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Improving the reliability of visual inspections conducted by environmental health and safety professionals, on a hyperscale data centre construction site

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The conduct of visual inspections on construction sites is of crucial importance for workplace safety. This is because visual inspection is the primary method by which construction site hazards are routinely observed, monitored and controlled. However, there is no consensus guidance as to how such visual inspections should be conducted. This is resulting in many observable hazards going unseen and therefore not being appropriately managed on construction sites worldwide. In an attempt to improve the reliability of visual inspection, this study presents results from an innovative method called systematic visual inspection which utilises an iterative set eye scan pattern during observation. In this study using one construction site, systematic visual inspection is compared with custom and practice visual inspections conducted by four environmental health and safety professionals (EHSPs) and four senior site managers. The results were as follows; the lead investigator who used the systematic visual inspection method observed a mean 37.70 hazards per inspection (SD=40.92). In sharp contrast, the mean number of observable hazards identified by EHSPs per inspection was 11.94 (SD=13.51). For site managers, the results were 10.87 per inspection (SD=12.40). This improvement in hazards observed by the use of the systematic visual inspection method was highly significant (p=<.001) and with a large effect size as measured by Cohen's d. In conclusion, this study presents evidence to support the use of systematic visual inspection as a method of improving the observation of construction site hazards during visual inspections.

Keywords: Systematic, Visual, Inspection, Observation, Reliability, Hazard, Identification, Construction.

1. Introduction

The European Union's construction sector is crucially important from an economic perspective. However, it remains a hazardous work environment as recent data illustrates. In 2018, construction work represented the largest sectoral cause of EU fatalities at over 21% together with 296,800 non-fatal accidents and 591 fatal accidents (Eurostat, 2019).

In order to provide safe workplaces, EU safety related legislation under the framework and daughter directives, mandates for a preventative ethos. This requires hazard identification, prior to risk evaluation and subsequent controls designed to appropriately manage all construction hazards (EU 89/391/EEC, 1989; EU 89/654/EEC, 1989). The resultant risk assessments are the embodiment of this preventative approach to appropriately managing workplace safety on construction sites.

The importance of hazard identification, which lies at the very heart of these risk assessment and related safety audits, cannot be understated. As Aven, (2011 pp62); Carter & Smith, (2006); ILO, (2014) all axiomatically state; an unidentified hazard cannot be appropriately managed. Therefore, the visual inspection phase of the risk assessment process is of crucial importance in order to minimise the non-observation of construction site hazards.

However, it remains that the principal method of identifying construction site hazards being the visual inspection, has not received the academic attention its importance deserves (Liao Sun & Zhang, 2021; Zhang et al, 2017). But recent construction safety related research has begun to investigate visual inspection performance. This published evidence reports that hazard observation performance on construction sites needs to improved (Albert et al, 2014 & 2017; Bahn, 2013; Perlman 2014; Liao et al, 2021; Zhang et al, 2017).

In particular, Albert Hallowell & Kleiner, (2014) and Albert et al, (2017) demonstrated visual search reliability limitations in a study of construction site personnel observing, recognising and recording workplace hazards for

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safety purposes. Even though as pointed out by Liao et al, (2021) and Zhang et al, (2017) the ability to recognise construction site hazards is of paramount importance, studies have noted that the recognition of construction site hazards was found to be between circa 32% and 38% Albert et al (2014 & 2017).

There is however, an innovative visual search method that has the potential to increase the observation of construction site hazards. This method called systematic visual inspection, has demonstrated its ability to significantly (p=<.001) improve visual inspection performance in food production (Hrymak & deVries, 2020) and aircraft maintenance (Hrymak & Codd, 2021). This study presents the findings from applying this novel systematic visual search method to the observation of hazards on a hyperscale data centre under construction.

There were two research questions formulated for this study. The first was to investigate what was the current rate of construction site hazard observation by existing Environmental Health and Safety Professionals (EHSPs) and site managers, when they conducted their visual inspections. The second research question was to see if this innovative systematic visual inspection method could improve on hazard observation rates for the same construction site.

1.1 Hazard identification in construction

Risk assessment is a two-step process that combines hazard identification with an evaluation of the risk from these hazards (IEC 31010, 2019). There are currently over 800 separate risk assessment methods published as detailed by Mariken et al, (2013). Summarised overviews of the main risk assessment methods that can be used for construction sites are well detailed for example by, Gould et al, (2005); IEC 31010, 2019; Marhavilas Koulouriotis & Gemeni, (2011); Tixier et al, (2002).

But whilst risk assessment and the closely related concept of safety auditing is accompanied by abundant guidance (for a construction related example see ILO, 2017) how safety professionals actually conduct visual inspections for construction related risk assessments is still not well detailed in the literature (Liao et al, 2021; Zhang et al, 2017).

Extrapolating from published construction safety research as exemplified by Albert et al (2014 & 2017); Bahn, (2013); Carter & Smith, (2006); Laitinen & Päivärinta, (2010); Moore et al, (2001); Woodcock, (2014); Zhang et al, (2017) these risk assessments will typically include identifying hazards at the design and planning stage as well as during visual inspections conducted by EHSPs and site managers. Checklist use is also ubiquitous in the wider EHS community as a hazard identification method (Clift et al, 2011; Neathey et al, 2006). In this study it was noted that checklists were also utilised by EHSPs during their visual inspections (see section 2.2).

1.2 Systematic visual inspection

Systematic visual inspection fundamentally alters the approach to current visual inspection custom and practice. It requires the application of a very proceduralised visual search behavioural algorithm for any area or object under analysis. It is a three-step iterative process that begins with the user selecting a precisely defined area or object under analysis for example, a room. The user is then required to break down this room into its main constructional elements which will typically entail the ceiling, four walls and the floor. Each of these elements are then selected in turn for individual observational analysis, using a specific eye scanning strategy to ensure a meticulous and exhaustive visual search.

The eye scanning strategy used in this study is best described as the "reading a book" pattern. The user is directed to imagine the element selected has an overlay of words written onto its surface. The user is then required to "read" the element in the same was as reading a page in a book. Using the wall as an example, the user will first fixate their gaze in the top left-hand corner of the wall. They will then scan along the wall until their vision reaches the right-hand side of the selected wall. At this point, the user returns their gaze to the left-hand side of the wall, underneath the area already observed. Eye scanning to the right then continues until the entirety of the wall is observed. Further detail on how systematic visual search is conducted together with suggested eye scan strategies can be found in

Hrymak & deVries, (2020) and Hrymak & Codd, (2021).

The time needed to master systematic visual inspection is not onerous. As found in the Hrymak & Codd, (2021) study from the aircraft maintenance sector, proficiency can be achieved after practicing the method about three times with feedback. The total times taken to train users in that study was under five hours. This consisted of; 40 minutes initial instruction, followed by three additional practice trials taking 120 minutes and 120 minutes of instructor feedback.

In summary systematic visual inspection can be considered an innovative visual search behavioural algorithm. It represents an easily mastered skill and can be considered a development on current visual inspection custom and practice by EHSPs

2. Methodology

The datacentre under analysis in this study is located in a Northern European country, and data was gathered between September 2021 and February 2022. The datacentre is 30 Hectares in size and employed between 300 and 500 site operatives during the study. Construction of datacentres typically consist of units that are progressively built and handed over to clients whilst further units are built. During the study period; one unit was complete, two units were undergoing internal fit out, two units were used for construction materials storage, and groundworks were being undertaken throughout the site in preparation for external electrical back-up systems. Fig 1 below, illustrates a typical data centre in the final stages of construction.

Fig, 1. A typical data centre

The lead investigator, is a part time PhD candidate in the school of Food Science & Environmental in TU Dublin. He is also a qualified safety and electrical engineer with five years experience and employed by the main contractor as an EHSP. He conducted 27 visual inspections using the systematic visual inspection method for the entire site, as described in section 1.2 above. The time taken for the lead investigator's visual inspections varied between one and three hours, dependant on site conditions and activities encountered.

There were between two and four further EHSPs also employed by the main contractor on the construction site at any one time, dependent on the total number of employees present. These EHSP visual inspections were conducted in the following manner. Each inspection included walking through the entire site and included asking questions and reading any relevant site documentation. Based on the level of risk encountered, certain site activities were often prioritised by these EHSPs for specific attention for example; heavy lifting, work at height or excavation. All EHSPs used various checklist type forms for recording observed hazards. Once these forms were filled in with any accompanying photographs, they were inputted into the site safety database. In total, four EHSPs conducted 18 visual inspections during the study period. The time taken for these visual inspections varied between half an hour and two hours.

The site managers performed their visual inspections in the same general manner as EHSPs but differed in that not all the site was accessed. Instead site managers concentrated on specific site activities or problems arising such as locations with a lack of expected progress, or commissioning issues. As a result, it was difficult to ascertain the time taken for these visual inspections accurately. In addition, site managers tended to use far more photographs of hazards observed when filling in these checklist forms. Nevertheless, these site managers walked their areas of choice and thereby conducted visual inspections recording and photographing any hazards they observed. In total four site managers conducted 15 visual inspections during the study period. All visual inspections on the construction occurred within 1 to four days of each other and EHSPs and site managers were aware that the lead investigator was conducting construction site safety research.

In summary, the experimental design was correlational in nature within a naturalistic research environment (Breakwell, Smith & Wright, 2012). In addition there was a high degree of ecological validity with regard to the data elicited from EHSPs and site managers, all of whom had at least five years of post-qualification construction site experience.

2.1 Construction site hazards observed

The lead investigator was able to access the main contractor's database. This detailed the number and type of all hazards observed and recorded during the study period by the lead investigator, EHSPs and site managers. All data was subsequently inputted into Excel and SPSS v23, by the lead investigator, allowing the mean number of hazards observed with standard deviations to be subsequently calculated, together with an independent *t* test (see Section 3). This database also allowed for the observed hazards to be categorised into six constructs as detailed in Table 1 below.

Table 1, Site hazards observed

Category	Examples
Behavioural	Accessing restricted areas
	No fall protection
	Damaged equipment
Electrical	Bypassing lock outs
	Working live
Fire Safety	Blocking exits
	Fire doors left open
Environment	Not segregating waste
	Not recycling waste
Site Transport	Speeding
	Not using set traffic lanes
Housekeeping	Leaving work sites untidy
	Incorrect storage practices
PPE	Not wearing PPE
	Ill-fitting PPE

2.2 Limitations

Potential bias could have been introduced due to the lead investigator's motivation and level of experience in using the systematic visual inspection method. His involvement in the study may well have positively influenced the number of hazards he recorded. The use of inter-raters was not possible in this study, making the resultant data derived from the systematic visual inspection method reliant on one investigator. The lead investigators level of experience in the use of the systematic visual inspection method, could also have been a factor with Hrymak & Codd, (2021) reporting an increase in observed hazards (defects in their study) from practicing the systematic visual inspection method.

Another consideration is the influence of checklist use by EHSPs on visual inspection conduct. The question here is what form of visual search resulted from checklist use. Taking for example one particular required category from a checklist used on the study site being; work at height practices. Did the EHSPs specifically observe all work conditions and behaviours before filling in any work at height hazards observed under this category. Or did EHSPs use the checklist as an aide-memoir and follow the categorical order given in these forms. EHSPs could also have used a combination of both these visual search strategies.

Furthermore, did these checklists sufficiently capture all site hazards observed. If a hazard was resolved on observation by the EHSP for example, asking an employee to tidy up his working area, this housekeeping hazard may, or may not have been recorded. Similarly, subjectivity regarding a particular hazard may have played a part. Some EHSPs for example may, or may not have considered the level of untidiness observed as a hazard. The lead investigator is currently investigating these checklist issues, using semi structed interviews framed within an interpretative phenomenological research perspective (Smith Flowers & Larkin, 2009).

In addition, the visual inspections by the lead investigator, EHSPs and site managers were not conducted simultaneously. Therefore, the results precluded a direct comparison of all particular site hazards observed. This is due to the dynamic nature of construction risk meaning that site hazards fluctuate on a daily basis. Importantly though, the lead investigator in accessing the entire site during his visual inspections, did cover all areas observed by his EHSP and site manager colleagues.

Therefore, this study was ecologically valid and had a good sample size. In particular, the experimental design is considered to have produce good quality data to inform the two research questions set being; how many construction site hazards are typically observed and can this important safety related metric be increased. In short, this study investigated the number of observable hazards typically seen on a large data centre construction site by EHSPs and site managers using their normal custom and practice visual inspection conduct. This allowed for a comparative analysis of observed hazards between the visual search strategies utilised by EHSPs, site managers and the lead investigator.

3. Results

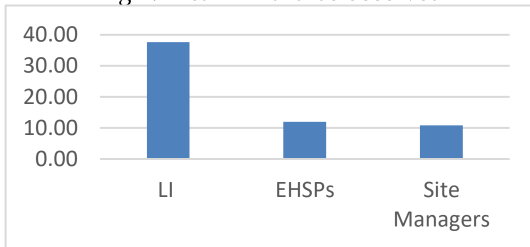
The mean number of observable hazards identified by the lead investigator using the systematic visual inspection method was 37.70 per inspection (SD=40.92). In sharp contrast, the mean number of observable hazards identified by site EHSPs per inspection was a mean 11.94 (SD=13.51). For site managers, the results were 10.87 per inspection (SD=12.40) The comparative results between systematic visual inspection and EHSPs were also highly significant (p=<.001) using an independent t test and returned a large effect size as measured by Cohen's "*d*" (Field, 2013). The difference in the mean number of hazards observed per inspection between the EHSPs and site managers was not found to be significant. These results are summarised in Table 2 below.

Table 2. Mean N hazards observed

Systematic Visual Search	EHSPs	Site Managers	*p*	Cohen's *d*
37.70	11.94	10.87	<.001	1.91

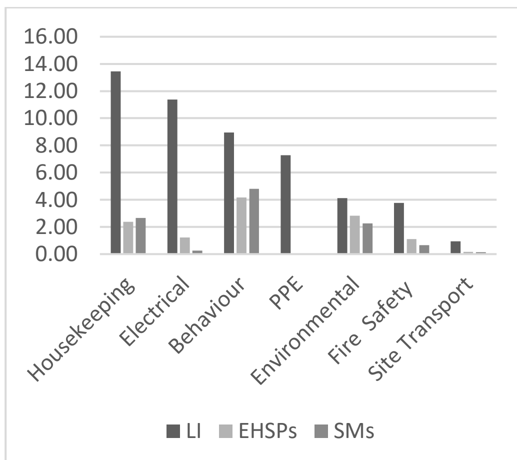
A graphical representation between the lead investigator (LI), EHSPs and site managers (SMs) is shown below in Fig 1 below. This bar chart illustrates how the lead investigator using the systematic visual inspection method, observed just over three times the number of construction site hazards per inspection when compared to his EHSP and site manager colleagues.

Fig 1. Mean N hazards observed



A further noteworthy finding is the differences in the number of site hazards observed when categorised into constructs as seen in Fig 2, below. This bar chart demonstrates not only the variability in the number of hazards observed between the lead investigator, EHSPs and site managers, but also the type of hazards observed.

Fig. 2 Mean N hazards observed by construct



4. Discussion

The data in this study was generated under ecologically valid and naturalistic correlational research conditions. The findings demonstrated that the systematic visual inspection method can significantly increase the observation of construction site hazards during visual inspections (p = <.001). This study further supports earlier research (Hrymak & deVries, 2020; Hrymak & Codd, 2021) whereby the observation of hazards was similarly improved using this innovative visual search behavioural algorithm.

The lead investigator who used the systematic visual search method in this study observed just over three times the number of hazards compared to his EHSP and site manager colleagues. Although empirical in nature, this particular multiple is not of primary importance. Given that this investigator was in effect, getting used to the method in the first month of its application, his final mean observed hazard rate per inspection could well have been higher. Therefore, of more importance is the data supporting the theory that the reliability of visual inspection conduct on construction sites, can be improved by using systematic visual inspection.

Concern regarding the reliability of current construction hazard observation practice is not new as exemplified by Albert et al, (2014 & 2017); Carter & Smith, (2006); Liao et al, (2021); Moore et al, 2011; Perlman Sacks & Barak, (2014); Zhang et al, (2017) who all report similar reliability concerns in construction related visual inspection conduct. There is also further evidence from the wider visual search literature (for example see; Biggs Kramer & Mitroff, 2018; Biggs & Mitroff, 2014; See, 2012) that not seeing observable hazards during visual inspections are not isolated occurrences.

Together, these scholars have long reported evidence that such visual search tasks are in fact, error prone and difficult to do well. The many and varied causes of visual search error are detailed by Eckstein, (2011); Hrymak & deVries, (2020); See, (2012). This published evidence is in contrast with a widely held but erroneous assumption that visual inspections have a level of intrinsic accuracy, that can be relied on (Woodcock 2014).

The question marks raised over the reliability of current visual inspection reliability for construction site safety, strengthens the case for the better proceduralisation of the visual inspection task in order to improve the quality of resultant risk assessments. In this regard, the use of systematic visual inspection as described in this study offers for the first time, a proceduralised and evidence based potential standardisation of the visual inspection task for construction site safety. This visual search behavioural algorithm can also be used in conjunction with research from Albert et al, (2014 and 2017), who also successfully increased the observation of construction site hazards by using innovative training intervention methodologies.

Finally, it should clearly be borne in mind that the findings from this study are not in any way a critique of the EHSPs or site managers detailed on this study site or in the wider safety community. It cannot be overstated that the results from this study reflect cognitive limitations we all possess as humans, and that manifest themselves during any visual search task undertaken. (Eckstein, 2011; Hrymak & deVries, 2020; See, 2012). The aim of this study has always been and remains, to improve visual inspection reliability which by necessity will involve presenting data on current visual inspection performance for comparative analysis. Therefore, the lower mean number of hazards observed by EHSPs and site managers relative to the systematic visual search user should not be viewed in a negative sense. Instead, this study reports on a visual behavioural algorithm which if used, has the potential to increase hazard observation by EHSPs and sites mangers thereby improving construction site safety.

5.0 Conclusions

Hazard identification in the construction industry is of crucial importance for risk assessment and safety auditing purposes. This sector has an unenvious safety reputation as borne out the number of accidents and fatalities on construction sites worldwide. Clearly, any improvement in the very fundamental requirement of all workplace risk assessments and safety audits, that of the visual inspection, should therefore be welcome.

The adoption of systematic visual search will be beneficial not only for construction workers, but also from the economic and productivity benefits that will result from reducing site accidents and fatalities. As shown in this study, the number of observable hazards on construction sites can be increased by using the systematic visual inspection method which can only benefit safety in the construction sector.

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