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Identifying Environmental Factors near Construction Sites Affecting Pedestrian Safety

Taegwan YOON[1]*, Seulbi LEE[2]

[1] *Department of Architectural Design and Engineering, Incheon National University, South Korea,* E-mail address: x8333x@inu.ac.kr
[2] *Division of Architecture & Urban Design, Incheon National University, South Korea, E-mail address:* sblee@inu.ac.kr

Abstract: Construction projects in urban areas often disrupt pedestrian paths and expose pedestrians to risks by forcing them to detour onto roadways. Despite rising pedestrian fatalities and injuries near construction sites, most research predominantly focuses on the safety of on-site workers, with limited studies addressing pedestrian safety. This study aims to fill this gap by identifying environmental factors that cause discomfort to pedestrians, potentially leading to hazardous impacts. A total of 252 photos of streetscape areas near construction sites, including seven environmental factors (i.e., traffic cones, fences, barrier walls, materials, heavy equipment, roads, and sidewalks), were collected and evaluated by 41 participants using a 5-point Likert scale. The survey findings indicate that barrier walls enhance pedestrians' perception of safety. Conversely, it is observed that traffic cones, materials, and heavy equipment have adverse effects on pedestrian safety. These results underscore the need for enhanced safety measures targeting these high-risk factors to create pedestrian-friendly construction sites. This study contributes to developing more proactive pedestrian safety management strategies and ultimately reduces pedestrian injuries.

Key words: Pedestrian safety, Construction sites, Environmental Factors, Hazard Identification

1. INTRODUCTION

In the vicinity of construction sites, sidewalks are often occupied with significant amounts of building materials, unattended debris, and even heavy equipment, thereby endangering pedestrian safety [1,2]. According to the United States National Highway Traffic Safety Administration (NHTSA), there were 173 fatal traffic crashes in construction work zones for persons on foot or bicyclists in 2021 [3]. While no official statistics are available, it is undoubtedly the case that non-fatal injuries such as trips, slips, and abrasions occurred much more frequently than the reported fatalities. As one relevant instance, an accident occurred in which a woman was unexpectedly impaled by a flying metal shard while walking alongside an operating crane in Singapore [4]. As a result of these issues, pedestrians experience discomfort when walking on sidewalks adjacent to construction sites, leading them to encroach on roadways and ultimately exposing themselves to additional hazards [5]. Notwithstanding these potential problems, the implementation of suitable safety measures for pedestrians during construction periods has garnered comparatively less emphasis [6-8]. Although most cities have building codes for pedestrian safety, which mandate that pedestrian traffic should be controlled by flaggers in construction zones, in reality, these regulations are rarely followed [9]. This is because of a lack of investment to create a safe environment for pedestrians near construction sites, in contrast to the resources allocated for workplace injury mitigation.

Pedestrian safety has traditionally been addressed in the disciplines of transportation engineering and urban planning. Several previous studies have employed survey methods to collect pedestrians' opinions on the physical environmental factors in urban areas that cause them discomfort [10]. The survey results

have consistently underscored the significance of both the presence and width of sidewalks as critical factors in pedestrian safety [11,12]. However, there is limited investigation into sidewalks that are occupied by construction materials and equipment, thereby obstructing pedestrian traffic. To address this gap, this study aims to identify environmental factors that cause discomfort to pedestrians, potentially leading to hazardous impacts, by using photos taken near construction sites. Our hypothesis is that the objects frequently observed in photos, which are evaluated as hazardous situations, contribute to an environment that is insufficiently pedestrian-friendly. The remainder of this paper is organized as follows: The second section categorizes environmental factors commonly found near construction sites and explains how data for the survey were collected. The third section describes the survey results in terms of the impact of the presence of environmental factors on pedestrian safety. Finally, the concluding section summarizes the main findings of this study.

2. MATERIALS AND METHODS

2.1. Environmental factors

Through a comprehensive literature review and field observations, this study identified seven types of environmental factors that may influence pedestrian traffic near construction sites. The first three objects are temporary measures used to separate pedestrians from construction work zones. These measures encompass traffic cones, fences, and barrier walls, as depicted in Fig. 1 (a) to (c). Previous research indicates that many construction sites often lack adequate temporary measures for pedestrian safety [13]. Furthermore, while these measures are intended to enhance pedestrian safety, improper placement can introduce hazards and lead to confusion among pedestrians [13]. The fourth environmental object is construction material (as depicted in Fig. 1 (d)). Various materials including piles of rebar, stacks of bricks, bags of cement, and construction debris all fall into this classification. In general, construction materials are perceived as encroaching on pedestrian space, reducing the usable width of sidewalks. It has been found that sidewalk encroachment is consequently linked to fatal pedestrian crashes [14]. The fifth environmental object is heavy equipment (as depicted in Fig. 1 (e)). Heavy equipment always requires careful attention to protect pedestrians, and therefore, flaggers should be in place to manage traffic [7]. The last two objects are roads and sidewalks, as depicted in Fig. 1 (f) and (g). From statistics regarding pedestrian fatalities, it is evident that high-volume and high-speed traffic on the roads can significantly increase the likelihood of crashes [8,15]. Conversely, the presence of sidewalks, particularly straight, wide, and well-paved sidewalks, could mitigate the likelihood of pedestrian accidents [5,12].

Figure 1. Environmental factors pertaining to pedestrian safety

2.2. Data collection

This study collected photos of streetscape areas near construction sites by utilizing a web scraping tool to extract images from Google Images (https://www.pullywood.com/ImageAssistant/). The collected photos underwent manual screening, and any photo that did not include at least one of the seven specified environmental factors was removed from the dataset. Photos with resolutions below 320*320 or above 1920*1080 were also excluded from the dataset. To supplement the dataset, artificial intelligence-generated images were created using text-to-image models (https://www.bing.com/images/create). Consequently, a total of 216 photos were collected for the experimental dataset, and an additional 36 photos containing only sidewalks were collected to serve as a control dataset. The number of environmental factors found in a single photo ranges from 1 to 6. As an example, the representative photo from the experimental dataset, shown in Fig. 2 (a), encompasses six environmental factors: traffic cones, barrier walls, construction materials, heavy equipment, roads, and sidewalks. In contrast, the representative photo from the control dataset, illustrated in Fig. 2 (b), solely features sidewalks. Among the seven types of environmental factors, excluding roads and sidewalks, barrier walls are the most frequently observed in the experimental dataset, appearing in 98 out of 216 photos. Table 1 provides an overview of the frequency of occurrence of environmental factors across the two datasets.

(a) Experimental dataset (b) Control dataset

Figure 2. Representative photos from the experimental and control dataset

Table 1. Frequency of occurrence of the environmental factors

Dataset	Traffic cones	Fences	Barrier walls	Materials	Heavy equipment	Roads	Sidewalks
Experimental	91 (42.1%)	63 (29.2%)	98 (45.4%)	83 (38.4%)	92 (42.6%)	182 (84.3%)	153 (70.8%)
Control	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	24 (66.7%)	32 (88.9%)

2.3. Survey design

To evaluate pedestrian safety around construction sites depicted in the photos, an online image-based survey was conducted. Participants were asked to rate the extent of their discomfort when imagining passing by construction sites depicted in the photos using a 5-point Likert scale, which ranged from '1 = very dangerous' to '5 = not at all dangerous'.The survey was carried out from July 1, 2023, to August 10, 2023. Participation was voluntary, and no identifiable information was collected. The survey protocol was approved by the Institutional Review Board of Incheon National University (Approval No.: 7007971-202305-010A). A total of 41 participants, including 32 males and 9 females, completed the survey. Most of the participants (64.3%) strongly agreed or agreed with the statement expressing feeling unsafe when walking near construction sites in their daily lives.

3. RESULT

3.1. Pedestrian safety near construction sites

As indicated in Table 2, the mean pedestrian safety scores for the experimental dataset were 2.62 ± 0.77, whereas for the control group, they were 4.20 ± 0.42. The Shapiro-Wilk test of normality revealed a significance level below 0.05 for both the experimental and control groups, indicating a departure from normal distribution. Consequently, a Mann-Whitney U test was conducted to assess the differences between the two groups. The results demonstrated that the experimental dataset exhibited significantly higher risk scores in pedestrian safety compared to the control dataset ($p < 0.001$). In essence, this suggests clear negative impacts of construction sites on pedestrian safety levels.

Table 2. Mann Whitney-U test results for the experimental and control dataset

Dataset	Sample size	Pedestrian safety score (1: very dangerous, 5: not at all dangerous)		U	p-value
		Mean	SD		
Experimental	216	2.62	0.77	7,446	0.000*
Control	36	4.20	0.42		

* Significant at the 0.001 level

3.2. Effects of the environmental factors

To investigate the significant contributors to pedestrians' perceived safety, this study conducted a Mann-Whitney U test comparing the pedestrian safety scores between conditions with and without the presence of each environmental object with the experimental dataset. Table 3 presents the mean pedestrian safety scores categorized by different environmental factors. Each environmental object is divided into two conditions: "With" indicates the presence of the object in a photo, while "Without" indicates its absence. For example, when examining the presence of barrier walls, the mean pedestrian safety score was 2.91 when barrier walls were present, compared to 2.38 when they were absent. The mean difference between the two conditions was 0.53, with a significant p-value of less than 0.001. This suggests that the presence of barrier walls led to a notable increase in pedestrian safety scores, indicating that pedestrians feel safer when barrier walls are present while walking near construction sites.

Table 3. Differences in pedestrian safety scores by condition

Environmental factors	Condition	Sample size	Mean	SD	Mean Difference	U	p-value
Traffic cones	With	91	2.44	0.64	-0.31	4,460	0.007**
	Without	125	2.75	0.83			
Fences	With	63	2.74	0.73	0.17	5,579	0.069
	Without	153	2.57	0.78			
Barrier walls	With	98	2.91	0.80	0.53	8,022	0.000*
	Without	118	2.38	0.65			
Materials	With	83	2.18	0.61	-0.71	2,552	0.000*
	Without	133	2.89	0.73			
Heavy equipment	With	92	2.21	0.57	-0.71	2,691	0.000*
	Without	124	2.92	0.76			
Roads	With	182	2.59	0.71	-0.17	2,785	0.356
	Without	34	2.76	1.05			
Sidewalks	With	153	2.68	0.81	0.20	5,483	0.112
	Without	63	2.48	0.65			

* Significant at the 0.001 level
** Significant at the 0.01 level

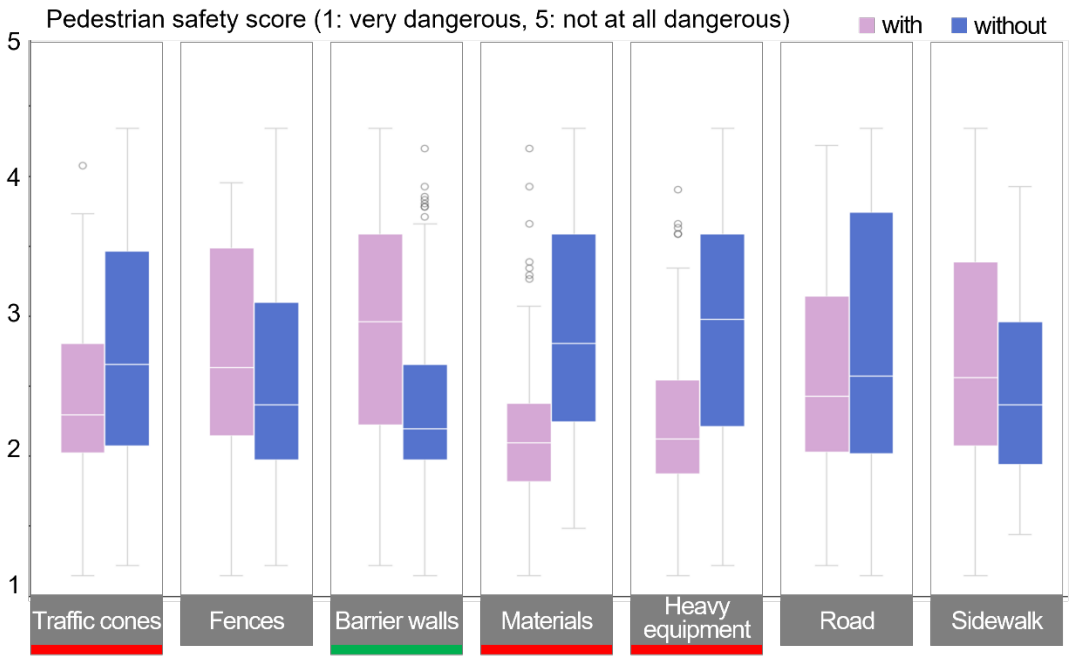

Figure 3. Boxplot of environmental impacts on pedestrian safety

Conversely, for factors with negative values in the mean difference, such as traffic cones, materials, and heavy equipment, significantly lower pedestrian safety scores were observed when these objects were present compared to when they were absent, as indicated in Table 3. This is because traffic cones often indicate ongoing construction activity or hazards, causing pedestrians to perceive higher risks. Similarly, the presence of construction materials and heavy equipment can create obstacles and reduce the available space for pedestrians, leading to a heightened sense of danger to pedestrians. On one hand, the presence of fences and sidewalks slightly raised pedestrian safety scores, while the presence of roads slightly lowered them. However, there was no statistically significant difference in the mean pedestrian scores between conditions for factors like fences, roads, and sidewalks. Fig. 3 presents a box plot that graphically demonstrates the impact of different environmental factors on perceived pedestrian safety. Factors that significantly improve pedestrian safety, such as barrier walls, are highlighted in green. In contrast, elements that have a statistically significant negative effect - such as traffic cones, materials, and heavy equipment - are marked in red.

3.3. Effects of pedestrians and workers

In addition to studying how environmental factors affect pedestrian safety, this research also looked into whether pedestrians and construction workers play a role near construction sites. The findings, shown in Table 4, indicate that there were statistical differences in pedestrian safety scores when pedestrians and construction workers were present compared to when they were not ($p < 0.05$). However, these differences were not very large. This suggests that while human presence may affect how safe pedestrians feel, it seems to have less impact compared to environmental factors.

Table 4. Differences in pedestrian safety scores by human

Human	Condition	Sample size	Mean	SD	Mean Difference	U	p-value
Pedestrians	With	104	2.49	0.70	-0.24	4,767	0.02
	Without	112	2.74	0.82			
Construction workers	With	55	2.42	0.68	-0.27	3,537	0.03
	Without	161	2.69	0.79			

3.4. Correlation between environmental factors

Fig. 4 displays the pairwise correlations among seven environmental factors, pedestrians, and construction workers, with correlation values ranging from -0.26 to 0.32. The highest significant positive correlation is found between heavy equipment and traffic cones ($p < 0.01$), and heavy equipment also shows a positive correlation with construction workers. These results accurately reflect the typical dynamics at construction sites. Interestingly, there is a significant positive correlation between pedestrians and roads, while no correlation is found between pedestrians and sidewalks. This finding aligns with several previous studies suggesting that when sidewalks are occupied by construction, pedestrians are often forced onto the roads [5,12].

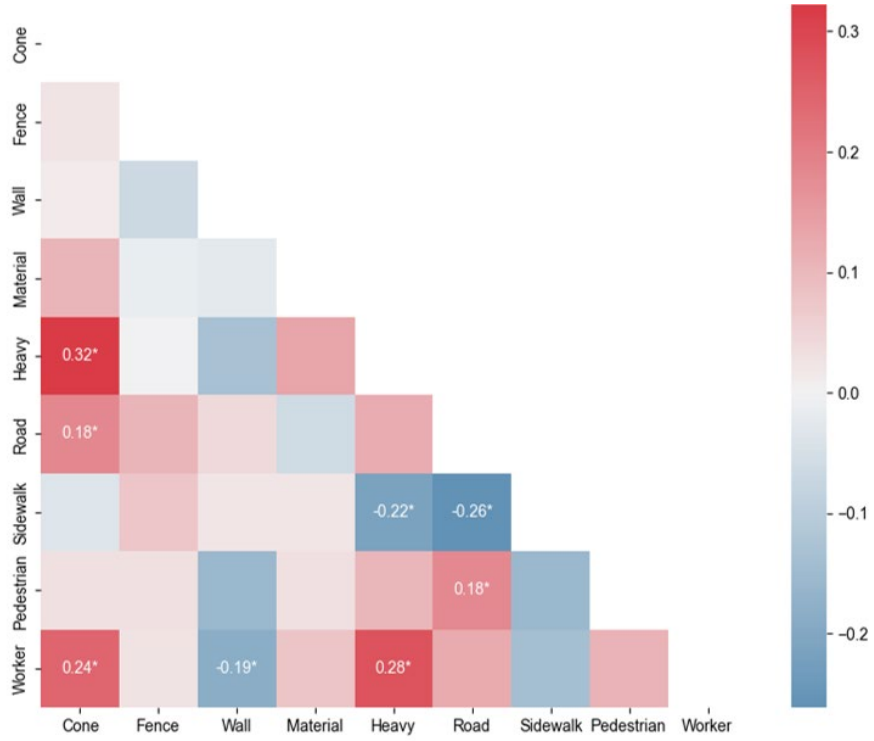

Figure 4. Corrleation heatmap between the environmental factors

4. CONCLUSION

This study identifies the environmental factors that significantly influence pedestrian safety by analyzing survey results of collected photos of streetscapes near construction sites. The findings underscore the critical role of environmental factors in shaping pedestrians' perceptions of safety, explaining both positive and negative impacts. Firstly, certain environmental factors, such as barrier walls, play a pivotal role in enhancing pedestrian safety by effectively delineating between pedestrians and construction activities, providing a sense of security and separation. Conversely, factors like traffic cones, construction materials, and heavy equipment have adverse effects on pedestrian safety, as they obstruct pedestrian pathways, reduce available space, and consequently heighten the possibility of pedestrian accidents. Moreover, the study sheds light on the correlation between pedestrians and roads, emphasizing the current problem posed by sidewalk encroachment, which often necessitates pedestrian navigation onto roadways. Overall, the findings of this research highlight the urgency of prioritizing pedestrian safety in construction site management. The results of this research provide insight into proactive measures that can manage environmental hazards and create pedestrian-friendly construction sites. This research, therefore, contribute to reducing inconvenience to pedestrians and the frequency of safety incidents associated with construction activities. Future research will involve assessing the impact of various types of human (e.g., children, older people) on safety levels at construction sites. Additionally, a computer vision-based automated approach to identifying environmental factors in photos will be proposed.

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REFERENCES

[1] H.S. Chadda, H.W. McGee, “Pedestrian Safety Through Work Zones; Guidelines”, Journal of transportation engineering, vol.109, no.6, pp.785-799, 1983.

[2] S. Deb, L. Strawderman, J. DuBien, B. Smith, D.W. Carruth, T.M. Garrison, “Evaluating pedestrian behavior at crosswalks: Validation of a pedestrian behavior questionnaire for the US population”, Accident Analysis & Prevention, vol.106, pp.191-201, 2017.

[3] National Center for Statistics and Analysis, “Traffic safety facts 2021: A compilation of motor vehicle traffic crash data”, National Highway Traffic Safety Administration, 2023.

[4] O.S. Mann, “Metal shard lodged in her throat: Woman nearly killed by debris from passing crane at AMK worksite”, STOMP, 2023.

[5] M.V. Corazza, P. Di Mascio, L. Moretti, “Managing sidewalk pavement maintenance: A case study to increase pedestrian safety”, Journal of traffic and transportation engineering, vol.3, no.3, pp.203-214, 2016.

[6] A. Moricca, V. Ikalovic, “Pedestrian mobility in the proximity of construction sites: An approach to analysis and improve the pedestrian experience”, Risk Analysis, Hazard Mitigation and Safety and Security Engineering XIII, vol.214, pp.59-70, 2022.

[7] E.C. Noel, “Practices and needs in work zone pedestrian safety”, Transportation research record, no.1352, 1992.

[8] K.B. Anapakula, G.A. Eranki, “Developing an index to evaluate the quality of pedestrian environment: Case study application in an Indian metro”, Transportation research interdisciplinary perspectives, vol.11, pp.100406, 2021.

[9] K.H. Hyari, M.S. El-Mashaleh, S.M. Rababeh, “Framework for managing the traffic impacts of building construction projects”, Journal of Construction in Developing Countries, vol.20, no.2, pp.97-113, 2015.

[10] M. Lee, S. Kim, H. Kim, S. Hwang, “Pedestrian visual satisfaction and dissatisfaction toward physical components of the walking environment based on types, characteristics, and combinations”, Building and Environment, vol.244, pp.110776, 2023.

[11] P. Griew, M. Hillsdon, C. Foster, E. Coombes, A. Jones, P. Wilkinson, “Developing and testing a street audit tool using Google Street View to measure environmental supportiveness for physical activity”, International Journal of Behavioral Nutrition and Physical Activity, vol.10, no.1, pp.1-7, 2013.

[12] H. Abou-Senna, E. Radwan, A. Mohamed, “Investigating the correlation between sidewalks and pedestrian safety”, Accident Analysis & Prevention, vol.166, pp.106548, 2022.

[13] G. D'Orso, M. Migliore, “A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments”, Journal of transport geography, vol.82, pp.102555, 2020.

[14] D. Mukherjee, S. Mitra, “Identification of pedestrian risk factors using negative binomial model”, Transportation in developing economies, vol.6, pp.1-14, 2020.

[15] C.-Y. Yu, A. Woo, “How to design built environments around parks that ensure pedestrian safety”, Journal of Transport & Health, vol.26, pp.101464, 2022.