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Safe construction through design: perspectives from the site team

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How does the work of designers impact on the safety of operatives at the construction site? Safety research and policy emphasize the importance of designing for safe construction, yet the interface between design and construction is poorly understood: accidents have multiple causes making it hard to establish causal links between design choices and safety outcomes. An in-depth case study of a major station project examines how professionals on the construction site perceive and manage the safety challenges of a building design. Analyses reveal understandings that, on the project studied, design has an impact on safety because of: (1) the timing of design work, where the volume of late design changes increased the difficulty of planning safe procedures, e.g. for working at height, lifting heavy items, refurbishing and demolishing old buildings; and (2) inputs from design stakeholders with insufficient practical knowledge of construction and operation required unplanned work-arounds, e.g. to coordinate different sub-systems, provide maintenance access, and manage loads during construction. These findings suggest that safety suffers where projects are under-designed, and that alongside regulation, there is a need for robust management attention to the contractual structures, incentives, processes and tools that enable clients and designers to understand material practices of construction and operation.

Keywords: Capability, design, digital practices, safety, site.

Introduction

The research is concerned with safety issues within the UK construction sector. While over recent years there has been a significant decrease in accidents and fatalities, the construction sector is still one of the most dangerous UK industries to work in. The particular concern for this research is the design of the built structure and the impact that design may have upon safely constructing it. These issues were highlighted by regulators through the 1994 Construction (Design and Management) Regulations, and then the 2007 revisions that followed.

There are of course numerous ways of looking at the relationship between design and safety, with a number of competing agendas from various stakeholders. It is these various stakeholders: the client, designer, engineer, contractor and numerous subcontractors that all have the potential to have an impact on how safely a structure can be constructed and maintained. The Construction (Design and Management) (CDM) Regulations 2007 in the UK require designers to minimize the hazards associated with construction at as early a stage as possible, thus through the design. Brace *et al.* (2009) gave reasons for this requirement based upon empirical research, claiming that designers—of permanent structures, temporary structures and equipment—could have reduced the incident likelihood in 17–47% of the 100 incidents studied. In their analysis, designers of built structures have a key role to play associated with safety, by reducing (or even better removing) potentially dangerous site operations either through the technical detailing or through choosing prefabricated options to reduce dangerous site work. This is an argument also made by a growing literature on prevention by design (e.g. Szymberski, 1997; Gambatese and Hinze, 1999). However, procurement routes such as design build can often blur where the designer's role ends and the contractor's role begins.

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Similarly, understanding the safety issues embedded within a design which the contractor and subcontractors are charged with undertaking is vital. While injuries to people within the UK construction sector have fallen over the last 20 years, the UK Health and Safety Executive (HSE) (2011) still claims that 'construction remains a high risk industry' (HSE, 2011, p. 2). That description of the UK construction sector is justified, at least in part, because the level of injuries and amount of accidents are disproportionate to the number of people employed by the construction sector. The HSE notes that:

> Although it [the UK construction sector] accounts for only about 5% of the employees in Britain it still accounts for 22% of fatal injuries to employees and 10% of reported major injuries. (HSE, 2011, p. 2)

The above HSE statistic provides significant justification for continued efforts in the field of design and safety research. Clearly the numerous stakeholders mentioned play a role in these incidents, yet it remains a fact that the fundamental design of a built structure can impact on how safely it can be constructed. Understanding this connection between design and construction is important and a useful starting place is those charged with the construction process: the project managers, contractor and subcontractors.

The aim of this study is to understand how the construction team perceive the inherent safety challenges embedded in the building design and how they respond to those challenges in practice. By adopting an interpretive research approach, this study draws on a tradition of work that has examined the important contributions of knowledge practices and a culture of safety on site (Gherardi *et al.*, 1998; Gherardi and Nicolini, 2000; Pink *et al.*, 2010) in achieving safe working practices. This is done by drawing on interviews at the site offices exploring safety and workshop data to further stimulate discussion. The paper is structured as follows. Initially, the landscape of site safety is introduced before focusing upon the existing literatures that have tackled the connections between construction safety and the design of the built structure. The importance of the research context and the methods are then discussed, demonstrating the challenges faced when dealing with complex construction projects. The findings and discussion follow; these are based around key themes set against the literature reviewed together with findings beyond the initial aim associated with safety and the maintenance and future adaptation of the built structure.

Landscape of construction safety

The subject of safety within construction is complex. The challenge of achieving high levels of safety associated with construction projects is characterized by the different procurement routes available, fragmented and traditional approaches, the numerous stakeholders involved and their formal and informal responsibilities, the interplay between regulations and the unique context setting. Beginning with context, safety standards and requirements vary around the world, with different countries operating different systems and regulations. What is deemed acceptable in one country may be viewed as grossly dangerous in another. This can be illustrated through the use of traditional methods developed against modern methods using advances in materials and equipment (e.g. scaffolding systems). Also valuable is the acknowledgement that the construction sector (regardless of country) is actually made up of many different trades and professions as well as manufacturers and other stakeholders. Thus, it is essential for any safety orientated research to be sensitive to this fact, as these different construction sector constituents experience safety in different ways and have different roles to play within the process.

The work by Aksorn and Hadikusumo (2008) within the Thai construction industry illustrates such importance. They concluded that safety programmes were multi-dimensional and that the very nature of how the programme was implemented was a critical factor in reducing accidents. Key to this was the *perception from the site operatives* of the relevance and care taken to address specific issues. Thus it is necessary to be sensitive to the context in which safety programmes are being implemented if they are to be successfully adopted. It is argued that this ensures the buy-in of the site operatives to the new programmes or new methods of working, as they feel part of the process and have a sense of ownership related to it and are therefore more willing to engage with it. Lingard has published on a range of topics associated with health and safety within various contextual settings of different construction industries from around the world: first aid training associated with motivation and injury avoidance (Lingard, 2002); understanding safety through behaviour within Hong Kong's construction sector (Lingard and Rowlinson, 1998); and occupational health and safety risk control in small business construction (Lingard and Holmes, 2001). However, more recently Lingard *et al.* (2009) offered an increasingly fine-grained analysis through studies heavily embedded within particular constituents that make up the construction sector, thus

further emphasizing the importance of context and various stakeholders involved. Lingard *et al.* (2009) looked beyond the notion of a project, firm or constituent of the construction sector as having a unitary voice. Instead, the work offered a refreshing and convincing argument based around self-forming groups with different levels of homogeneity. Such conclusions reignite the informal and unstructured attributes of the health and safety debate and how these might best be engaged with to achieve a reduction in accidents. Lingard *et al.* (2010a) noted the role played by subcontractors within safety practices. As small subcontractors make up the vast majority of firms it is important to gain an understanding of how they experience safety issues. It is this more contextually sensitive type of study into safety within construction that is now making real steps forward associated with the perceptions of actors and sub-groups in order to understand where tensions exist.

Contextually situated safety

Certainly construction sectors within different countries and their unique structures play a key role in best practice and industry improvement recipes, including those associated with safety. For example, the UK construction sector is dominated by SMEs, with some 125 000 currently operating. As a consequence of this even the largest construction firms operating in the UK only contribute to a tiny amount of the sector's turnover, thus meaning they have limited power to bring about change within the construction sector. Considering this, it is surprising that SMEs are rarely the target of health and safety research with just a few exceptions such as Lingard (2001). Lingard (2002) focused upon SMEs within the Australian construction sector. That study used 22 SMEs in order to understand the effect of first aid training on safety behaviour and concluded that first aid training had a particularly positive effect upon site housekeeping and better use of personal protective equipment (an area where SMEs typically underperform).

Understanding how safety and safe working practices are perceived by relevant stakeholders is clearly important, often being viewed as a matter of opinion and even experience and training. What appears safe to one actor, gang, group or subcontractor may appear extremely dangerous to others (cf. Lingard *et al.*, 2010a). Research has attempted to investigate such issues; Cameron and Duff (2007) identified three perspectives which found resonance with empirical data, namely cognitive (goal setting), behaviourist (behaviour modification), and practice-based (social learning). With an increasing number of stakeholders now engaged in and responsible for safety, such methodologies for gaining a consensus of what is and is not safe may begin to gain purchase thus bringing all stakeholders closer together. This may also prove relevant at an operational level, focusing upon site teams.

Drivers for improvement

Such concerns are not in isolation from the drivers and methods to bring about change regarding safety. The change management literature may offer some fresh perspectives for the construction sector. Fundamentally, the current landscape within the construction sector seems to characterize change led by either a reward or a penalty. Dichotomizing a problem in this fashion rarely results in a suitable outcome as it often oversimplifies the problem, whereas it may be more useful to understand the connections between the issues in order to occupy some middle ground (cf. Larsen *et al.*, 2006). It is acknowledged that previous safety research has focused on site operatives and underplayed the role of management and other stakeholders. Cameron and Duff (2007) sought to better engage with the management component, looking at construction managers and their motivation regarding safety. That study highlighted issues of goal setting and measurement associated with induction training, toolbox talk training, safety committees, subcontractor safety, maintenance of safety records, safety manager actions and safety consideration (interaction, communication and worker engagement). Cameron and Duff (2007) argued that improvements in goal setting and measurement of safety performance improved the management team's performance by over 30%. Gaining management buy-in and commitment is viewed as key to the success of any change programme (in this case associated with safety), but it must be recognized that it is only one of the key ingredients.

Issues regarding behaviour of actors and safety did gain the attention of a number of academics, with studies undertaken in the UK and Hong Kong (Duff *et al.*, 1994; Lingard and Rowlinson, 1994). However, in the recent construction management literature there is a strong focus on regulations and the roles of stakeholders. The recent research on behaviour has focused on the training of actors (thus modifying their behaviour). Wilkins (2011) is a case in point, seeking to gain construction workers' perceptions of health and safety training programmes. Such demands are changing, with young professionals seeking faster training in order to acquire skills. The engagement of those being trained is critical along with methods used to ensure trainees take in as much knowledge as possible. Unsafe worker actions contribute greatly to the frequency and severity of construction injuries. The connection between company safety policy and accidents has also

gained attention, often being a source of tension between managers from the main contractor, sub-contractors and the site operatives. Hallowell (2010) noted that in parts of the United States there is concern within the contracting community over the quantity of accidents resulting as an apparent violation of company safety policy. Importantly, it was argued that there was a mis-alignment in the risk perception of managers and workers, although it was unclear how designers perceived construction risk. This manifested itself into the dissatisfaction of workers regarding the quality of serious accidents.

As discussed, the construction sector of any country has a number of professions and stakeholders. Thus the responsibility for safety during the life cycle of a built structure cannot rest with one profession or actor. The UK construction sector recognized this and since 1994 has had Construction, Design and Management (CDM) Regulations. Bishop was at the forefront of research associated with the CDM Regulations (see Bishop, 1994), highlighting the need for great coordination regarding safety from inception to completion and beyond. Stakeholders would have new responsibilities, and there was to be a new profession of planning supervisor. It was during these early stages that concerns were raised associated with the practicalities of the Regulations and precisely where the liability will stop. Some 18 years after the CDM Regulations were first introduced such questions remain, together with doubts as to how well the Regulations actually work. Griffith and Phillips (2001) identified a number of challenges faced during small projects (mainly associated with decanting of buildings), and the difficulty in making sense of the ambiguous legislation. They called for the legislation to actually form part of the contract documentation and new processes to be developed so that professions knew their specific responsibilities and that a commitment to those new responsibilities could be nurtured, demonstrated and potentially rewarded.

Connecting the design process and safe construction practices

The work of Brace *et al*. (2009) has been mentioned and does provide a strong link between the design of a built structure and how safely it can be constructed. It was stated that for every 100 accidents the root cause of up to 47 of those accidents could be traced back to a design issue and not actually a site safety issue. Such a claim demands attention. And the research and findings of Brace are not isolated but in fact they built upon the earlier works of Szymberski (1997) and also Gambatese and Hinze (1999). Those works presented convincing arguments of how and why design can impact upon how safely a structure can be built. Construction safety should, according to Szymberski (1997), be a prime consideration in the conceptual and preliminary design phases, a position which is now reflected in the CDM Regulations 2007. Szymberski (1997) argues that the ability to influence construction site safety is progressively lost as the project moves into the construction phase, but there is a significant opportunity for such influence in design. However, until recent legislation in the UK, France and Australia, designers' consideration of construction safety had been mainly discretionary (Gambatese and Hinze, 1999). Indeed, and despite the evidence from the research discussed above, the USA's Occupational Safety and Health Administration (OSHA) clearly places the responsibility for worker safety solely on the constructor (Behm, 2005) thus missing the opportunity to take advantage of early consideration. That approach of removing responsibility from the designer is still widespread across many countries, but has been changing since more parties have been brought into litigation regarding worker injuries. A recent study of the effect of European Directives on construction workplace accidents shows a statistical decrease in incidents since legislation came into force (Aires *et al.*, 2010). Project owners have been concerned about safety performance on their projects for some time, which has issues associated with adverse publicity (Gambatese and Hinze, 1999) and now the corporate social responsibility agenda (Larsen *et al.*, 2012).

Brace and others have continued to expose the initial concerns they raised, and relatively recent research indicates that:

> many designers still think that safety is 'nothing to do with me' although there are a small cohort who want to engage and are having difficulty doing this because they do not fully understand what good practice looks like. (Brace *et al.*, 2009, p. 12)

Such research illustrates the complexity of the challenge ahead, raising questions regarding the historical and embedded role of the designer, the outlook and agenda of clients and also how designers can engage in and champion change when faced with resistance. Such arguments must however be tempered with the changing practices of design, digital tools now available and the potential influence these may have upon safety. The ever increasing demands on the designer cannot be ignored as buildings become ever more complex. The CDM Regulations have a role, requiring consideration to be given to health and safety (H&S) in the planning and design of construction work in the UK. This should mean that the contractor is no longer left with the sole responsibility for

safety during construction, but rather the responsibility is shared among all those that influence safety. The aim of the CDM Regulations is to bring about a culture change in the construction industry. That change is driven by the requirement of *all those involved* in the development and construction process to consider H&S issues. But has that actually been achieved? Baxendale and Jones (2000) argue that the philosophy behind the regulatory framework is to establish a team that will have the competence and resources to manage the project without undue risk to H&S. In order to facilitate this a new role termed planning supervisor has been created, namely the CDM coordinator following the new CDM Regulations 2007 release, and this is central to a client's responsibilities. The CDM coordinator should be appointed as early as possible to allow adequate time to address issues during the planning and design stage, including the preparation of the pre-tender stage H&S plan (Baxendale and Jones, 2000). The Regulations acknowledge other parties, including the client, designer, principal contractor and subcontractors, as having responsibilities for H&S management on a construction project. They highlight the importance of multi-party collaboration for safe construction. The level of awareness of the distinctive duties and how well these are coordinated during the various phases of the construction project underpin H&S (Perry, 2003). Researchers have become involved in developing short courses for construction professionals, adopting an integrated problem-based and collaborative learning approach, to help them understand these CDM roles and duties (Oloke *et al.*, 2007).

An early CDM implementation study (Baxendale and Jones, 2000) suggested designers need to indicate a knowledge and understanding of how risks and hazards to H&S can arise in construction and how they can be avoided or reduced through design. However, designers are not typically trained in this way, nor do they have experience of site operations. Some designers, especially those in design-build firms, are able to address construction worker safety in their designs (Gambatese and Hinze, 1999). These designers work with their colleagues who are responsible for the construction of the project and thus have onsite experience. By working together in the same firm, they begin to appreciate each other's concerns. Good ideas will be remembered and used on subsequent projects. Nevertheless, many designers, who are not part of design-build firms, note that they lack the skills and training to address construction worker safety. This brings up the need for a central body of knowledge available for designers to address safety issues in their designs. To further this, Gambatese *et al.* (1997) accumulated over 400 design suggestions for construction safety through a literature search, construction industry personnel interviews, worker safety manuals, safety design manuals and checklists. These design suggestions were compiled in the 'Design for Construction Safety Toolbox'. The relationship between construction fatalities and design has been investigated by Behm (2005). This research was rooted in the USA's NIOSH Fatality Assessment Control and Evaluation (FACE) Program, which provides approximately 500 construction industry fatality descriptions, including a detailed incident narrative and recommendations (www.cdc.gov/niosh/face/). It used statistical hypothesis testing to examine 224 fatality investigation reports, and the results suggested that 42% of the fatalities reviewed were linked to design issues. This implies that the associated risk that contributed to the incident could have been reduced or eliminated had construction safety been considered in design. The research established a link between construction fatalities and design for construction safety. Behm (2005) and Gambatese *et al.* (2008) provide retrospective evidence that design had an impact on construction site safety. Fatalities that occurred during construction of thermal and moisture protection, doors and windows (including skylights), and metal design elements were more often related to design issues. This finding was largely due to:

> the prevention of falls when erecting structural steel framing and while building and maintaining roofs where permanent anchor points, lifeline systems, and other forms of permanent fall protection could be designed into the permanent features of the structure. (Gambatese *et al.*, 2008, p. 678)

Gambatese *et al.* went further, arguing that 'roofing and structural steel constructors would benefit mostly from the implementation of the design for safety concept' (Gambatese *et al.*, 2008, p. 678). This finding indicates that design for safety suggestions and modifications may have a positive impact on fall prevention and protection measures. Statistical data continuously demonstrate that these are a major cause of fatalities in construction. Being a work framework rather than a specific safety knowledge body like the toolbox, the Construction Hazard Assessment Implication Review (CHAIR) method provides a process for the evaluation of the construction, maintenance, repair, and demolition safety issues associated with design (Workcover, 2001). It is based on hazard and operability studies (HAZOPs) (Lingard and Rowlinson, 2005) to develop a process for evaluating occupational health and safety (OHS) risk implications in construction design. The CHAIR consists of a three-stage review by multidisciplinary teams, involving all stakeholders

in the design, construction, and use of a facility. The first review occurs at the conceptual design phase. At this stage, the design is divided into logical components and, for each component, sources of OHS risk are identified and assessed. Taking place prior to construction, after the detailed design is completed; the second review focuses on OHS issues arising in the construction and demolition phases of the project, while the third review focuses on maintenance and repair of the facility. Trialled by several projects, this is an innovative adaptation of HAZOPs methods in construction.

To improve construction safety, Atkinson and Westall (2010) identify a number of practical actions that designers can take, including asking the contractor how work will be constructed; finding out component sizes for safe installation; coordinating the programme for safe sequencing of work and ensuring the contractor has in-depth understanding of the design rationale. However, the prevalence of traditional design-bid-build contracting arrangements and the resulting complex hierarchy of subcontracting on any modern building create a significant organizational distance between designers in any domain and the relevant subcontractors who will actually perform the work. In the USA, for example, there is still significant reluctance on the part of designers to take an active role in addressing construction safety due to liability concerns when dictating means and methods (Gambatese *et al*., 1997). There are significant challenges in implementing these actions. Toole and Gambatese (2008) state that changes in design are often only implemented as attempts to protect the designer from liability rather than to effect any real change in design to support safety. Design for safe construction requires collaboration of the designer, owner, constructor, and other project parties (Gambatese *et al*., 2008), and such collaboration is emphasized in the CDM Regulations. Yet Gambatese *et al*. (2008) note that any suggestion that design for safety will automatically eliminate construction site fatalities is false. It is one element within a more holistic approach to minimizing construction project risk and enhancing worker safety, through multi-level risk assessment and hazard prevention mechanisms throughout the delivery of a building project. There is more work to do to establish a robust evidence base to show the aspects of construction safety where design has the largest role to play. Yet the work discussed here indicates that the quality and nature of design do impact on construction safety. Procurement methods play a role, yet at present there is little statistical evidence to confirm that design and build firms (where in-house designers are used) actually have a better safety record than those firms embracing more traditional procurement where the designer and contractor are separate.

It is thus vital to understand the complexity of these issues from the actors charged with the production process on site. Their experience regarding how safety is influenced by design can help our understanding. The aim of this study is therefore to understand the challenges of building delivery and the inherent safety challenges embedded in the design and how the construction team address these challenges. Hence, in the next section, the research setting is outlined before the case study research design is introduced.

Research setting and methods

Research setting

It is important to describe the case study project used for this research, thus helping illuminate and contextualize the analysis that will follow. For the purposes of publication, the name of the project has been changed; however, it can be stated that it is a large national train station in the centre of London in the UK. The project is set at the interface between a number of key stakeholders associated with London's transport system and heritage buildings. These included Network Rail, train operating companies, London Underground, Transport for London, and English Heritage to name but a few. The project presented an extremely complex construction challenge, on a highly constrained site, involving both a renovation and a new-build with many restrictions around as well as underneath the site. Because of the London 2012 Olympics the completion date for the project was fixed and extensions could not be considered. Briefly, the project was made up of a number of sub-projects. First the relocation of staff from Grade 1 listed buildings (protected by English Heritage) in order to change the use of those buildings (these buildings are referred to as the Range). This involved an enormous amount of consultation with English Heritage regarding material choice and alterations for this large four-storey building. To further complicate this element of the project an entirely new ticket hall facility was to be constructed underneath the top three storeys of the Range building. This involved a complex temporary works design, whereby the top three storeys were jacked up, in order to allow the construction of a new ticket hall using modern methods of construction. Once completed, the three-storey Range was then lowered back down on to the newly constructed ticket hall which was able to accommodate the new loads. Finally, an entirely new atrium was to be designed and built, adjoining the existing

Grade 1 listed buildings and thus increasing the size of the actual station. This used steel tree structures and bomb-proof glazing to make a striking visual statement. This included a mezzanine floor to be occupied by retail outlets servicing the station. This atrium affectionately became known and referred to by some of the project team as the 'conservatory'. It is important to note that all of this was taking place in a live train station in the centre of London, and the station was never actually closed. Furthermore, the project was taking place directly above a London Underground station, which imposed numerous restrictions upon site processes especially associated with cranes and safe loading weights. Traffic and pedestrian routes were affected during the construction, yet were maintained through numerous evolving schemes at different stages of the project.

While for many the description offered so far would seem complex enough, further challenges were presented with other main contractors also engaged in works on and around the station. These included an entirely new roof being installed to the existing train hall (where the trains pull into) thus meaning another main contractor was often working above the case study project and stakeholders. A further main contractor was engaged in the refurbishment of a hotel (also a listed building) with which the glazed atrium roof would form a junction. Having set the scene of the case study project, the research methods are now discussed.

Research methods

This interpretive study uses the work of Green *et al.* (2010) as a methodological touchstone. The initial interactions with the project managers related to research on how site safety issues are associated with design and the technologies used during that process. The empirical work included in-depth interviews conducted at the site offices with the construction team, as well as site safety data, design models, informal conversations and a workshop. The site near-miss and incident data collected by H&S professionals on the project were also viewed. As such, the research sought to understand the lived reality of design for safe construction as experienced by the construction team using multiple data sources.

Seventeen in-depth interviews were conducted in the site offices, to understand the reality of the impact of design upon a safe construction process as experienced by the members of the site team. These interviews were conducted as 'ethnographic interviews', with a focus on listening to the stories that emerged from the site, and steering the conversation to cover the themes of interest around safety, design and modern design methods rather than pre-structuring a detailed set of questions. That approach offered the required experience and sensitivity, as the interviews were conducted with key individuals from numerous organizations engaged in the project with specific experience and expertise. A number of the interviews occurred through informal recommendations from the initial interviewees identified, thus enacting an emergent snowballing strategy. The details of these interviewees, and the other main interactions with the project, are shown in Table 1.

Each interview lasted approximately 60 minutes, and covered a range of professionals responsible for the production process from different stakeholders including the client. As the interviewees have a range of different responsibilities and experiences on the site, the conversations with each interviewee unfolded differently, relying in part on the experience and skill of the researcher. Examples where such knowledge and sensitivity were required included: an interviewee focusing on safety of demolition and temporary works; another on the issues surrounding the safe movement of materials; others regarding the challenges and uncertainties associated with the refurbishment of a listed building including identifying live services, etc. and that many interviewees wished to talk about the impact of design decisions on the safe maintenance and cleaning of the built structure during its life span. There were themes that cut across a number of the conversations, yet are clearly connected with design for safe construction. Together with the in-depth interviews, the research team mobilized complementary methods to help add to any understanding offered. The busy roles of prospective interviewees did result in rescheduling some interviews; however, the research team embraced this 'extra' time by chatting to other members of the project team informally. The research team spent six days on site during a five-week period as the project was in its latter stages. Additionally, time was allocated to look over various drawings and discuss particular issues, followed by site walkabouts to see some of the challenges first hand. All of this provided rich contextual and background knowledge that proved helpful in interpreting the interview data. During this period the research team also had access to and reviewed the digital design model for the project, safety data from the site, and publically available information on the project.

Following all of this, the final stage of the research design took the form of a feedback workshop. The contractor selected a range of participants to bring to a workshop (there were also suggestions from the research team); these included key consultants and subcontractors. During the workshop the design model for the project was visualized in an immersive VR stereo display. This experience was then used as a prompt for further roundtable discussions about the

Table 1 Interactions and the roles of interviewees in the study

Interaction	Duration (hrs)	Participants	Authors (1st and 2nd)/Other
Set-up meeting 1	2:00*	Engineering design firm visualization manager	2nd
Workshop/set-up meeting 2	2:00*	Project manager, 2 contractor H&S managers, project manager for related project b	2nd + other
Set-up meeting 3	1:00*	Project manager	1st
Interview 1	1:02**	Deputy project manager	1st
Interview 2	1:22**	Technical manager	1st
Interview 3	1:04**	Client programme engineering manager	1st
Interview 4	1:03**	Mechanical, Electrical, Plumbing and Heating services design manager	1st and 2nd
Interview 5	0:55**	Logistics	1st
Interview 6	0:57**	Senior Temporary Works Engineer	1st
Interview 7	1:14**	Client senior project engineer	1st
Interview 8	0:52**	Senior construction manager	1st
Interview 9	1:01**	Deputy project manager for a package	1st
Interview 10	1:08**	Package project engineer	1st
Interview 11	0:46**	Site manager	1st
Interview 12	0:56**	Senior asset engineer	1st
Interview 13	0:41**	Site manager for services subcontractor	1st
Interview 14	1:00**	Client senior construction manager	1st
Interview 15	1:27**	Senior engineer for subcontractor	1st
Interview 16	1:01**	Section project manager	1st
Interview 17	1:05**	Package manager for lifts and escalators	1st
Conversation	2:00*	Project manager and health and safety manager	2nd
Workshop/feedback meeting (after project opened)	3:00*	***Project***: project manager *Related projects* **A and B:** contractor senior design manager; contractor project manager; subcontractor design manager; client discipline engineer; client; engineering designer	1st, 2nd +others

Notes: *approx, **transcript.

issues of design and its inherent impact upon a safe construction process.

Safety challenges and the design

Analyses of the interviews and supportive data present a strong argument that design has an impact on safety because of: (1) the timing of design work, where the volume of late design changes increased the difficulty of planning safe procedures, e.g. for working at height, lifting heavy items, refurbishing and demolishing old buildings; and (2) practical knowledge and inputs from design stakeholders with insufficient practical knowledge of construction and operation often requiring additional and thus unplanned work-arounds, e.g. to coordinate different sub-systems, provide maintenance access, and manage loads during construction. While these two themes will form the basis of the analysis in the sections below, they are followed by the emerging issue of design for life, maintenance and adaptation in the future.

Timing of design work

Changes to design were discussed by every interviewee, in informal corridor conversations and during the workshop discussions. It was acknowledged that the client is constantly trying to fine-tune precisely what they want from their building or structure (a significant investment), and that certain decisions can only be made following previous decisions. Notwithstanding this the volume of late design changes on the case study project was described as a significant challenge, which increased the difficulty of planning safe procedures. A number of interviewees commented that this was more problematic on this project than on other projects. Central to these issues were the relationships between the types of changes, the timing

of changes (often very late), the delay in receiving information associated with changes and the knock-on effect of changes to other elements of the project. This resulted in a number of suggestions, not least imposing a design freeze:

> I think we just kept on sort of absorbing change and we got to a stage and said, 'well if you want this finished, there's no more'. But, it's difficult when it's fundamental in that oversights, I don't know, for fire strategy, whatever, we've got some secondary glazing, they've suddenly realized that one of the windows is a bit bigger than they can provide secondary fire rated glazing on the staircase. That's a fundamental … (Interviewee 1)

While contractors wish to accommodate client needs they do need the relevant information to work with and for it to be fixed to ensure progress is not adversely affected. There was some discord regarding what was produced by the designers, the format and just how fixed that was for the construction team to use:

> well it would have helped actually to have a 3D model of what the designs intent was … and we just got to go very, very firmly, 'we stick to this'… (Interviewee 15)

Interviewees acknowledged that project management is fundamentally based around managing change, thus within the construction of such a complex structure changes are expected. There are digitally mediated tools to help improve communication within the process. A handful of interviewees mentioned the use of building information modelling (BIM) and associated tools and the role these play in identifying construction clashes, and areas where there was poor buildability and therefore a higher risk to the safety of operatives might occur. Interviewees went on to discuss the issues of buy-in and commitment associated with BIM and associated tools and then actually ensuring that the model is continually updated.

> [With] 3000 introductions of extra services … that we didn't know about at the time, changes here, there and everywhere … so as time's gone on 3D models have become less useful. (Interviewee 1)

This continuous story of late changes to the design led the construction team to question the priorities of the designers:

> I don't think our designers have that as to the forefront of their minds as we do. Um, I think they are more driven by aesthetics and the like. (Interviewee 3)

These late changes exerted additional pressures on both the designers to consider how an element could be designed to ensure safe construction and also the site team and construction programme, essentially squeezing the resources available for considering safety. The changes resulted in a plethora of work-arounds, and rebuilds and making good to overcome issues. While the timing and changes to the design had technical and safety impacts, they also had an adverse effect upon the motivation of the construction team:

> because the last thing we wanted was for more drawings and schedules to come to us, us to look at them, find errors, you can guarantee there would always be errors … re-design so a massive, massive thing on our part was keeping enthused on this particular job. (Interviewee 14)

Timing was not the only issue raised by participants; the quality of the design information provided and its knock-on effect was also raised whereby there would be an iterative process which itself then began to impact upon the programme:

> so the design information would have had a series of assumptions and once the building started to be opened up then they would have discovered anomalies to the design and, you know. (Interviewee 11)

The issue of communication was raised in connection with a number of issues, but especially those around managing such changes. These ranged from the limited number of actors with the responsibility to sign off proposed solutions to such anomalies, through to getting questions answered in the time required. When faced with so many changes, the relevance, value and buy-in to digitally mediated tools is questioned, as staff struggle to ensure they are fully up to date and integrated.

Practical knowledge and the inputs of design stakeholders

Design priorities

The design, as experienced by the interviewees, was dominated by aesthetics. A number of interviewees commented that aesthetics were seen by the client and the designers as of paramount importance over and above other criteria. This relates back to the CDM Regulations and the roles of particular project stakeholders and their capability to fulfil those roles (to be dealt with in coming sections).

> and the interface between the two buildings and also a lot of it is governed by aesthetics, architectural aesthetics, and has got nothing actually to do with the

> reality of it in the long term and its gone to such a stage architecturally where it has to be clean and uncluttered and everything has to be disguised and discreet from view, but how do you maintain all these things. (Interviewee 2)

A number of interviewees raised the issue of site surveys and the discrepancy between the information required and the information available before construction actually started. This was exaggerated by the current vogue of concurrent design and construction. The site team felt that attention and resources were directed toward aesthetics, rather than the practicalities of understanding the challenges involved in an existing Grade 1 listed building with almost no as-built records. This resulted in numerous problems associated with existing services and hazardous materials such as asbestos. Of particular concern was gaining as-built information for live cables and services (electric, gas and water) within the existing structures and nearby facilities resulting in numerous 'untraced live cables, services, gas, water' (Interviewee 8). This not only had a potential impact on safety, but also adversely affected the progress of the contractor during the early stages of the project. While such 'unknowns' are a risk historically associated with contracting, it is difficult to see who actually benefits from such an approach. All of the issues raised above point to the dominant aesthetic driver behind the project. However, through the voice of the site team other issues are perhaps given less attention and fewer resources and it is this fact that can have an adverse effect upon site safety.

Roles, knowledge and capabilities

Knowledge, capabilities and skills continue to be a theme associated with the provision of the built environment literature generally. These were issues echoed from the construction site:

> when you draw a valve it's a few lines on a piece of paper, but what does that valve look like in reality? If I gave them [Draughtsman and Designers] the valve out on site and I said to them, that's the valve, a lot of them probably wouldn't be able to relate that to a valve on a piece of paper. They wouldn't understand what would be needed to maintain the service of that valve. (Interviewee 4)

The professions and their roles associated with design and construction continue to evolve. The subject of changing professional roles, career development, experience and future capabilities were all raised at various times. Some suggested that young professionals seek the title of 'project manager' but really lack experience in the field which can take years and a number of different projects to gain. Lack of time at the coal face had adverse effects upon capabilities. This lack of knowledge and experience appeared to have an adverse effect upon responsibility and accountability. When considering the challenges associated with the aspect of safety, many participants stated the key issues for improvement were with 'the younger members of the team' (Interviewee 1).

Others went further, noting the lack of exposure to onsite activities and operations that young and relatively recently graduated professionals experience. Some noted that many people coming into the construction industry simply want to enter at too high a level, as site or project managers without gaining real site experience. It is through such onsite experience that a real understanding of safe approaches to working can be developed. Many felt that onsite experience was invaluable compared to currently available digital tools in helping develop capabilities of future site and project managers, and stated that:

> part of the problem is that I think if you are a young graduate coming through you have only actually been used to looking at a screen. (Interview 12)

Related to the above point a number of interviewees questioned where the project managers of tomorrow were coming from and how they can get practical onsite experience in order to really understand how a building is put together and importantly put together safely. This was reflected though communication and fragmentation in the industry:

> the mentality nowadays I find it with the young people, they don't have that sort of interest of trying to understand (how the building is put together safely) it they're just so dispassionate approach … 'Well I want the instructions; you tell me what to do …' (Interviewee 15)

Enacting the CDM Regulations

Building upon the issues discussed regarding professionals, the roles played by the various stakeholders associated with the CDM Regulations were continually mentioned throughout many of the interviews and the workshop. Respondents were not actually critical of the CDM Regulations per se, but rather found fault with how the Regulations were enacted in practice by stakeholders. In particular, interviewees raised how the roles played and the knowledge and capabilities to fulfil those roles needed to move in line with the latest CDM Regulations. When asked about the role and in particular the use of CDM Regulations on the project to ensure safe construction,

respondents typically gave a somewhat negative answer, including 'There is no such thing as CDM! There might be on paper' (Interviewee 5).

While many repeat clients may offer insight into the process, their role regarding the CDM Regulations is still somewhat less well developed. This raised concerns for the site team, stating that:

> I presume CDM is involved. It's there but we [main contractor] haven't had direct involvement with it. I've had no involvement with it whatsoever. As far as the design is concerned I'm going to say it is designed by the client. I don't think the client has involved [with the CDM Regulations]; and I'm speaking open. (Interviewee 17)

It would be foolish to suggest that all the issues regarding safety rest solely with the designer. Like many projects the specialist subcontractors played a key role and the main contractor was charged with managing them. There were a number of instances where the meaning of safe practice was interpreted differently by different stakeholders. This ambiguity regarding a safe working practice is not uncommon. Seasoned specialist subcontractors often develop specific approaches based upon experience and tacit knowledge developed over many years which other professionals simply cannot match. However, those approaches can come under scrutiny from the main contractor as they struggle to make sense of the reasoning behind them. Thus, negotiation skills can be increasingly important in finding an agreeable solution for all concerned and one interviewee described the difficulty in achieving this;

> I said, John [subcontractor foreman] that is an unsafe act. [John said] No it's not and he could not see the problem with it. In the end I had to get Network Rail involved and our Health & Safety Team and he was told to stop it and we came up with the gantry idea. (Interviewee 8)

Emerging issue of design for life (cleaning, maintenance and adaptation)

While the issue of design for safe cleaning, maintenance and future works was not the initial focus of the research, the approach adopted enabled participants to continually raise the subject as they saw fit. The main thrust of the discussion around these points was that the designers and the constructors have very different interpretations of what is deemed as 'design for life', thus safe cleaning maintenance and future works. The lack of provision for safe maintenance was described as a major design problem. The impression was that the provision for maintenance was not considered during the design stage. Instead, maintenance appeared to become an issue as the building was realized on site, and designers and other stakeholders could then see more clearly and begin to question issues of maintenance.

Concerns were raised regarding the level of detail designers offered and exactly how helpful that was. Examples include project documents (including drawings) which simply gave overarching statements but with little detail to support them. This somewhat generic approach left the site team with little faith in how the CDM Regulations were enacted in practice on the case study project, for example:

> I mean the access maintenance strategy, you have a funnel and if you look on the drawing which says access maintenance it says access by cherry picker and it doesn't actually show the cherry picker reaching the bit there. (Interviewee 16)

The site team relayed a number of examples whereby the lack of safe maintenance considerations during design required the development of complex solutions. The issue of designing for safe access was a dominant theme. This was of particular concern when considered against the lifetime of the building, and being able to clean and service key elements including safe access, plant rooms and the safe working space within plant rooms were continually referred to:

> There's no permanent system and there's still (work) about walkways and how we (are) to maintain certain M&E systems and louvers in the roof, we've got some quite inaccessible sort of lofts where most of the plant is on the western range building, the loft space, the existing loft space has been used as a sort of plant room and of the accesses there are quite … basic. (Interviewee 1)

There were a number of statements similar to those, regarding high level safety issues and those systems where not designed in. The interviewees describe the approach to maintenance by the designers as 'a bolt-on' to the design at best. There was little evidence to support the consideration of safety within the design; to the contrary, it was argued that what should be viewed as the last report was at times the default first choice of designers. Concerns were also raised and evidence offered that documents would include generic statements, such as 'use cherry-picker'. However, questions were raised regarding access for the cherry-pickers into a finished building, loads, and ability to reach, with some stating:

> I think when you look at it inside I think that's questionable how you're actually going to reach it. I mean we're going to have a go to see if you can get on the back of it somehow so you might be ?… but I'm not convinced that the thought process has gone in there in saying yes there is a way of doing it. (Interviewee 16)

Others commented about the number of discussions they had with the designers regarding such issues:

> [we have been talking] quite a lot to our designers about how do we clean this thing, how do we maintain this thing, what's the access like to do that, we're very hot on that. (Interviewee 3)

The design of certain elements left the interviewees bewildered. Cases in point were the down pipes from the glass concourse roof. The design of these involved a number of very sharp bends in order to follow the profile of the edge detail. That was clearly an aesthetic decision, which the interviewees believed would result in a need for increased maintenance. Despite this apparent need for increased maintenance, there were no integral safety systems designed into the structure for the level of maintenance envisaged. Another area of concern related to the interface between the Grade 1 listed Range building and the domed glass roof forming the concourse area. The design left a number of windows inaccessible and a particular area of the glazed roof inaccessible. 'You look at it and think my god how are we going to get back to that' (Interviewee 5). While the abseilers are suitably trained, such an approach by its very nature is dangerous and time consuming. From a financially sustainable stance, this issue cannot be underplayed: with the life span of the train station being considerable, the ongoing maintenance and cleaning costs using abseilers will also be considerable. Interviewees felt that the designers have simply opted from the outset to choose what they felt should be (and best practice might suggest) the last resort, that being specialist abseiling teams.

The desk studies by the designer regarding access appeared flawed, where a particular piece of plant was deemed to provide access. While the interviewees welcomed such considerations, they noted that,

> well actually that equipment isn't readily available, if we have got something that needs to be sort of replaced as a matter of urgency we need to get on and do that and we can't sort of book a crane in a week or two's time. (Interviewee 7)

Other maintenance access issues were raised and in particular the nature of the discussions undertaken between the designers and the construction team:

> we have had some interesting discussions on what they (the designers) think can be done and why it can't be done. So they make suggestions to me and they have done and I can change light fittings by hanging out of the windows on the Western Side of the building, seriously, harnessed on, mind you. (Interviewee 12)

These findings suggest that designers are perhaps actually thinking about such issues more than the site team perceive. However, from these examples at present there still appears to be a disconnection between understanding such issues as a desk or BIM exercise, the solutions then proposed and the actual practicalities of implementing them in practice to meet the client's needs. This is especially important in a public building like a train station that essentially never closes.

It was noted that the lead designers had produced a maintenance strategy for the finished building. However, there was once again a degree of tension between the designer's perspective and that of the construction site team.

> I don't, for one minute think it considered access or maintenance and I think that was the shortfall. (Interviewee 10)

Discussion

The complexity of design, safety and construction is clearly apparent and, while the research did not aim to reach any consensus per se, the voices from the construction site team were clear on number of issues. First, the research acknowledged that better safety is still required and that there were a number of areas where this could be achieved. There is a disconnection between the reality experienced by the construction team and the site near-miss and incident data collected by H&S professionals on the project. Clearly the voices from the construction site team link design with safety concerns, yet this is not reflected through the near-miss and accident data recorded. Such a realization brings into question the very methods currently used for understanding safety on site and tracing the reasoning for potential risks during the construction phase. It is here that a fundamental reconnection needs to be made.

Initially the design of the proposed built structure and the roles of relevant stakeholders in that process and the regulations designed to improve this were

seen as key. At the time of writing the CDM Regulations have been in force in the UK construction sector for 18 years, yet challenges still abound. Challenges remain in getting buy-in to these Regulations from the relevant stakeholders, with some interviewees stating CDM Regulations are not enacted in practice and only exist on paper. Such concerns resonate with previous research undertaken by Bishop (1994) and it is apparent that additional effort and research are required regarding the take-up and enforcement of these Regulations and the responsibilities of the stakeholders. The CDM Regulations were designed, in part, to ensure safety provision becomes a more integral part of the design and construction process by bringing stakeholders closer together. However, based on these research findings safety is still very much seen as an afterthought or bolt-on to the design, rather than an integral part of the process. The relevance and power of the CDM Regulations as a change agent are seriously limited. Until there is a paradigm shift regarding safety during the design process, accidents influenced by poor design will continue within the UK construction sector.

Commercial pressures now necessitate that design and construction occur concurrently (cf. Larsen and Hughes, 2012). It is accepted that the drivers behind this are convincing in part, yet there are real challenges associated with design changes and information requirements that have a real impact upon the safe planning and execution of onsite activities as well as other production issues. The result is that the planning and execution time for particular onsite tasks and operations are squeezed to breaking point because the design details take too long to be realized, thus squeezing the construction programme. On projects as complex as the case study, the quantity of changes, and managing all the relevant information to ensure any knock-on effects were identified were difficult. It is proposed that improved information modelling tools may offer some relief and the construction sector is certainly moving in that direction. While the notion of freezing the design is appealing, it can be difficult to manage in reality. Currently there are limited methodologies or tools to effectively achieve this in a way that engages all stakeholders.

The UK construction sector is often criticized regarding investment in training and skills of both operatives and managers. The research findings support such concerns, and the fragmentation between onsite activities and the role of professionals or managers. The overarching issues here are associated with onsite experience at the coal face where construction happens and challenges occur. The reality experienced by the research participants (interviewees and workshop participants) suggests that designers need to have greater engagement with site operations and should visit the site more often if they are to improve their capabilities. But such concerns were not limited to designers. The ever evolving professionalism associated with construction managers and project managers was evident as concerns were raised regarding engagement with the site operations of recently graduated and junior managers. While those actors were identified as having key skill sets, there was real concern regarding how much they engaged with onsite activities and how they would ever really understand the practicalities of constructing something safely. It was claimed that many junior employees don't wish to engage at an operational level, as they see themselves as office-based professionals.

Despite the digitally mediated age of design and construction, the process of building is a practical activity, and onsite exposure and experience were seen as playing a key role. Concerns are raised regarding how this experience is being eroded. While developments in digitally meditated tools have a role to play, the research participants questioned where the practical experience, knowledge and capabilities regarding safety were going to come from for the next generation of construction managers when many young professionals do not wish to engage in the site experience. As design and construction become increasingly digitally mediated, the UK construction sector needs to invest now in capabilities associated with both technology and the skills of using such technology to help improve safety. These data suggest such tools are currently underdeveloped and lack buy-in from potential users especially during periods of rapid design changes. This needs to be balanced against more effort to encourage professionals to gain practical experience. The issues raised through this research: a shift from bolt-on safety during design to it becoming an integral part; managing the concurrent nature of design and construction; and the role, knowledge and capabilities of stakeholders can offer three key areas where such digital methodologies may contribute.

The research participants clearly had numerous concerns associated with safety and issues inherited from the design. However, an additional concern in the debate was the participants' experience of design for life and how the building could be maintained and even adapted in the future. Much was made about the issues around future access for cleaning and maintenance. The impression was that of last minute bolt-on solutions. To further compound the problem many of these (bolt-on) solutions lacked real detail, whereby specified equipment would not reach or even fit in the area of interest. This links back strongly with understanding the practical nature of the tasks in sufficient detail to realize what is and is

not achievable in practice. The research participants described many of the solutions proposed by the designers for cleaning or maintenance as the last resort possible. Yet, it appeared to the research participants that such solutions were readily offered by the designers as the first choice and not the last. Regardless of how true that is, this is the impression and reality experienced by the research participants. The knock-on effect of poor safety considerations in running the finished building is far reaching. The additional time, disruption and costs of having to use elaborate safety systems to carry out what should be fairly routine activities increase exponentially over the life of the building thus offering poor value to the client in the long term.

Conclusions

The research set out to understand how the design of a built structure influences safety during the construction process. By drawing upon multiple sources the empirical analysis makes a strong case that the design produced, and thus those who are part of the design process, have an important role to play regarding safe construction. While the AEC sector has had its fair share of critics regarding safety, it is important to note that buildings have grown in complexity exponentially during the past century. Developments in materials, power and thermal controls along with demands of an industrialized society with complex financial models and increasing regulatory requirements place increasing and often competing demands on the building and the stakeholders involved in the process. Safety has improved and clearly has an important role to play but it is not the purpose of the building activity.

Analyses of the interviews reveal perceptions that designers prioritize aesthetics over material processes leading to difficulties in building construction together with future maintenance. The CDM Regulations were a recurring theme throughout the interviews. It became increasingly clear that the Regulations are interpreted differently by different stakeholders. This led almost all of the interviewees to claim that the CDM Regulations were not being enacted in the manner intended. While more research is required, conclusions suggest that the CDM Regulations have too much room for interpretation, making it easy for the designers to focus too much on aesthetics. The analysis in the sections above has clearly outlined that the understanding and enactment of the roles outlined in the CDM Regulations are not yet operating at a suitable level.

The nature and complexity of the construction project certainly have a role to play, as these led to extensive design changes. The data show that despite the use of some digital management tools it became challenging to manage the volume and timing of the design changes while also accommodating safe practices. The notion of design freeze was mentioned numerous times by interviewees, yet it is acknowledged that such projects need a more robust methodology to cope with this.

Questions are raised about the roles, knowledge and capabilities of designers to understand safety. However, it is concluded that all stakeholders need a high level of empathy, thus understanding the challenges through each other's eyes. As design becomes increasingly digitally mediated, new questions arise about how best to visualize and understand safety in design practice, and how to draw on construction and maintenance experience in the design as well as construction stages. Future research may seek to involve other stakeholders associated with a case study project, including the client, the architect and the end-users. If undertaken, particular focus could be directed toward the communication and coordination between the key decision makers, and those highlighted within the CDM Regulations may be actually considered formally.

While the aim of the research was met and a greater understanding of how design impacts on the safe construction of a built structure has been presented further questions abound. There were additional findings relating to the design for life of the building. With increasing consideration given to long-term sustainability by clients, government and academics alike, this is a developing space and where the cost of operating the built structure in a safe manner becomes a key consideration. While mindful of this closing point, future research will seek to understand how design, influenced by new digital practices, can influence safe construction but also safe operation of built structures.

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