A Retrospective Assessment of Safety in Design (SiD) in Existing Public Buildings

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Abstract

The concept of Safety in Design (SiD) is strongly influenced by the UK CDM Regulations and the drive to improve safety and health in the industry. Designers have a responsibility not only for design and build; but for use and maintenance by designing out any hazards at any of these phases. The impact that designers have on site safety is dependent on their skills, knowledge, experience and organisational capability to modify designs towards improving safety. This study reviewed the impact of SiD during use and maintenance of 12 existing public buildings in London by visually inspecting and adopting a scoring matrix for the design hazards. The inspection data acquired were evaluated using a design control-measure database with recommended alternative design decisions capable of improving safety. The findings suggest that buildings post-CDM 1994 incorporated better safety initiatives in the designs than buildings pre-CDM. In principle, 9 out of the 12 (75%) buildings inspected had good level of SiD implemented in the design e.g. the foyer. Eight (8) of the 12 buildings had safety-related issues with manhole chambers/access shafts located in busy access areas, damaged or uneven entrance to the buildings, external wall-window systems, working at height, slips and trips, location of plant rooms and SiD implementation in buildings pre and post-CDM regulations. This study contributes to the discussions around public building safety by demonstrating that the implementation of SiD in the overall design of the entire building significantly improves the safety of buildings rather than SiD in some specific areas of the building. The limitations of this study included restricted access to plant rooms and small sample size which inhibits the generalisation of the findings. Therefore, future studies would benefit from using larger sample sizes and prior permission from the building operators to gain unrestricted access to conduct inspections.

Keywords: Safety in Design Design hazards CDM Regulations Designers Site safety

Contextualising SiD

Every construction project is unique in its own right and it is acknowledged that there is a connection between design and construction related accidents as suggested by Haslam et al. (2005). The evolution of the UK Construction (Design and Management) Regulations from 1994 - 2015 places emphasis on the role and duties of designers involved in construction projects to consider the health and safety implications of their designs.

The EU directive 92/57/EEC which was transposed into UK law in 1995 as the Construction (Design and Management) Regulations (CDM) 1994 recognises that the CDM Coordinator (presently duty of principal designer) has the responsibility for coordination of health and safety in construction projects. The duty of the designer using the pre-construction information however, is to take account of the general principles of prevention with the aim of eliminating foreseeable risks. The

CDM Regulations have since undergone changes from CDM 1994; replaced by CDM 2007 to address the perceived shortfalls and presently, the CDM 2015, see Table 1. The rationale for incorporating Safety in Design (SiD) in construction project is to address the workers' health and safety needs in the design and redesign processes to prevent or minimize work-related hazards and risks associated with the construction, use, and maintenance of structures. However, some designers still struggle to recognise how to incorporate and improve health and safety through design (Haslam et al., 2005), even though it is mandated by the Construction (Design and Management) Regulations, 2015.

lthough construction accidents in the UK are in the downward trend year-on-year, it does not however infer that the implementation of SiD alone has been the main precursor to these fall in numbers as there are other multiple factors responsible. Hayne et al., (2017) suggests that the construction industry needs to evaluate the effectiveness of graduate training programmes to ensure that suitable on-site experience is gained, otherwise there is a danger that the principles of eliminating design hazards that are enshrined in the CDM Regulations will not be achieved. Howarth et al., (2000) identified that a survey of civil engineers found that an issue commonly raised was the lack of understanding of the CDM Regulations. Also, the abolishment of the role of the CDM Coordinator in CDM 2015 has further split the responsibility of health and safety between the client, principal designer and contractor. CDM Regulations provide a broad spectrum of responsibilities for designers to design a facility that is safe to construct, maintain, use and demolish. However, there are trade-offs between designing a building to be safe to construct and designing a building that is safe to operate. Some design decisions that improve health and safety during operation and maintenance of a building could increase some risk in the construction phase. Therefore, Lingard et al., (2013) suggest that SiD policy documents and guidance notes should provide practical guidance on how to identify and manage conflicts and trade-offs in reducing health and safety risks across the life cycle of a project.

There are existing criticisms of CDM 2015 regarding the lack of legislative guidance and lack of clarity for designers (Carpenter 2016); same issues raised by Gambatese et al. (2009) regarding CDM 2007. The lack of guidance on best practice from the HSE makes it difficult for projects to be benchmarked against best practice criteria which could help designers manage risk to an acceptable level. Such guidance would also be useful for scoring the safety of the design in terms of build, use and maintenance similar to the BREEAM sustainability rating matrix. Carpenter (2016) suggests that guidance is therefore required in order to establish acceptable risk in a project and with proportionate response.

Research shows that designing to eliminate or reducing the impact of hazards should be given higher priority than simply controlling a hazard within the worksite (Gambatese et al., 2008). The long-term benefit of implementing SiD results in lower construction costs and improved safety during construction, operation and maintenance. The use of design and build promotes partnership between the design and construction teams, thus providing a natural motivation to address safety in design. Haslam et al. (2005) further suggested that the use of design and build on a project could overcome the barriers to SiD because the responsibility of design and construction is assigned to one project team. Sacks et al. (2015) argued that the use of design-bid-build where there is a complex hierarchy of contractors and subcontractors may well limit the input the designers can have on the construction process. Design and build also have the capacity to limit the use of SiD because construction contractors may prioritise the need to maximise profit before the safety of the design. According to Bell (2017), the aim of construction contractors is to make projects as cost-effective as possible and therefore, they have less commercial interest in the manageability or running of a building.

Also, designers face conflicting priorities such as client requirements and cost which could impede the implementation of SiD. Pirzadeh & Lingard (2017) identified that there is a disconnect between design and construction functions because the absence of free and effective flow of information is still a major hurdle due to iterations made in the design. Collaboration and communication between the design and construction team facilitates SiD and Pirzadeh & Lingard (2017) indicate that the design of a project involves complex and dynamic interdependencies between activities and parties and this is best undertaken collaboratively; resulting in a better flow of knowledge (tacit and explicit) and information which reduces iterations and resolve inter-task issues. The adoption of Virtual Reality (VR) technology to facilitate dialogue or collaboration between the design and construction teams to overcome the difficulty of knowledge transfer has been highlighted by Sacks et al., (2015). Sacks et al., (2015) found that dialogue with construction professionals conducted while touring a virtual construction site improved designer's awareness and sensitivity of hazards with the designers openly expressing that some design changes will improve safety. This further emphasises the importance of close collaboration between designers and other construction professionals including Facility Managers (those in charge of use and maintenance) towards integrating SiD in designs (Bell, 2017).

The designers play a major role in securing the safety of maintenance workers for example, the location, design and size of plant rooms can reduce ergonomic hazards and working in confined spaces, (Stanford, 2010). Therefore, the adoption of design decision tools in the form of a mixed-media approach according to Hare et al., (2019) can aid designers in their statutory duty to identify, prevent and mitigate hazards emanating from their designs. Iterations and design changes are characteristic of the construction design process and this can be mitigated by improved information quality and reduced uncertainty in decision making (Pirzadeh & Lingard, 2017), and hazard identification should be repeated with every iteration to ensure hazard reduction (Hayne et al., 2017).

Table 1. Construction (Design and Management) Regulations - A Timeline

Time	Event	Rationale
June 1992	Temporary or Mobile Construction Sites Directive (TMCSD) adopted	
March 1995	The Construction (Design and Management) Regulations 1994 (CDM 94) come into force	To implement, in part, the TMCSD
Sept 1996	The Construction (Health, Safety and Welfare) Regulations 1996 (CHSW 96) come into force	
Late 1996 – 1998	Interim evaluation of CDM 1994	To establish stakeholders' views on implementation
Sept 2003	HSC agrees to revise the CDM 94 and CHSW 96 regulations (paper HSC/03/93 for the review)	To respond to industry's comments on the discussion document
April 2007	CDM 2007 Regulations come into force	
Oct 2010	Draft evaluation report of CDM 2007	Showed general improvement over CDM 94 with concerns remaining in areas of competence assessment, coordination and bureaucracy
Nov 2011	Publication of Löfstedt report – An independent review of health and safety legislation	Recommended that: - the CDM 2007 evaluation should be completed by April 2012 - HSE should review all ACOPs, although the CDM 2007 ACOP should be managed separately

April 2015	CDM 2015 Regulations come into force, HSE Legal Series (L153) guidance and industry guidance published

Aim

The aim of this study is to evaluate the implementation of SiD as part of the CDM Regulations and how it improves safety during use and maintenance of existing buildings. Buildings pre-CDM and post-CDM were visually inspected to establish how SiD has made buildings safer based on the requirements under the CDM Regulations. It is important to reaffirm that buildings pre-1995 may likely not have SiD implemented in the initial design but those retrofitted and refurbished after 1995 should have SiD implementations. The study adopted the use of a scoring matrix to assign scores for each of the public buildings based on ease of use and maintenance, through the identification of design hazards from inspections.

Benefits of SiD

The implementation of SiD can improve the safety and health of construction and maintenance workers and potentially benefit the end-users. For example, designing structural steel, plumbing, heating, ventilation, and air conditioning (HVAC) and electrical systems should take into account whether workers are required to install or fix such connections overhead or at an awkward position that could result in musculoskeletal injuries (Toole & Gambatese, 2008). The adequate consideration of ergonomic hazards during designs can also mitigate musculoskeletal injuries which often lead to lifetime disability and early retirement. Other benefits of implementing SiD is productivity improvement and Manuele (2008) alluded that it could decrease operating costs and avoidance of expensive retrofitting. Therefore, the design of the workplace, work task etc. are important considerations in accident causality and Hare et al., (2019) indicated that few designers in the UK embrace the principles of designing for occupational safety even though it is a requirement.

Method

A multiple case study approach was adopted to examine 12 public buildings selected through purposive non-probability sampling. The case study method explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information… and reports a case description and case themes (Creswell, 2013, p. 97). Multiple case study strategy was adopted (Fellows & Liu, 2015), using structured inspection to enable replicating same SiD ideas across several public buildings (Saunders, et al., 2012). The use of public buildings was profoundly due to accessibility issues to allow structured inspection to be undertaken by adopting the Likert scale scoring methodology to assess SiD issues within the buildings. The Likert scale was developed to score design hazards from 1-5 depending on the level of SiD implemented within the design. The significance of using the visual inspection was to identify design hazards using an adapted hazard identification checklist made up of 22 design hazards to produce an overall safety score for each building inspected, (Hare et al., 2019).

Sampling

The purposive non-probability sampling technique was used to identify twelve (12) key public buildings in London with the aim to have unrestricted access and to acquire relevant information through inspection as opposed to using private buildings with limited access for the study. Table 2 gives a description of the six categories of buildings used for this study (DWQR, 2007).

Table 2 – Description of the buildings inspected

Public Building	Description
Education	University – Postgraduate campus
	University – Institute of Education
Health Care	GP Surgery
	Dental Surgery
Hostelries	Restaurant
	Café
Exhibition	Art Gallery
	Museum
Sports	Leisure Centre
	Cinema
Miscellaneous	Jobcentre Plus
	Library

In the UK, a building is regarded as a public building if it is occupied by a public authority and frequently visited by the public. Two buildings per category were assessed to provide a reasonable sample size, although larger sample sizes would potentially have provided more depth and variance on the impact of SiD during use and maintenance.

Data Collection

Design hazard data was collected through structured observation and inspection (Saunders, et al., 2012), using a scoring matrix (Likert scale) that scores the quality of SiD implemented during the design phase by the designer, see Table 3. The use of structured observation as the data collection tool allowed the researcher to utilise inspection procedures as a measuring tool using predetermined template adapted from the design hazard identification list (Hare et al., 2019) to mitigate against observer bias. Using this design hazard identification list allows for replicability of the study and updating the repository for list of undocumented design hazards. The inspection process is a relatively smooth and quick process that can last between half a day or one full working day depending on the size, complexity and accessibility of the structure.

Table 3 - Description of the observation using Likert Scale scoring matrix

Scale	Definition	Description
1	Unacceptable	Nil or inadequate SiD implemented in design. Hazard is present
2	Poor	Poor attempt to design out hazard. Hazard present but mitigated through control measure
3	Acceptable	Hazard designed out using SiD; but design could have been improved
4	Good	Hazard avoided through good implementation of SiD
5	Excellent	Hazard avoided through excellent implementation of SiD in design.

*NA - Not Applicable to the building; *NI - Not Inspected

Inspection considerations included:

- Inspections conducted within normal opening hours of the buildings

- The researcher observed the interaction between people, processes, premises, plant and substances e.g. slippery floor and people, wall cladding and the cleaning process.
- Asking questions without disrupting work activities e.g. how the windows are cleaned - rope access or ladder
- Roofs visually inspected from the ground level
- Hazards and the existence and effectiveness of related control measures

Design hazards found during inspection were mapped on to the design hazard checklist to score individual buildings against the criteria (the quality of SiD implemented in design), see Table 4. Once a design hazard is identified, the researcher examines if control measures are put in place to reduce the risk of the hazard and scores the hazard using the Likert scale. These are then recorded on the inspection form.

Table 4 – Design hazard identification checklist

Design Hazard types	
1. Structural openings	12. Fragile surface/roof light
2. Lifting operation risks	13. Cleaning glazing
3. High-level light	14. Fall from ladder
4. Open edges	15. Confined space
5. Plant maintenance at height	16. Manual handling
6. Manholes in traffic route	17. Struck by plant/vehicle
7. Single-step trip hazard	18. Fire/explosion
8. Foyer entrance slip risk	19. Working using rope access
9. Clean/maintenance pitched roof	20. Small step trip hazard
10. Slip/trip on stairs	21. Hazardous Pinch Points
11. Large floor-ceiling heights	22. Fall from open edge

The procedure for scoring the buildings adopted the following steps:

Step one: Identify the hazards. For example, the building may not have curtain wall systems (non-structural cladding systems) therefore the hazard will not be inspected. This will vary from building to building.

Step two: Inspect and score the building. Inspect up, down, around and inside the building thoroughly and methodically. Score the design hazard using the Likert scale on the inspection form. Document inspected areas with photographs.

Step three: Repeat step two for all the hazards applicable to the building.

Step four: Calculate the final score. Add all the scores from the inspection. Divide the overall score by the number of hazards inspected to get the final mean score for each building, see Table 5.

Table 5 – Retrospective inspection of design hazards

Rank	Building	Identified Design Hazards (H)	Total Score (T) = Sum (H*Scale)	Ave. Score = (T/H)
1	Leisure Centre	19	83	4.4
2	University – Postgraduate Campus	14	53	3.8
3	Library	10	47	4.7
4	Art Gallery	12	44	3.7
5	University – Institute of Education	9	40	4.4
6	GP Surgery	8	30	3.8

7	Museum	8	28	3.5
8	Restaurant	8	28	3.5
9	Cinema	7	25	3.6
10	Café	6	24	4
11	Jobcentre Plus	8	23	2.9
12	Dental Surgery	5	15	3

This study acknowledges that certain areas in some of the buildings were not accessible for inspections due to security and other safety related issues. Therefore, to mitigate this problem and to acquire consistent and reliable data, the 22 commonly occurring design hazards was adopted for uniformity (Hare et al., 2019).

Findings and Discussion

The findings from the retrospective inspection of design hazards involving 12 buildings and the impact of SiD in their designs are shown in Table 5. A score of 1 indicates inadequate or no implementation of SiD and a score of 5 indicates excellent implementation of SiD in design. The average score for each of the building indicates the category of that buildings within the Likert Scale; from unacceptable to excellent SiD implementation.

Buildings pre and post-CDM

Table 5 show that the Library had the highest implementation of SiD (4.7) in the design which reflects in the use and maintenance of the building. The Jobcentre Plus had the least implementation of SiD (2.9) initiatives in the design and this directly impact on the use and maintenance of the building. The Art Gallery, Jobcentre Plus, Museum and Restaurant were the buildings with the highest design hazards within the scale of 1, i.e. inadequate SiD implemented in design with the hazards still present. The Jobcentre Plus was built before the introduction of CDM 1994 and ranked lowest amongst the 12 buildings inspected based on the inadequate attempt to design out hazards and the lack of adequate control measures. However, the Library built under CDM 2007 had excellent implementation of SiD i.e. level 5 within the Likert scale with practical hazards avoided.

The Leisure Centre was opened to the public in 2010 and the newest building from the list of 12 buildings inspected. Seventeen (17) of the design hazards at the Leisure Centre were classed between 5 and 3 while two design hazards were ranked at one on the scale (e.g. manhole in traffic routes). This suggest that the designer of the Leisure Centre holistically integrated SiD in the design of the building. The Leisure Centre, Library, GP Surgery, University, Café and Cinema all had average inspection score of above 3.5 per building. It suggests that designers of buildings post-CDM implemented SiD measures to an acceptable level through designing out the hazards, including the buildings that were retrofitted or refurbished. The Art Gallery which was formerly a power station was converted in 2000 to a public building. Although the construction work was under the CDM Regulations and the implementation of SiD should have been a requirement; the designers would have struggled to fully integrate SiD into the design as the building project commenced same time that the CDM 1994 Regulations was introduced. Therefore, the designers may have struggled to understand and incorporate SiD in their designs which thus limits full implementation of SiD. Also, research identifies that refurbishment projects are more difficult to manage than new construction works due to the high level of uncertainty associated with the works (Egbu, et al., 2002). The four least performing buildings (Museum, Restaurant, Dental Surgery and Jobcentre Plus) in terms of SiD implementation were all designed and built before CDM 1994 Regulations came into effect in the UK. With these four buildings, the inspection revealed that there was little effort on display regarding designing out the hazards during the build phase and the future use and maintenance of these buildings were not adequately considered. Inspection of buildings post-CDM suggests that the adoption of the CDM Regulations since 1994 has encouraged progressive steps toward implementing SiD initiatives by designers in the design of safer buildings.

Manholes in traffic route

The most common hazard to all the buildings was location of manholes in very busy locations (pedestrian and vehicular access routes). Eight (8) of the buildings were ranked on the Likert scale at 1 because the location of their manholes was in busy traffic and access routes; i.e. inadequate or no SiD measures implemented in design and the hazards are still present. The RIDDOR report 2018/19 indicated that 'struck by moving object' accounted for 10% of the entire non-fatal injuries to employees by most common accident kinds, and it is essential that the welfare of maintenance workers is addressed in the design including the location of major sewerage systems. Other issues with open manholes in some busy pedestrian areas was the lack of edge protection and this could result in disproportionate numbers of members of the public falling into such manholes. It is also important that designers review the site layout during the design phase as this could influence the planning and design of access or busy traffic routes away from such existing manholes.

Working at Height

In order to manage work at height, the task being carried out is required to adopt the hierarchy of controls, i.e. to avoid, prevent and mitigate if such a task cannot be carried out safely from the ground. The lack of implementation of SiD in some of the buildings could obviously result in falls from height with tasks involving high-level light fittings and fixtures, working near open edges, plant maintenance at height, maintenance involving large floor-ceiling heights, frequent use of ladders, and working using rope access. Four buildings were grouped at level one (1) on the Likert scale indicating inadequate implementation of SiD and the hazards that were visually identified from inspection had no control measures in place. One of the inherent risks identified included workers potentially falling through fragile pitched roof light with no preventive measures. Also, the use of mobile elevating work platforms (MEWPs) in the Museum and Art Gallery to perform some maintenance work due to extreme ceiling lighting heights presented its own challenges and hazards such as entrapment, overturning, falling and collision during MEWP deployment. These dangers typically arise from operation and use of the machine rather than from their movement as a site vehicle. Falls from height continue to account for a significant number of workplace injuries and fatalities every year. The inspections revealed that the use of leaning ladders and stepladders for jobs of a slightly longer duration was pervasive and guidance regarding compliance with the Work at Height Regulations 2005 (WAHR) regarding the use of ladders for low-risk, short-duration tasks was not enforced in some of the maintenance and repair works carried out. The buildings with high-level light also had issues with large floor-ceiling heights, thus presenting major risk of workers falling from height during the use of ladders. Six buildings were classed as level three (3) indicating that although the hazards were designed out, the design itself is still susceptible to further improvement.

Slips and trips

The installation of suitable flooring in buildings could potentially minimise the risk of slips and trips on surfaces that are used as main access or foyer areas in buildings. Maintenance of the floor (cleaning) can significantly cause slip and trips to both the cleaning staff and users of the public buildings and during rainfall most especially around entrances of the buildings. Instances of damaged and uneven block paved areas around entrances of the buildings were captured from the inspections and these could further aggravate the risk for trips and falls. The Workplace (Health, Safety and Welfare) Regulations 1992 require floors to be suitable for the purpose for which they are used and free from obstructions and slip hazards. The likelihood for slips (foyer entrance slip risk), trips and falls on same level or uneven surfaces was recorded in majority of the buildings inspected. The imbalance of work equipment from uneven surfaces could also impact maintenance work and result in accidents.

Location of plant rooms

The plant room which is also referred to as the mechanical or boiler room contains the equipment that majorly provides the building services including but not limited to water, electrical distribution, and ventilation. The size and design of the plant room reflects the size and complexity of the structure and the requirements of the building services. There was restricted access to inspect nine (9) of the plant rooms due to their location and other safety related issues. Two (2) buildings however granted partial access while one (1) granted full access to inspect the plant room situated on the ground floor. The two buildings that granted restricted access due to health and safety risks had their plant rooms located on the roof of the buildings. The record of inspection noted issues related to ease of access for maintenance crew and the possibility of replacing larger equipment and expansion would prove difficult because of the location and size of the rooms. However, the Library building which was redesigned in 2009 indicated evidence of integration and implementation of SiD under the CDM 2007 Regulations with the plant room located on the ground floor. The designer of the Library complex considered SiD in the design of the plant room from build, use, safe maintenance and future expansion capabilities. The Jobcentre Plus which is classed as the least functional buildings amongst the 12 buildings inspected was built pre-CDM Regulations and SiD was not legislation driven at that time. This therefore highlight the significant differences in the ways safety related issues were addressed in the design of the plant room.

Conclusion

The most common hazard was the risk of slips, trips and falls at the entrance of the buildings resulting from cleaning or when it rains. There was poor attempt to design out this hazards in ten (10) of the buildings but these were mitigated in some instances through adequate control measures. However, two of the Grade 2 listed buildings that were refurbished had no mitigating control measures put in place to reduce slips and trips. It further reinforces the suggestion that designers struggle to fully incorporate SiD in their designs in refurbishment projects when compared to newer projects. This study reveal that there are significant variations in the implementation of SiD in buildings built pre-CDM and post-CDM. Eight of the buildings inspected exceeded the threshold of an acceptable integration of SiD in designing out the hazards or avoiding the hazards through excellent implementation of SiD by adopting the principles of prevention. The findings suggest that the adoption of CDM Regulations positively encouraged the use of SiD and buildings built post-CDM 1994 are safer to use and maintain than older buildings pre-CDM that had minimal or no SiD integrated during the initial design and build. The inspection show that the refurbished buildings had low safety ranking compared to buildings designed and built with full integration of SiD. There are still divisive opinions in terms of SiD integration in designs as some designers still contend that the design statement of a building overrides any of the safety concerns. Overall, the incorporation of SiD in the refurbishment of public building stock can potentially enhance the safety of such buildings for maintenance workers and users. The internal areas of refurbished or retrofitted buildings ranked highly on the Likert scale but the external areas e.g. the entrance to the buildings, external wall window systems and location of manhole chamber/access shafts ranked very poorly. The buildings post-CDM that integrated SiD from the conceptual phase of the projects were considered significantly safer. This study therefore recommends the integration of mixed media digital tool to improve designers' knowledge of SiD and also provide alternative design options that could prevent hazards emanating from their designs.

Limitations of study

The sample size of twelve (12) inspected buildings should be increased to improve the validity of the study and the focus of this present study which is London-centric should reflect other parts of the UK. Therefore, findings from the study based on sample size is too small to generalise to all public buildings in the UK. The restricted access to some parts of the public buildings for inspection hindered the acquisition of other relevant information that could improve industry practice.

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