The Application of Eye-Tracking Technology for Life Safety in the Built Environment: A Systematic literature review

Ji-Hyoun Hwang

Dept. of Housing & Interior Design, Chungbuk National University, Cheongju, Korea

Abstract

As the built environment becomes increasingly complex, safety has become a paramount concern. The recent advent of eye-tracking technology has provided researchers with a powerful tool to investigate visual attention within safety-related contexts. This study aims to identify potential applications of eye-tracking technology to enhance life safety in built environments by thoroughly examining and evaluating existing research. Through a comprehensive literature search and screening process, 23 eligible studies published between 2015 and 2024 were identified. A systematic review was conducted, focusing on research area and study characteristics such as experimental details (including participants, devices, tasks, conditions, types of stimuli, and eye-tracking indicators), and methods of data analysis. Although the application of eye-tracking technology in life safety research is still in its nascent stages, the findings hold significant implications for user experience and safety management, warranting continued attention in future research.
Key words: life safety, built environment, eye-tracking, review

I. Introduction

Research on designing for resident safety within buildings has been ongoing, but it has predominantly relied on the experience of designers or a limited set of regulations. With the increasing complexity of built environments, there is a growing need for enhanced attention and consideration towards life safety. However, there is currently a deficiency in technical support for architectural designs that prioritize life safety. Recently, eye-tracking technology, which monitors eye movements and aids in capturing visual attention (Günther et al., 2021), has emerged as a valuable tool. This technology is extensively utilized not only in construction safety (Hong et al., 2024) and safety management (Balaji et al., 2023) but also in diverse fields such as marketing (Fu et al., 2020), transportation (Qin et al., 2023), medicine (Wang et al., 2019), criminalistics (Lee et al., 2023), and advertising (Yen & Chiang, 2021). This study aims to explore the application of eye-tracking technology to enhance life safety in architecture by conducting a thorough examination and evaluation of existing research, and to derive implications for its potential application.

II. Research Method

A systematic review was conducted to explore the role of eye-tracking technology in enhancing life safety within the built environment. The review process comprised the following steps: (a) journal search, (b) duplicate removal, (c) screening, and (d) classification and review (Figure 1).

1. Journal search and duplicate removal

The literature search was conducted using titles, keywords, and abstracts within two prominent academic databases: Web of Science Core Collection (WoS) and Scopus. The retrieval codes used were: “eye tracking” AND “safety” AND “building” (or “architecture”). This study included only research papers published in peer-reviewed journals written in English, thereby excluding conference papers, books, and non-international journals. Consequently, 103 papers were retrieved from WoS and 40 from Scopus. To eliminate duplicates, all retrieved articles from both databases were imported into Endnote software, resulting in a final set of 115 articles.

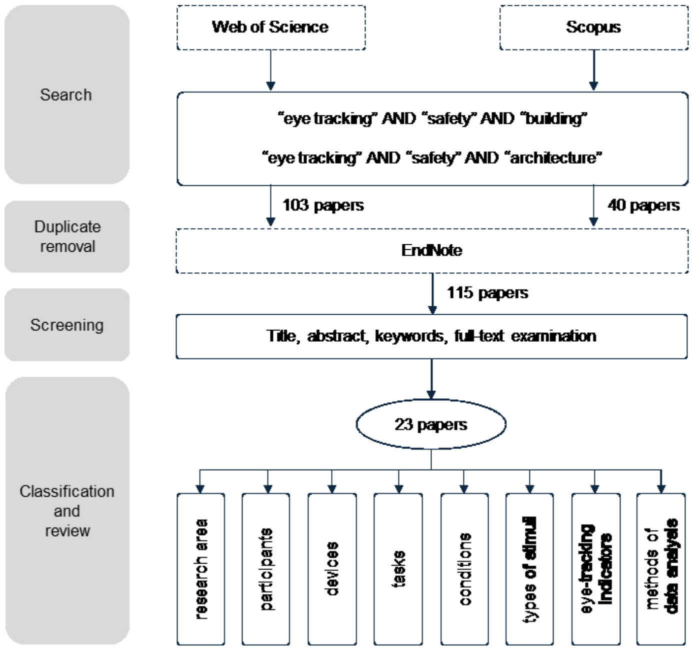

Figure 1. Research process

2. Journal screening

This review aimed to explore the application of eye-tracking technology for life safety in the built environment. Despite the use of specific retrieval codes, some literature not directly related to the study's focus was included. Therefore, a rigorous screening process was necessary to identify relevant papers. Titles, abstracts, keywords, and full texts were reviewed and filtered based on predefined criteria. Exclusion criteria encompassed journals not closely related to buildings (e.g., those focusing on transportation, medicine, system development, or online shopping), journals unrelated to eye-tracking, journals focused on occupational environments (e.g., construction safety, occupational safety), journals related to the architectural design process, and review papers. Following this screening process, a total of 23 papers published between 2015 and 2024 were selected for analysis.

3. Classification and review

The Ministry of the Interior and Safety in South Korea categorizes life safety into several areas: disasters (e.g., evacuation from earthquakes, fires), transportation, daily life (e.g., hiking, maritime accidents), crime, health (e.g., diseases), and facilities (e.g., heat waves, shelters) (The Ministry of the Interior and Safety, 2024). Based on these categories, the topics of the collected papers were analyzed from the perspective of the built environment, and the research areas were broadly classified into evacuation, crime, pedestrian environments, green environments, and safety signage. Subsequently, study characteristics, including experimental details (participants, devices, tasks, conditions, types of stimuli, eye-tracking indicators), methods of data analysis, and results, were thoroughly reviewed.

III. Result

The main findings of the study are as follows. Firstly, the most common research areas were evacuation and pedestrian environments, comprising 70% of the studies. This indicates that the use of eye-tracking technology for life safety in building environments remains limited. Secondly, the number of experimental participants was mostly fewer than 100, reflecting the inherent limitations of experimental research in targeting a large population. The experimental conditions were divided into field and laboratory settings. In field settings, wearable eye trackers were used, and participants performed tasks in real-world contexts. In laboratory settings, VR and desk-mounted eye trackers were employed, with stimuli presented through images or videos shown to participants to collect relevant data. Thirdly, eye-tracking indicators including is critical to eye-tracking studies, including fixation time, search duration, time to the first fixation, fixation count, visual attentions index, the accuracy rate of the first fixation, fixation sequence, and intersection coefficient pupil diameter, blink count, and so on. The major derived indicators in life safety research of buildings are fixation count, fixation time (fixation duration, dwell time) and pupil diameter. In addition, time to first fixation, total fixation duration and gaze path, and AOI analysis were also used. Lastly, in most papers, traditional statistical models such as descriptive statistics, regression, t-test, and ANOVA analysis, etc. were used to analyze data collected through eye-tracking.

IV. Conclusions

This study aimed to explore the applications of eye-tracking technology for life safety in the built environment. A comprehensive systematic review of selected articles published between 2015 and 2024 was conducted. The review revealed that eye-tracking research for life safety in buildings primarily focuses on improving safety during emergency situations and improving pedestrian safety outside buildings. Consequently, this study identified a significant gap in research addressing safety-related user experiences within buildings and safety management. Additionally, recruiting a large number of participants for eye-tracking experiments poses challenges due to the nature of experimental research. Nevertheless, researchers should strive to recruit a sufficiently large and representative sample and reduce missing values in a small number of experimental subjects. Participants should be informed that they will be tasked with identifying potential hazards in the given stimulus materials, whether in a field or virtual environment. Experiments were conducted both in laboratory settings and in actual field conditions, with wearable, glass-based eye trackers used in the latter. When selecting devices, the type of stimuli and experimental conditions should be considered. Desktop eye trackers are suitable for 2D data, such as videos and images, while wearable eye trackers are appropriate for real-world environments. Although traditional statistical models are predominantly used to analyze eye-tracking data, recent studies indicate that machine learning models and qualitative comparative analysis offer superior performance in eye movement data analysis (Cheng et al., 2022). These advanced analytical models should be considered for future research. This systematic review highlights the growing popularity of eye-tracking technology and underscores the critical importance of further development in the area of life safety.

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