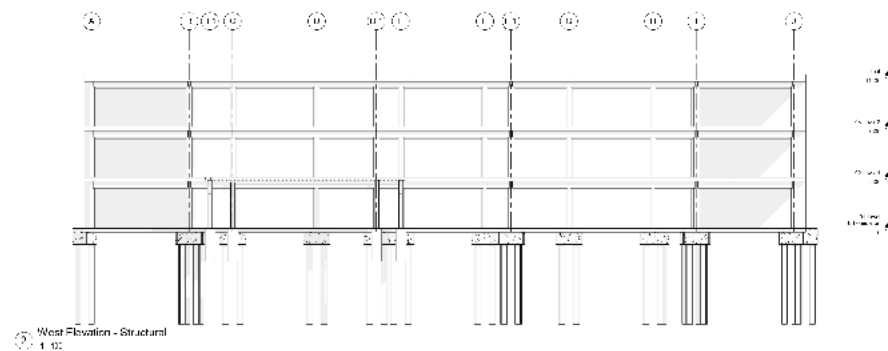
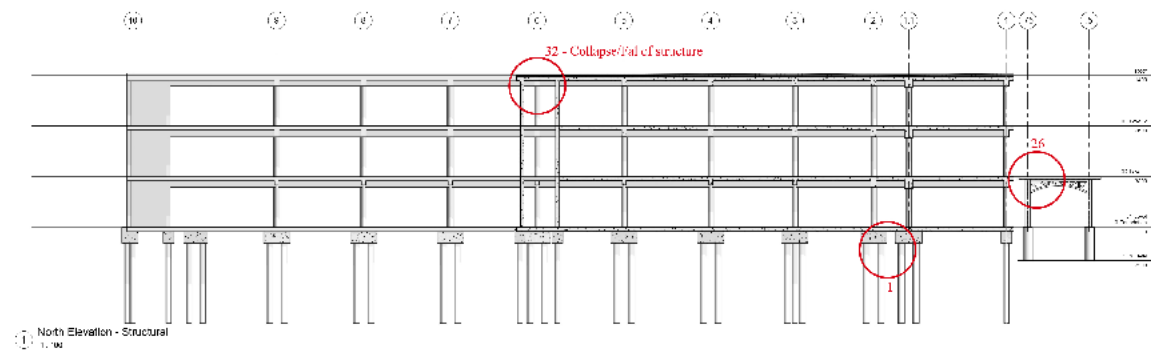
S101

Scale:

1 : 100



	
Notes: Hazard number: 1 - 26 - 32	
Project Name:	Architectural Design Hazard Identification
Title:	Sections - Structural
Project Number:	IOSH-180518-01
Date:	18/05/2018
Drawing Number:	S102
Scale:	As indicated



Notes:

Hazard number:
1 - 26 - 32

Project Name:

**Architectural Design
Hazard Identification**

Title:

Elevations - Structural

Project Number:

IOSH-180518-01

Date:

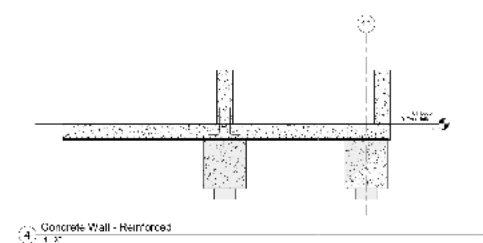
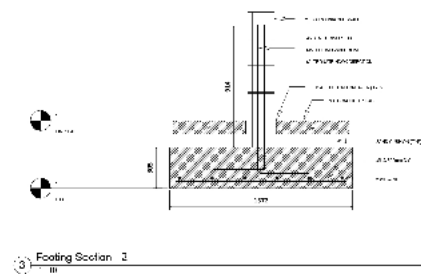
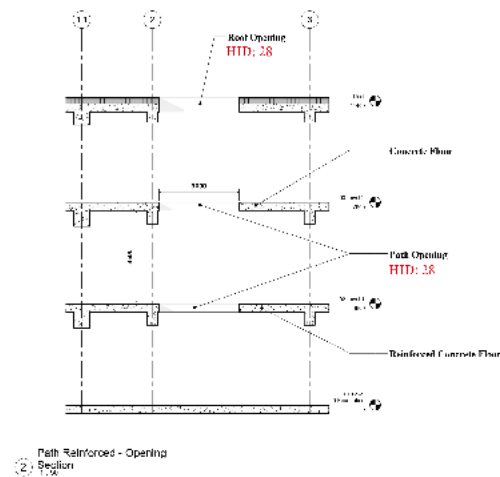
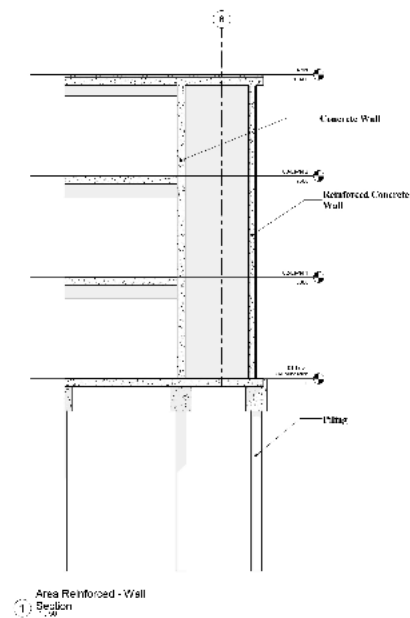
18/05/2018

Drawing Number:

S103

Scale:

1 : 100



Notes:

Hazard number:
28

Project Name:

**Architectural Design
Hazard Identification**

Title:

Detail Sections - Structural

Project Number:

IOSH-180518-01

Date:

18/05/2018

Drawing Number:

S104

Scale:

As indicated

Appendix IV List of hazards used in drawings

HAZARDS FROM DATABASE	A101	A102	A103	A104	A105	A106	A107	A108	A109	A110	M101	S101	S102	S103	S104
Using a hand-held breaker on concrete	x											x	x	x	
Using a vibrating hand-held scabbling tool	x		x					x							
Working on a fragile roof light								x							
Using a powered tool to cut plasterboard		x													
Using a powered tool to cut bricks, blocks or paving slabs creates dust	x														
Application of preservatives, paint systems and retarders	x		x												
Working on a flat roof with no fall protection						x					x				
Working from abseil ropes for too long		x		x	x										
Working on a ladder for too long	x			x	x										
Walking into building from rain	x														
Installing a light on a ladder							x								
Lack of construction stage fire containment						x									
Open manhole fall										x					
Manhole in traffic route										x					
Lip detail trip hazard	x														
Small step trip hazard	x														
Lifting heavy blocks		x		x	x										
Lifting heavy cladding		x		x	x										
Lifting heavy lintels		x	x												
Curtain wall systems with no anchor points for scaffold	x			x	x										
Inadequate traffic route										x					

HAZARDS FROM DATABASE	A101	A102	A103	A104	A105	A106	A107	A108	A109	A110	M101	S101	S102	S103	S104
Fumes from welding														X	
Working at height open edge		X							X						X
Stability of temporary works (scaffold)	X			X	X	X	X								
Stability of temporary works (shoring)													X	X	X
Stability of temporary works (rebar)													X	X	

Appendix V Data collection sheet

Name: _____

Qualifications & Experience:

Record the following:

1. Hazardous construction processes
2. Hazardous operations
3. Hazardous forms of construction
4. Details of how they would eliminate or reduce the identified hazards

Write a number for each item on the drawings. Repeat the number below along with any comments. Do not start a new number sequence on each drawing.

No.	Description of hazard	How could this be eliminated or reduced

Appendix VI Examples of rejected hazards

Reasons for rejection:

- Generic – no corresponding item on drawing or not enough information;
- Compliance with building standards/regulations;
- Not in scope, e.g. aesthetics.

Description of hazard	How could this be eliminated or reduced
Travel distance for escape	Add additional escape
Travel distance room to room	Combine rooms
Landing space for circulation	Rearrange
Rain water drainage	Add RWP's
Escape signs	Add escape signs
Add toughened glass	-
Fix handrails	-
Groundworks	Site checked for gas/water/elec. Temp. access for workers
Glazing visibility	-
Fumes and pollutants	PPE
Slip hazards	Signage, floor free of obstructions
Moving vehicles	Create work zone, barrier protection
Excavation	Excavated areas stabilised
Fire on site	Escapes with appropriate distances
Work at height	Amount of curtain walling reduced
Additional substrate for carpet	Add to drawing
No cavity	Include more finishing detail
Review detail where curtain wall meets slab	-
No traffic calming	Construction traffic management plan
No drainage detail for water run off	-
Eng. Spec. for piling detail	-
Smoke prevention	Fit automatic smoke/fire screens
Handrail not fixed	-
Check height of steps for regs	-
Interior partitions	To have requisite fire rating
Check fire escape distances	-
Check stair case wide enough	-
Check cavity wall detail	-
No drainage detail for water run off	-
No direction for traffic route	-
Work at height	Provide fall protection
Traffic routes	One-way and barriers
Work at height	-
Moving plant	-
Unstable scaffold	Adequate design, qualified contractor
No ground bearing slab	Add to drawing
Detail not marked on plan	-
No level marked	-
Fire integrity	Check if class O
Lobby to stairs	Add lobby to stairs
Travel distance fire	-
Escape door	Add escape door
Can 1200 flight withstand human impact	-
Add disabled space	-

Description of hazard	How could this be eliminated or reduced
Stair missing from drawing	-
Edge protection for construction	-
Hazardous construction	Precast concrete
Working at height	Appropriate safety measures
Position of guardrail on stair	Re-position
Gap in construction of roof	Redesign to connect two surfaces
Handrail too close to edge	-
Need 2nd fire escape	-
Location of service void not aligned	-
Inner room	-
Stair too long	Split with fire door
Glazing spec. required	Safety glass and signs
Flashing detail	Design to be water-tight
Rainwater surface treatment	Indicate RWP on drawing
Cold bridging issue	-
External FFL too high	-
Disabled parking	-
Risk of falling	Barriers
Pedestrian access to building	Paths
Traffic routes	Allow enough space
Foundations excavations	To be proper as necessary
Dust from cutting blocks	PPE
Crane collapse	BS2121, Method Statement
Access point, traffic route short	Control access
Precast structure, risk of collapse	Ensure props installed by competent person
Working on 3-storey building	Comply with work at height
Handrail required	Designed to required height
Escape route	Check building regs
Foundations into ground	Trial pits and ground testing
Collapse of excavations	Cover or barrier
Collapse of structure	Support with props
Hazardous substances	Comply with COSHH
General concrete risks	PPE and hard hats on site

Appendix VII Hazards identified per groups

	wet in-situ conc.	struct. opening	lifting op. risks	high-level light	clean glazing	piling risks	open edges	Handling of cladding	flooring coshh	plant maint. height	traffic route	fire spread during build	em. escape during build	heavy blocks/lintels	m. holes in traffic	single-step trip hazard	foyer entrance slip risk	clean./maint. pitched roof	welding steel frame	cutting dust	buried services	slip/trip on stairs	column layout risks	large floor-ceiling heights	fragile roof light	temp. works	paint coshh	excavations	misc.	TOTALS
Hazards Before	23	30	28	14	25	31	35	12	10	18	19	11	3	24	22	31	3	5	3	10	14	7	8	2	17	17	3	15	27	467
Hazards After	3	2	2	10	1	3	0	5	10	4	3	6	7	8	2	2	3	1	8	12	1	2	0	0	5	7	11	1	13	132
Total Hazards	26	32	30	24	26	34	35	17	20	22	22	17	10	32	24	33	6	6	11	22	15	9	8	2	22	24	14	16	40	599
Architects Before	11	16	11	10	13	8	20	5	5	12	5	7	1	11	12	14	3	5	0	4	0	7	5	2	11	0	0	0	14	212
Civil engineers Before	12	14	17	4	12	23	15	7	5	6	14	4	2	13	10	17	0	0	3	6	14	0	3	0	6	17	3	15	13	255
Hazards Before	23	30	28	14	25	31	35	12	10	18	19	11	3	24	22	31	3	5	3	10	14	7	8	2	17	17	3	15	27	467
Architects After	2	0	2	2	0	3	0	0	4	3	2	5	3	6	2	2	1	0	4	7	1	2	0	0	1	5	5	0	7	69
Civil engineers After	1	2	0	8	1	0	0	5	6	1	1	1	4	2	0	0	2	1	4	5	0	0	0	0	4	2	6	1	6	63
Hazards After	3	2	2	10	1	3	0	5	10	4	3	6	7	8	2	2	3	1	8	12	1	2	0	0	5	7	11	1	13	132
Architect Experiment After	0	0	2	1	0	1	0	0	2	3	2	5	3	6	2	2	1	0	4	5	0	2	0	0	0	4	3	0	5	53
Architect Control After	2	0	0	1	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	1	2	0	2	16
Civil engineer Experiment After	0	0	0	8	1	0	0	5	6	1	0	1	4	1	0	0	2	1	4	2	0	0	0	0	4	2	5	1	4	52
Civil engineer Control After	1	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	3	0	0	0	0	0	1	0	2	11	
Hazards After	3	2	2	10	1	3	0	5	10	4	3	6	7	8	2	2	3	1	8	12	1	2	0	0	5	7	11	1	13	132

	wet in-situ conc.	struct. opening	lifting op. risks	high-level light	clean glazing	piling risks	open edges	Handling of cladding	flooring coshh	plant maint. height	traffic route	fire spread during build	em. escape during build	heavy blocks/intels	m. holes in traffic	single-step trip hazard	foyer entrance slip risk	clean./maint. pitched roof	welding steel frame	cutting dust	buried services	slip/trip on stairs	column layout risks	large floor-ceiling heights	fragile roof light	temp. works	paint coshh	excavations	misc.	TOTALS
Experiment Before	11	17	13	8	13	16	18	7	4	8	8	5	1	12	11	14	3	3	2	7	5	4	3	1	9	7	3	7	14	234
Control Before	12	13	15	6	12	15	17	5	6	10	11	6	2	12	11	17	0	2	1	3	9	3	5	1	8	10	0	8	13	233
Hazards Before	23	30	28	14	25	31	35	12	10	18	19	11	3	24	22	31	3	5	3	10	14	7	8	2	17	17	3	15	27	467
Experiment After	0	0	2	9	1	1	0	5	8	4	2	6	7	7	2	2	3	1	8	7	0	2	0	0	4	6	8	1	9	105
Control After	3	2	0	1	0	2	0	0	2	0	1	0	0	1	0	0	0	0	0	4	1	0	0	0	1	1	3	0	5	27
Hazards After	3	2	2	10	1	3	0	5	10	4	3	6	7	8	2	2	3	1	8	11	1	2	0	0	5	7	11	1	14	132
Experiment All	11	17	15	17	14	17	18	12	12	12	10	11	8	19	13	16	6	4	10	14	5	6	3	1	13	13	11	8	23	339
Control All	15	15	15	7	12	17	17	5	8	10	12	6	2	13	11	17	0	2	1	7	10	3	5	1	9	11	3	8	18	260
Total Hazards	26	32	30	24	26	34	35	17	20	22	22	17	10	32	24	33	6	6	11	21	15	9	8	2	22	24	14	16	41	599
Novice Before	9	13	13	6	10	15	16	4	3	9	9	5	0	6	10	15	2	1	1	3	7	3	1	0	7	4	1	7	8	188
Expert Before	14	17	15	8	15	16	19	8	7	9	10	6	3	18	12	16	1	4	2	7	7	4	7	2	10	13	2	8	19	279
Hazards Before	23	30	28	14	25	31	35	12	10	18	19	11	3	24	22	31	3	5	3	10	14	7	8	2	17	17	3	15	27	467
Novice After	0	0	2	9	1	1	0	5	8	4	2	6	7	7	2	2	3	1	8	7	0	2	0	0	4	6	8	1	9	105
Expert After	3	2	0	1	0	2	0	0	2	0	1	0	0	1	0	0	0	0	0	5	1	0	0	0	1	1	3	0	4	27

	wet in-situ conc.	struct. opening	lifting op. risks	high-level light	clean glazing	piling risks	open edges	Handling of cladding	flooring coshh	plant maint. height	traffic route	fire spread during build	em. escape during build	heavy blocks/intels	m. holes in traffic	single-step trip hazard	foyer entrance slip risk	clean./maint. pitched roof	welding steel frame	cutting dust	buried services	slip/trip on stairs	column layout risks	large floor-ceiling heights	fragile roof light	temp. works	paint coshh	excavations	misc.	TOTALS
Novice Experiment After	0	0	2	5	1	0	0	5	6	3	2	3	5	5	1	1	3	1	5	4	0	0	0	0	2	4	5	1	6	70
Novice Control After	0	0	0	4	0	1	0	0	2	1	0	3	2	2	1	1	0	0	3	3	0	2	0	0	2	2	3	0	3	35
Expert Experiment After	2	1	0	0	0	2	0	0	0	0	1	0	0	1	0	0	0	0	0	4	1	0	0	0	0	1	1	0	4	18
Expert Control After	1	1	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2	0	0	9
Hazards After	3	2	2	10	1	3	0	5	10	4	3	6	7	8	2	2	3	1	8	12	1	2	0	0	5	7	11	1	13	132
Expert Control Before	5	7	8	4	6	7	9	3	4	6	6	5	2	8	6	9	0	2	1	3	5	3	4	1	4	7	0	5	9	139
Novice Experiment Before	2	7	6	4	4	7	8	2	1	5	4	4	0	2	5	7	2	1	1	3	3	3	0	0	3	1	1	4	4	94

Appendix VIII Hazards and controls per participant

No.	Experiment (1) /Ctrl(2)	Arch(1) /Eng(2)	Novice(1) /Expert(2)	Pre-Hazards	Pre-Controls Number	Pre-Controls Score	Post-Hazards	Post-Controls Number	Post-Controls Score
1	1	1	1	5	5	19	8	8	34
2	1	1	1	9	5	17	20	18	66
3	1	1	2	17	15	42	25	25	79
4	1	1	2	16	16	53	21	21	72
5	1	1	1	10	2	7	11	6	21
6	1	1	1	14	13	46	19	19	69
7	1	1	1	10	10	30	20	20	67
8	2	1	2	13	9	36	13	9	36
9	2	1	1	8	8	26	10	10	30
10	2	1	1	9	9	23	10	10	25
11	2	1	1	6	6	18	9	8	21
12	2	1	1	12	12	38	15	15	45
13	2	1	1	8	8	23	9	9	24
14	1	1	2	4	4	13	8	8	30
15	1	1	2	5	5	14	10	10	31
16	1	1	2	18	18	60	19	19	65
17	2	1	2	12	9	37	12	9	37
18	2	1	2	14	14	51	15	15	54
19	2	1	2	17	15	44	20	20	59
20	2	1	2	5	4	12	7	6	16
21	1	2	1	5	5	20	9	9	35
22	1	2	1	8	7	21	19	19	65

No.	Experiment (1) /Ctrl(2)	Arch(1) /Eng(2)	Novice(1) /Expert(2)	Pre-Hazards	Pre-Controls Number	Pre-Controls Score	Post-Hazards	Post-Controls Number	Post-Controls Score
23	1	2	2	21	20	63	21	20	63
24	1	2	2	16	16	54	22	22	75
25	1	2	1	10	6	12	18	15	46
26	1	2	1	12	12	44	18	18	62
27	1	2	1	11	11	33	22	22	73
28	2	2	2	13	9	36	13	9	36
29	2	2	1	10	8	28	14	12	35
30	2	2	1	9	9	23	10	10	25
31	2	2	1	7	7	21	9	9	26
32	2	2	1	14	14	54	14	14	54
33	2	2	1	11	10	31	12	11	36
34	1	2	2	17	15	45	20	19	64
35	1	2	2	8	8	25	10	10	32
36	1	2	2	18	18	62	19	19	68
37	2	2	2	20	16	53	21	16	53
38	2	2	2	14	14	52	15	15	55
39	2	2	2	19	19	66	20	20	71
40	2	2	2	12	10	32	12	10	32

Appendix IX Future report

This document outlines recommended potential future work along with recommendations needing completion on the tool. Currently the tool is a prototype that was used for the experiment, meaning that it showcases the potential of the final tool.

Future work

Tool design

- Review user interface design to cope with increase in content
- More research into additional filters, what different users (types of designers) need, finding out those categories that are going to work for the user
- A more visually pleasing way to display external links
- Design the tool to be suited for more designers, e.g mechanical civil engineers. Possible solution could be they access as that user and the user interface is catered for them
- User tests with potential redesign of the ERIC tabs
- When the user returns from the second page, tool should remember the filters the user had selected

Photos

- Further user testing to find their usefulness to a wider group

Content

- More hazards and alternatives added to tool
- Demolition hazards

Users

- Users relationship with tool needing fully tested
 - Tests into how often the users are using the tool on a regular basis
 - In the long term, how well users retain the knowledge

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