The Application of Eye-tracking Technology in Architecture Engineering and Construction Industry: A Systematic Review

Abdul-Majeed Mahamadu[ab], Abhinesh Prabhakaran[a], Kait Clark[c], Krzysztof Dziekonski[a], Udonna Okeke[d], Wenhao Zhang[d], Clinton Ohis Aigbavboa[b] and Paul Matthews[e]

[a]Department of Architecture and the Built Environment, University of the West of England, Bristol, UK
[b]Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg
[c]Department of Health and Social Science, University of the West of England, Bristol, UK
[d]Department of Engineering Design and Mathematics
[e]Department of Computer Science and Creative Technologies

E-mail: abdul.mahamadu@uwe.ac.uk , abhinesh2.prabhakaran@live.uwe.ac.uk, kait.Clark@uwe.ac.uk, krzysztof.dziekonski@uwe.ac.uk, udonna.Okeke@uwe.ac.uk, wenhao.Zhang@uwe.ac.uk, caigbavboa@uj.ac.za, paul2.matthews@uwe.ac.uk

Abstract

Despite the scholarly attention on eye-tracking technology in the AEC industry, no studies thus far have attempted to aggregate the findings or knowledge. To bridge this gap and to better understand the state-of-the-art of eye-tracking technology's application in the AEC industry, this study reviews and synthesises the existing research evidence through a systematic review. Such a review is highly critical in this area, given the vast number of published work albeit a lack of aggregation of the findings and knowledge. A full range of journal articles between 2010 and 2020 (inclusive), that address the application of eye-tracking technology in the AEC industry was systematically assessed after a thorough search of key academic databases. Based on rigorous inclusion and exclusion criteria, 18 eligible articles were selected for final review. This study develops a generic taxonomy built upon a wide range of Scholarly journals. Further, the eligible literature was classified based on this taxonomy and presented.

Keywords – Eye-tracking, construction, human-behaviour, visual search

1 Introduction

Despite being one of the largest industries in the world economy, Architecture Engineering and (AEC) industry has persistently displayed a poor productivity index [3]. Modernisation and resulting in poor human performance were once the biggest challenge faced by the AEC industry [38]. However, in recent years the AEC industry has been constantly exposed to the advancements in digital information and technology leading to the development of innovative tools and processes. Eye-tracking technology is one of such technological advancements embraced by the AEC industry recently. The use of eye-tracking technology equips the industry with the ability to measure various gaze metrics and visual behaviour that can provide unique insights into human behaviours, which are otherwise impossible to measure using subjective tools [42]. This exciting opportunity offered by eye-tracking technology has attracted the attention of a growing number of researchers from the AEC domain.

Apart from the application of eye-tracking in aviation, driving, marketing, neuroscience, psychology etc, various studies (e.g., [10] [29] [11]) have reported that eye-tracking technology can be highly beneficial in building design, construction, and operation activities such as safety assessment, site inspection, space planning design evaluation, assessment of visual acceptability of design and ergonomics. Thus, eye-tracking technology's application in the AEC industry belongs cannot be over-emphasised. However, some studies (e.g., [42]) have pointed out that, the wider utilisation of eye-tracking technology in the AEC still faces challenges due to lack of knowledge about opportunities and complexity of the technology as well as associated methodologies for its effective use. To bridge this gap and to better understand the state of the art of eye-tracking technology's application in the AEC industry, this study reviews and synthesises the existing research evidence through a systematic review. Such a review is highly critical in this area, given the vast number of published work albeit a lack of aggregation of the findings to understand the knowledge domains.

2 Eye-tracking Technology

The human retina is bombarded with a vast amount of visual information as they move through a rich and complex environment in everyday life. In this complex environment, the human brain uses a mechanism called *selective attention* by which the brain selects and focuses on a few important areas for cognitive and visual processing [30]. Thus, tracking eye movement offers a direct way to measure overt spatial attention, cognitive process and arousal, providing a direct window into the brain [4]. Eye-tracking is a sensory technology that makes it possible for a computer or other device (screen-based, glasses or virtual reality-based) to understand where a person is looking based on optical tracking of corneal reflection, thereby making the analysis of eye movements and gaze positions in both 2D and 3D environments [40]. Through the utilisation of eye tracking, it is now possible to acquire unique insights into human attention and what information is processed, which could provide a deeper understanding of what affects human behaviours, decisions making and emotions. This provides both qualitative and quantitative analysis of the gaze, which is highly valuable in understanding human choice behaviour and perceptual decision making [4]. Initially used by psychology researchers in human behaviour research followed by marketing research, eye tracking gradually caught the attention of researchers from a wider domain like engineering, neuroscience, medicine and so on. For example, [1] used eye-tracking to understand how the gaze pattern of craft workers are influenced by the information format (2D and 3D) and spatial cognition which building complex spatial tasks. [36] utilised eye-tracking to evaluate the spatial orientation of attention, performance in visual tasks, the user's reaction to information presented on websites, and the emotional and cognitive impact of various spurs of the brain. Similarly, in the medicine domain also studies (e.g., [5]) have utilised the ET to understand the decision making and the mechanism underlying misinterpretation of a misdiagnosis. Beyond studies based on basic visual search, eye-tracking technology has also been of interest to the broader research community with applications ranging from saliency models of visual content analysis [22], design evaluation [6] usability studies [35], as well as by gaming industry [18].

3 Eye-tracking Technology in AEC Industry

Even though eye-tracking has been widely used for decades in vision research, language and usability studies, in recent years a greater interest has been witnessed by the researchers from the AEC industry. This could be because of the lagging productivity in the AEC industry which is mainly attributed to the issues related to human factors, where eye tracking can provide greater insights into human behaviours and cognitive processes, which is impossible to elicit using subjective measures. For instance, studies [29] suggest that human error is one of the main factors contributing to 80% of construction site accidents due to the lack of situational awareness. Apart from the pain, suffering and distress, these accidents and fatalities pose a considerable amount of economic burden on this sector. Estimates suggest that in the UK alone, the annual cost of the injuries exceeds 1.2 billion which accounts for 8% of the total cost across all industries as well as 2 million working days [21]. With the use of eye-tracking, it is now possible for the researchers to objectively study the role of cognitive failures (i.e., inattentiveness) in accidents and improve construction safety training based on these data. Similarly, eye tracking can assist architects and designers to design and develop complex buildings and potentially reduce the cost by understanding human behaviours and creating human-centric designs [37]. The application of eye-tracking in the AEC industry is not only limited to areas related to visual search patterns. For instance, [32] used a similar approach to understand end-user satisfaction in a building design. Further, studies (e.g., [11]) have also used eye-tracking to understand the problem-solving persons of civil engineering practitioners. Cumulative evidence shows that eye tracking has huge potential in the AEC industry. However, when compared to the application of other emerging technologies like virtual reality and augmented reality, a dearth in research can be seen in relation to eye tracking in the AEC industry. [42] point out wider utilisation of eye-tracking technology in the AEC still faces challenges due to a lack of knowledge about the complex eye-tracking metrics and potential of this technology. Thus, this study aims to reviews and synthesises the existing research evidence and aggregate those findings and knowledge for future studies.

4 Methodology

To comprehensively explore the role of eye-tracking in the AEC industry, a systematic review was conducted supported by both descriptive statistics and qualitative analysis of content. The additional qualitative data analysis was carried out to identify thematic areas of the application of eye-tracking in the AEC industry. A qualitative methodology is best suited for this study as it will aid in identifying findings from various studies on the subject area that will aid in achieving greater understanding and accruing a higher level of conceptual or theoretical knowledge of how eye-tracking technologies are evolving in AEC research [7]. The research stages in this study consist of *a)* identification of journals *b)* review of journals *c)* definition of classification framework *d)* classification of journals based on the framework.

To identify suitable literature an inclusion and exclusion criteria were developed for this study which aims in answering two key questions: *a)* " Is the study relevant for the review purpose?" *b)* "Is the study acceptable for review ?" as proposed by [31] (p.22).This laid fountain for the development of reliable inclusion and exclusion criteria. Even though a reliable inclusion and exclusion criteria might reject a large proportion of the literature, it promises a quality systematic review [8].

4.1. Inclusion and Exclusion Criteria

- Articles published between 2000 and 2020 (inclusive) were only considered to maintain currency.
- Articles that utilise eye tracking in the AEC industry was only considered
- Only peer-reviewed journals were considered for this study to maintain a predetermined threshold of quality. Conference papers, book chapters or non-international journals were excluded, thus satisfying the best evidence principle proposed by [43].
- Literature that discusses theory, concepts or proposals without any experimental testing were also excluded.

This study utilised a four-stage approach (Figure-1) based on the preferred reporting items for systematic literature review and meta-analysis (PRISMA) framework [33] and the inclusion-exclusion criteria were applied to identify relevant literature. Two prominent databases (Scopus and Science Direct) within the construction engineering and management domain were chosen to identify the eligible literature. Figure 1 explains the four stages of the literature selection process. The search criteria used to identify the literature within the scope of this study were: *("Eye-tracking") AND ("AEC" OR "Construction" OR "Engineering" OR "Architecture").* A total of 18 articles were identified as eligible for the final qualitative synthesis of this study.

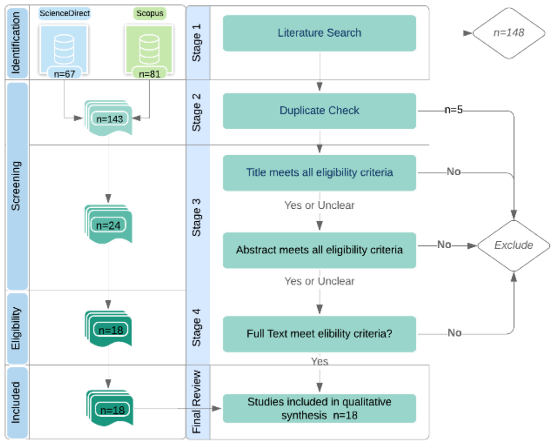


Figure 1- Literature Selection Process

5 Findings and Discussion

5.1. Framework for classification of literature

A grounded theory method [11] which is an emerging methodology popular in the categorisation of literature in ICT [44] was used in developing the classification framework (Table-1) that aided in the effective comprehension and segregation of the eligible literature as indicated in Figure 2. For definitions of all the eye-tracking metrics mentioned in Table 1, refer to [20]. Figure 3 further presents the yearly publication of literature based on the eye-tracking application between 2000 and 2021 (inclusive). Figure 2, reveals that the majority of the studies have explored eye tracking in construction safety (CS) (66.67%), followed by architecture (Arc) (16.6%), building services (MEP) (11.11%) and engineering education (EE) (5.5%). A higher number of literature in CS is because, as human error is the reason for 80% of the accidents in the construction industry, studies have shown that eye tracking can provide greater insights for the researchers to understand the factors that lead to human errors using reliable objective measure [29]. This also supports the findings from the task classification of the literature which revealed that the majority of the literature used eye-tracking to understand humans' ability to recognise hazards i.e., even more, important in construction where 57 % of site hazards remain unrecognized due to human error [45] [46]. It also revealed that the majority of the studies (66.6 %) were conducted in a laboratory setup. This could be due to the fact that in a real-site condition, the dynamic nature of the construction site poses a number of limitations for safety management and experimental stimuli that are difficult to overcome. However, experiment setups in laboratory conditions also pose limitations when the stimuli used are planar. Subtle environment factors like noise, lighting conditions, task and equipment movements are impossible to replicate in the laboratory and real site [45].

Table 1 Categorisation Framework

Dimensions	Categories
Utilisation Area	Construction Safety (CS); Engineering Education (EE); Architecture (Arc); Building Systems (MEP)
Task	Hazard Identification (HzD); Decision Making (DM); Situational Awareness (SA); Design Review (DR); Building Inspection (BI); Building Maintenance (BM); User Experience (UX);
Condition	Laboratory; Field
Sampling Rate	60 to 500
Eye tracker Technology	Screen Mounted (SM); Wearable Glass (WG); Virtual Reality Eye Tracking (VRe)
Stimuli Type	On-Site, 2D Based, Immersive Virtual Environment
Eye Tracking Metrics	Fixation Count (FC); Dwell Time (DT); Saccade (SC); Scan Path (SP); Pupillary Response (PR); Fixation Duration (FD); Fixation Time (FT); Blink Duration (BD); Blink Rate (BR); Attention Map (AM)

Further, this study also reveals that the majority of the studies (55.5.%) used two-dimensional stimuli. However, using planar stimuli reduces the dimensionality that could lead to the simplification of the stimuli representation, resulting in distorted visual search patterns yielding misleading eye movement data as opposed by [29]. Thus, utilisation of an immersive virtual reality environment would be an ideal solution as the development of high-fidelity virtual environments that can evoke experiences in users that are similar to real-world are now possible using various game development engines. Further, this study revealed that a wearable glass-based eye tracker was mostly used for the experiments. Even though these eye trackers are costly than screen-based ones, the data reliability is higher as well as it is easy to control noise creating factors like lights for wearable eye trackers [34].

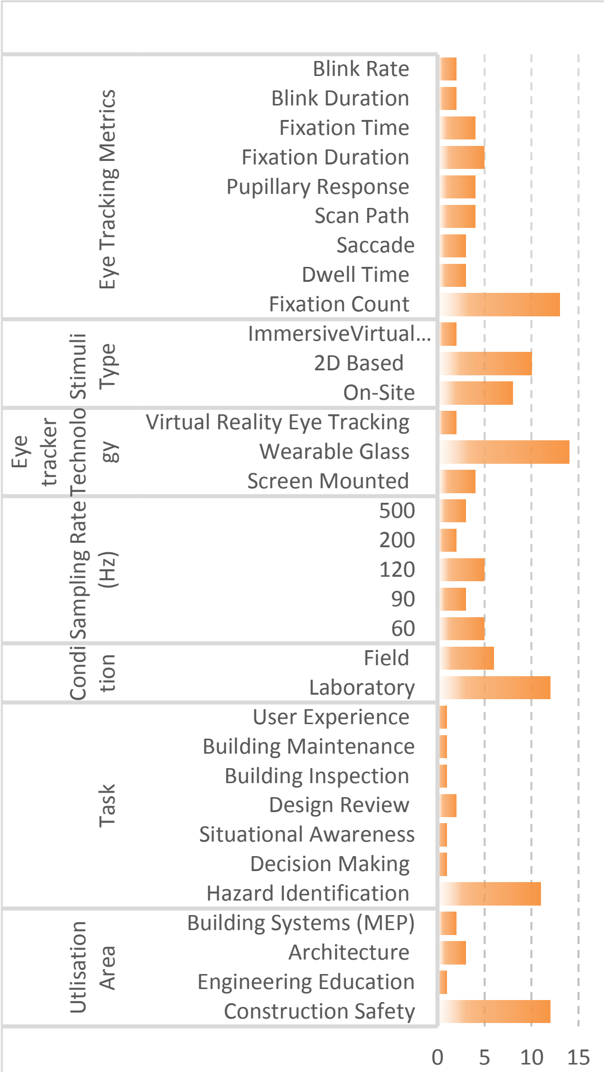


Figure 2 Literature Classification

Further, this study also identified the majority (27.7%) of the literature used an eye tracker with a sampling frequency of 60 Hz & 90Hz. Even though sampling frequency is very rarely highlighted in methodical discussions it is critical when precise measures (e.g., small saccades) are required for the study [2]. Further, fixation count (FC) (72.2%) is the most commonly used eye-tracking metric followed by fixation duration (FD) (27.7%). As the majority of the literature identified by this study focuses on CS in regard to hazard perception, this higher number of FC and FD are common, as crosscomparison of FC with FD can give insights into the areas that generate interest (i.e., potentially hazardous area) and those that caused confusions (i.e. bottom-up processing during identification of a hazard) for the users [19]. Further, the yearly publication (Figure 3) shows a steady increase in the number of publications utilising eye tracking in the AEC industry (articles published in 2020 was up to the end of October 2020) which indicates that research interest in this area is gaining momentum, even though one of the factors that could slow down the utilisation of this technology is the exorbitant cost of the eye-tracking peripherals and the software [25].

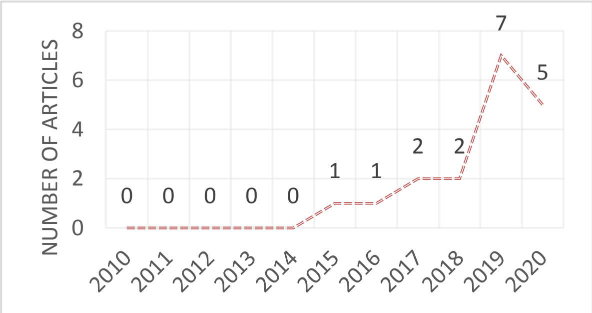
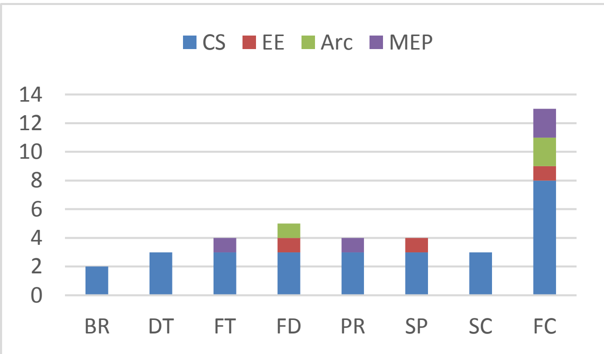


Figure 3 Yearly Publication 2010-2020

Figure 4 depicts the utilisation area of eye-tracking in the AEC industry in relation to the eye-tracking metrics.



Note: BR = Blink Rate, DT = Dwell Time, FT = Fixation Time, FD = Fixation Duration, PR = Pupillary Response, SP = Scan Path, SC= Saccade, FC = Fixation Count

Figure 4 Utilisation Area Vs Eye Tracking Metrics

Most of the CS studies have utilised various eye-tracking metrics to understand the human behaviour leading to failure in hazard identification. stimuli. Out of all the eye-tracking metrics identified FC is the most used eye-tracking metrics in all utilisation areas, as FC could provide information about a person's interest in specific. However, there are other least explored metrics like a pupillary response (PR) which can provide much detailed information about cognitive load while engaged in multiple tasks that can have an adverse effect on the hazard identification capabilities.

Table 2 Eye Tracking Metrics used in AEC Studies Literatures

Literature	Utilisation Area	Sample Size	FC	DT	SC	SP	PR	FD	FT	RD	RR	**Citation**
[10]	CS	25	√		√	√		√				41
[29]	CS	48					√					0
[13]	CS	55	√		√							0
[11]	CS	16	√			√		√				1
[41]	CS	47				√						2
[15]	CS	11	√			√						16
[23]	CS	23			√			√	√			14
[16]	CS	31	√	√								20
[15]	CS	28	√									2
[1]	MEP	60	√						√			2
[28]	CS	12	√				√	√		√	√	7
[27]	CS	6					√			√	√	3
[47]	Arc	63	√									2
[39]	MEP	90	√				√					0
[9]	Arc	14	√				√					0
[24]	CS	6	√	√					√			21
[17]	CS	27	√	√					√			29
[32]	Arc	8	√				√					6

Note: CS = Construction Safety, Arc = Architecture, MEP = Building Systems

Further research could explore these metrics by recreating subtle environment factors like noise, lighting and multiple tasks to understand how these could affect human performance in hazard identification.

It is interesting to note that some of the highest cited literature (table 2) which utilised eye tracking in the AEC industry (e.g., [10] [16] [17]) to understand human visual search patterns have used planar stimuli to evoke participant responses. Even though these studies are the most notable once that focuses on the use of eye-tracking in construction safety analysis, the results of these study might yield contradictory findings if the experimental set up was in a real or immersive environment due to the aforementioned fact that subtle environment factors like noise, lighting conditions, task and equipment movements are impossible to replicate in such stimuli [45] as well as they reduce the dimensionality that could lead to the simplification of the stimuli representation, resulting in distorted visual search patterns yielding misleading eye movement data as opposed by [29]. This points out that future research must focus on the utilisation of immersive virtual reality-based stimuli which can overcome these challenges. However, one of the factors that might restrict the utilisation of such technologies is the cost of hardware and software associated with conducting such experiments.

6 Conclusion

This study aimed to identify the areas of application of eye-tracking technology in the A &C industry. A full range of construction journal articles between 2010 and 2020 (inclusive), that utilised eye-tracking technology in the AEC industry was systematically assessed. Based on rigorous inclusion and exclusion criteria,18 eligible journal articles were selected for final review. A generic taxonomy based on grounded theory was developed based on a wide range of scholarly journals. The eligible articles were classified based on this taxonomy and are presented. The review revealed that eye-tracking studies in the AEC industry are mostly focused on improving construction safety through an understanding of human behaviours in hazard identification. This study also identified a paucity of studies in the areas like user experience in a facility, building inspection and maintenance, decision making and design reviews. Further, laboratory-based experiments are found to be the most performed methods in understanding human behaviour using eye-tracking in the AEC industry. A higher number of studies have used wearable glass-based eye trackers and only studied have tried to use immersive technology to recreate stimuli. Further, most of the studies have used 2D based stimuli regardless of their drawbacks (i.e., reduces the dimensionality that could lead to the simplification of the stimuli representation, resulting in distorted visual search patterns yielding misleading eye movement data). Also, real site stimuli were the second most preferred stimuli used in the experiments. Further, fixation count followed by fixation duration is the most commonly used eye-tracking metric used by most studies. This systematic review revealed that that eye-tracking technology is growing in popularity with safety being one of the most critical areas that require further development and recent advancements in ICT is naturing this trend.

Reference

[1]. Alruwaythi, O. and Goodrum, P. (2019) A Difference in Perspective: Impact of Different Formats of Engineering Information and Spatial Cognition on Craft-Worker Eye-Gaze Patterns. *Journal of Construction Engineering and Management* [online]. 145 (11), pp.04019065. [Accessed 27 October 2020].

[2]. Andersson, R., Nyström, M. and Holmqvist, K. (2010) Sampling frequency and eye-tracking measures: how speed affects durations, latencies, and more. [online]. [Accessed 30 October 2020].

[3]. Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N. and Brown, S., (2017) *Reinventing Construction: A Route to Higher Productivity* [online]. McKinsey Global Institute. [Accessed 19 May 2018].

[4]. Blair, M.R., Watson, M.R., Walshe, R.C. and Maj, F. (2009) Extremely selective attention: Eye-tracking studies of the dynamic allocation of attention to stimulus features in categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition* [online]. 35 (5), pp.1196. [Accessed 28 August 2020].

[5]. Brunyé, T.T., Drew, T., Weaver, D.L. and Elmore, J.G. (2019) A review of eye-tracking for understanding and improving diagnostic interpretation. *Cognitive Research: Principles and Implications* [online]. 4 (1), pp.1-16. [Accessed 27 October 2020].

[6]. Bylinskii, Z., Kim, N. W., O'Donovan, P., Alsheikh, S., Madan, S., Pfister, H., Durand, F., Russell, B. and Hertzmann, A., eds. (2017) *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology* [online]. Available from: https://dl.acm.org/doi/abs/10.1145/3126594.3126653. [Accessed 29 August 2020].

[7]. Campbell, R., Pound, P., Pope, C., Britten, N., Pill, R., Morgan, M. and Donovan, J. (2003) Evaluating meta-ethnography: a synthesis of qualitative research on lay experiences of diabetes and diabetes care. *Social Science & Medicine* [online]. 56 (4), pp.671-684. [Accessed 03 June 2019].

[8]. Chambers, E.A. (2004) An introduction to meta-analysis with articles from the journal of educational research (1992-2002). *The Journal of Educational Research* [online]. 98 (1), pp.35-45. [Accessed 03 June 2019].

[9]. De la Fuente Suárez, Luis Alfonso (2020) Subjective experience and visual attention to a historic building: A real-world eye-tracking study. *Frontiers of Architectural Research* [online]. [Accessed 10 September 2020].

[10]. Dzeng, R., Lin, C. and Fang, Y. (2016) Using eye-tracker to compare search patterns between experienced and novice workers for site hazard

identification. *Safety Science* [online]. 82 pp.56-67. [Accessed 25 August 2020].

[11]. Gestson, Sean L., Barner,M.,Ghodrat,M., Hurwitz,D.,Brown,S (2019) Problem Solving Personas of Civil Engineering Practitioners using Eye Tracking Techniques. [online]. 35 pp.1074-1093. [Accessed 25 August 2020].

[12]. Glaser, B.G. and Strauss, A.L. (2017) *Discovery of Grounded Theory: Strategies for Qualitative Research* [online]. Routledge. [Accessed 07 June 2019].

[13]. Han, Y., Yin, Z., Zhang, J., Jin, R. and Yang, T. (2020) Eye-Tracking Experimental Study Investigating the Influence Factors of Construction Safety Hazard Recognition. *Journal of Construction Engineering and Management* [online]. 146 (8), pp.04020091. [Accessed 15 August 2020].

[14]. Hasanzadeh, S., Dao, B., Esmaeili, B. and Dodd, M.D. (2019) Role of personality in construction safety: investigating the relationships between personality, attentional failure, and hazard identification under fall-hazard conditions. *Journal of Construction Engineering and Management* [online]. 145 (9), pp.04019052. [Accessed 15 September 2020].

[15]. Hasanzadeh, S., Esmaeili, B. and Dodd, M.D. (2018) Examining the relationship between construction workers' visual attention and situation awareness under fall and tripping hazard conditions: using mobile eye tracking. *Journal of Construction Engineering and Management* [online]. 144 (7), pp.04018060. [Accessed 20 September 2020].

[16]. Hasanzadeh, S., Esmaeili, B. and Dodd, M.D. (2017) Impact of construction workers' hazard identification skills on their visual attention. *Journal of Construction Engineering and Management* [online]. 143 (10), pp.04017070. [Accessed 20 August 2020].

[17]. Hasanzadeh, S., Esmaeili, B. and Dodd, M.D. (2017) Measuring the impacts of safety knowledge on construction workers' attentional allocation and hazard detection using remote eye-tracking technology. *Journal of Management in Engineering* [online]. 33 (5), pp.04017024. [Accessed 30 September 2020].

[18]. Heimler, B., Pavani, F., Donk, M. and van Zoest, W. (2014) Stimulus-and goal-driven control of eye movements: Action videogame players are faster but not better. *Attention, Perception, & Psychophysics* [online]. 76 (8), pp.2398-2412. [Accessed 30 August 2020].

[19]. Hofmann, M.J., Biemann, C. and Remus, S. (2017) Benchmarking n-grams, topic models and recurrent neural networks by cloze completions, EEGs and eye movements. In: Anon.(2017) *Cognitive Approach to Natural Language Processing* [online]. Elsevier, pp.197-215. [Accessed 23 September 2020].

[20]. Holmqvist, K. (2011) *Eye Tracking: A Comprehensive Guide to Methods and Measures* [online]. Oxford: Oxford University Press.

[21]. HSE (2020) *Health and Safety Statistics.* Available from: https://www.hse.gov.uk/statistics/ [Accessed 23 August 2020].

[22]. Itti, L. and Koch, C. (2001) Computational modelling of visual attention. *Nature Reviews Neuroscience* [online]. 2 (3), pp.194-203. [Accessed 22 August 2020].

[23]. Jeelani, I., Albert, A., Han, K. and Azevedo, R. (2019) Are visual search patterns predictive of hazard recognition performance? Empirical investigation using eye-tracking technology. *Journal of Construction Engineering and Management* [online]. 145 (1), pp.04018115. [Accessed 19 August 2020].

[24]. Jeelani, I., Han, K. and Albert, A. (2018) Automating and scaling personalized safety training using eye-tracking data. *Automation in Construction* [online]. 93 pp.63-77. [Accessed 05 October 2020].

[25]. Kumar, M. (2006) Reducing the cost of eye tracking systems. *Building, 4.Citeseer* [online]. [Accessed 30 October 2020].

[26]. Land, M. and Tatler, B. (2009) *Looking and Acting: Vision and Eye Movements in Natural Behaviour* [online]. Oxford University Press. [Accessed 30 August 2020].

[27]. Li, J., Li, H., Umer, W., Wang, H., Xing, X., Zhao, S. and Hou, J. (2020) Identification and classification of construction equipment operators' mental fatigue using wearable eye-tracking technology. *Automation in Construction* [online]. 109 pp.103000. [Accessed 02 September 2020].

[28]. Li, J., Li, H., Wang, H., Umer, W., Fu, H. and Xing, X. (2019) Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology. *Automation in Construction* [online]. 105 pp.102835. [Accessed 28 August 2020].

[29]. Liao, P., Sun, X. and Zhang, D.A multimodal study to measure the cognitive demands of hazard recognition in construction workplaces. *Safety Science* [online]. 133 pp.105010. [Accessed 25 October 2020].

[30]. Luck, S.J. and Ford, M.A. (1998) On the role of selective attention in visual perception. *Proceedings of the National Academy*

of Sciences of the United States of America [online]. 95 (3), pp.825-830. [Accessed 28 August 2020].

[31]. Meline, T. (2006) Selecting studies for systematic review: Inclusion and exclusion criteria. *Contemporary Issues in Communication Science and Disorders* [online]. 33 (21-27), [Accessed 19 June 2019].

[32]. Mohammadpour, A., Karan, E., Asadi, S. and Rothrock, L. (2015) Measuring end-user satisfaction in the design of building projects using eye-tracking technology. In: Anon.(2015) *Computing in Civil Engineering 2015* [online]. pp.564-571. [Accessed 08 October 2020].

[33]. Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G. (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine* [online]. 151 (4), pp.264-269. [Accessed 22 June 2019].

[34]. Narayan, A. (2019) *Eye Tracking Glasses Or Static Eye Tracker, which is Better?*. Available from: https://medium.com/@ankitnsingh/eye-tracking-glasses-or-static-eye-tracker-which-is-better-5fae2272de1a [Accessed 22 September 2020].

[35]. Nielsen, J. and Pernice, K. (2010) *Eyetracking Web Usability* [online]. New Riders. [Accessed 30 August 2020].

[36]. Popa, L., Selejan, O., Scott, A., Mureşanu, D.F., Balea, M. and Rafila, A. (2015) Reading beyond the glance: eye tracking in neurosciences. *Neurological Sciences* [online]. 36 (5), pp.683-688. [Accessed 27 October 2020].

[37]. Pring, A. (2018) *Eye-Tracking' VR Tool Improves Complex Building Design*. Available from: https://www.bimplus.co.uk/technology/eye-tracking-design-tool-improves-building-design-/ [Accessed 23 August 2020].

[38]. Rakib, M.F.H., Howlader, S., Rahman, M. and Hossain, A., eds. (2020) *Factors Affecting the Construction Productivity in the Contex of Khulna City of Bangladesh* [online]. Bangladesh, 7 February 2020. Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development. [Accessed 26 October 2020].

[39]. Shi, Y., Du, J. and Zhu, Q. (2020) The impact of engineering information format on task performance: Gaze scanning pattern analysis. *Advanced Engineering Informatics* [online]. 46 pp.101167. [Accessed 08 October 2020].

[40]. Tobii (2020) *this is Eye Tracking*. Available from: https://www.tobii.com/group/about/this-is-eye-tracking/ [Accessed 26 August 2020].

[41]. Xu, Q., Chong, H. and Liao, P. (2019) Exploring eye-tracking searching strategies for construction hazard recognition in a laboratory scene. *Safety Science* [online]. 120 pp.824-832. [Accessed 22 August 2020].

[42]. Yousefi, M.V., Karan, E., Mohammadpour, A. and Asadi, S., eds. (2015) *51st ASC Annual International Conference Proceedings* [online]. Available from: https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=752+Implementing+Eye+Tracking+Technology+in+the+Construction+Process&btnG=. [Accessed 26 October 2020].

[43]. Slavin, R.E. (1986) Best-evidence synthesis: An alternative to meta-analytic and traditional reviews. Educational Researcher [online]. 15 (9), pp.5-11. [Accessed 01 July 2019].

[44]. Urquhart, C., Lehmann, H. and Myers, M.D. (2010) Putting the 'theory'back into grounded theory: guidelines for grounded theory studies in information systems. Information Systems Journal [online]. 20 (4), pp.357-381. [Accessed 04 July 2019].

[45]. Albert, A., Hallowell, M.R., Kleiner, B., Chen, A. and Golparvar-Fard, M. (2014) Enhancing construction hazard recognition with high-fidelity augmented virtuality. Journal of Construction Engineering and Management [online]. 140 (7), pp.04014024. [Accessed 14 March 2021].

[46]. Perlman, A., Sacks, R. and Barak, R. (2014) Hazard recognition and risk perception in construction. Safety Science [online]. 64 pp.22-31. [Accessed 14 January 2021].

[47]. Shi, Y., Du, J. and Ragan, E. (2020) Review visual attention and spatial memory in building inspection: Toward a cognition-driven information system. Advanced Engineering Informatics [online]. 44 pp.101061. [Accessed 14 March 2021].